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Data Article

Performance and emissions data of an internal combustion engine operating with different ethanol/water mixtures and compression ratios

Darlan Jorge Gil Torres, André de Souza Mendes, Cyro Albuquerque*

Department of Mechanical Engineering, Centro Universitário FEI, Av. Humberto de Alencar Castelo Branco, 3972, Assunção, São Bernardo do Campo, SP 09850-901, Brazil

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ABSTRACT

This study presents performance and emissions data of an Otto cycle mono-cylinder combustion engine operating with two different compression rates and several mixtures of anhydrous ethanol fuel and water. The instrumented engine was mounted on a dynamometer with the ignition point and injection fuel advance calibrated to obtain the maximum torque and mixture in stoichiometric conditions. Characteristic engine performance parameters and emission fractions from its exhaust system were acquired from 2,000 rpm to 4,000 rpm with fuel mixtures of up to 50% water content. To our knowledge, data on this extreme operating condition are not available in the literature.

* Corresponding author.
E-mail address: cyroan@fei.edu.br (C. Albuquerque).

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Specifications Table

Subject	Automotive Engineering
Specific subject area	Engine performance and emission test with different fuel mixtures
Data format	Raw, Analyzed
Type of data	Table, Graph
Data collection	The data was collected in a dynamometer bench instrumented with an encoder to measure speed rotation, a load cell to measure torque and power, a gravimetric scale to measure fuel consumption, a lambda sensor, a universal gas analyzer, and thermocouples. Data from each measurement system was acquired and recorded in spreadsheets for each operating point.
Data source location	Collected in Instituto Mauá de Tecnologia (Praça Mauá 1, São Caetano do Sul, São Paulo, Brazil, 09580-900). Stored in Centro Universitário FEI (Av. Humberto de Alencar Castelo Branco, 3972, São Bernardo do Campo, São Paulo, Brazil. 09850-901
Data accessibility	Repository name: Mendeley Data DOI: 10.17632/yvb7khhbrj.1 Direct URL to data: https://data.mendeley.com/datasets/yvb7khhbrj/1

1. Value of the Data

- The presented dataset helps improve the understanding of how an internal combustion engine works, considering various ethanol/water mixtures. This information is essential for analyzing and improving engine performance parameters and evaluating greenhouse gas emissions in operations with this fuel type.
- Extreme operating conditions involving ethanol/water fuel mixtures containing up to 50% water content, a scenario rarely explored in existing literature, are presented. These results reveal the benefits and tradeoffs regarding these operating conditions.
- Since different compression ratios are used in the experimental tests, the presented dataset may help understand the impact of different compression ratios on engine performance and emissions, offering valuable insights into combustion behavior and efficiency.
- Automotive researchers and industry professionals may use this dataset in their studies and projects to improve performance and reduce fuel consumption and vehicle emissions.
- The infrastructure and human resources required to conduct a comprehensive experimental test, such as the one presented in this document, may be limited to those working on similar engines. Thus, this dataset could enable contributions and projects that are considered impractical.
- This dataset can be used to develop and validate mathematical models to help predict the performance, consumption, and emissions of vehicles equipped with internal combustion engines. Moreover, these models can be further applied in frameworks based on optimization strategies.

2. Background

In the literature, procedures for investigating performance and emissions have been applied to diesel engines under different load conditions [2] and varying concentrations of compressed natural gas and compressed natural gas enriched with hydrogen [3]. Data sets used to optimize efficiency, consumption, and emissions, considering specific fuel mixture characteristics, compression ratio, and injection instant, are also found in the literature [4]. Tests with different concentrations of diesel, biodiesel, and ethanol are presented in the literature, emphasizing emissions results [5]. Data comparing mono-cylinder engines at different speeds and loads allows a better understanding of the behavior of specific engine parameters [6].

None of the articles mentioned above specifically address high water concentrations in ethanol blends. Besides, experiments featuring different compression ratios are scarce in the literature. Nevertheless, they enable the investigation into how these ratios influence ethanol/water fuel mixtures, offering valuable insights into engine performance and operational dynamics. Both aspects, a wide range of water concentrations and different compression ratios, are considered in our experiments using a spark-ignition engine, which offers a distinctive perspective within the context of ethanol/water fuel blends.

There is a gap in the literature regarding performance and emissions data from engines with mixtures of anhydrous ethanol and water. Furthermore, despite its relevance, current literature does not adequately present engine performance over more comprehensive engine speed ranges, and sufficient information on the standard deviation of measurements still needs to be provided. Therefore, this paper aims to fill this gap by presenting representative performance and emissions data for different fuel blends and compression ratios. Its relevance is not only for the extensive set of experiments carried out but also for the presentation of the averages for each point, accompanied by the standard deviation, and the variation of the engine speed of each test in a comprehensive range.

3. Data Description

The measured conditions cover six variations in fuel composition (from 0 to 50% water mixed with ethanol, in increments of 10%), five different speeds (from 2,000 to 4,000 rpm, in increments of 500 rpm), and two compression ratios. (7.44:1 and 9.44:1). In total, 60 operating conditions were evaluated, with a sample of six measurement points for each. Some points were obtained directly from the measurements, and others were calculated. The measured points are some temperatures, torque, fuel consumption, and exhaust gas fractions (CO, CO_2, O_2, HC, and NO_x). The calculated data include power, specific fuel consumption, and efficiency. Additionally, the other data that complement the table indicate the operating condition.

The supplementary material [1] includes a spreadsheet that presents the results obtained under all operating conditions studied. The spreadsheet is made up of three distinct tabs. The collected data is organized within the first tab (raw), with each row containing the measured and calculated data for a particular operating condition. For every operating point, six sets of data are collected. The sets related to a specific operating condition are presented as vertically contiguous six-line blocks across the table.. The two subsequent tabs (Average and Std.Dev.) show these points' mean and standard deviation, respectively, under each condition.

The data from left to right in each tab of the spreadsheet is listed and detailed as follows:

- Water fraction [0-1] – Proportion of water in the fuel mixture, expressed as a decimal between 0 and 1.
- Rotational speed (rpm) – Number of revolutions per minute (rpm) of the engine's crankshaft.
- Compression ratio – Ratio of the maximum volume of the combustion chamber (when the piston is at its lowest point) to the minimum volume of the combustion chamber (when the piston is at its highest point).
- Ignition Advance Angle (°BTDC) – The timing at which the spark plug ignites the air-fuel mixture before the piston reaches the top dead center (TDC) during the compression stroke. This angle is measured in degrees before the top dead center (°BTDC).
- Fuel temperature (°C) – Temperature of the fuel mixture, measured in degrees Celsius (°C).
- Exhaust temperature (°C) – Temperature of the gases exiting the combustion chamber and entering the engine's exhaust system, measured in degrees Celsius (°C).
- Oil temperature (°C) – Temperature of the engine oil, typically measured in degrees Celsius (°C)
- Torque (N m) – Torque generated by the engine's crankshaft, measured in Newton-meters (Nm)
- Fuel consumption (g/s) – Rate at which the fuel mixture is consumed by the engine, measured in grams per second (g/s).

Table 1
Torque (N.m): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
Low (7.44:1)	2000	10.12 ± 0.10	10.77 ± 0.14	9.88 ± 0.12	9.90 ± 0.11	9.18 ± 0.47	8.70 ± 0.26
	2500	10.72 ± 0.41	11.32 ± 0.29	10.28 ± 0.12	10.43 ± 0.36	9.10 ± 0.42	8.33 ± 0.54
	3000	10.70 ± 0.06	11.20 ± 0.00	11.10 ± 0.13	10.60 ± 0.00	9.82 ± 0.21	7.10 ± 1.23
	3500	11.18 ± 0.04	11.35 ± 0.10	11.48 ± 0.42	11.22 ± 0.08	10.02 ± 0.69	6.37 ± 0.34
	4000	10.83 ± 0.08	11.58 ± 0.10	11.18 ± 0.08	11.15 ± 0.14	9.87 ± 0.33	6.57 ± 0.83
High (9.44:1)	2000	10.68 ± 0.19	11.07 ± 0.08	10.87 ± 0.10	11.37 ± 0.14	9.93 ± 0.66	10.32 ± 0.12
	2500	11.13 ± 0.23	11.98 ± 0.19	12.23 ± 0.18	12.13 ± 0.08	10.90 ± 0.59	10.97 ± 0.24
	3000	11.18 ± 0.04	11.58 ± 0.13	12.00 ± 0.00	11.92 ± 0.08	10.15 ± 1.23	10.58 ± 0.04
	3500	11.30 ± 0.00	11.90 ± 0.00	12.35 ± 0.05	12.18 ± 0.28	12.07 ± 0.26	11.15 ± 0.21
	4000	11.45 ± 0.19	12.02 ± 0.04	12.15 ± 0.15	12.18 ± 0.28	12.05 ± 0.18	9.38 ± 0.26

Table 2
Power (kW): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
low (7.44:1)	2000	2.12 ± 0.02	2.25 ± 0.03	2.07 ± 0.02	2.07 ± 0.02	1.92 ± 0.10	1.82 ± 0.05
	2500	2.81 ± 0.11	2.96 ± 0.08	2.69 ± 0.03	2.73 ± 0.09	2.38 ± 0.11	2.18 ± 0.14
	3000	3.36 ± 0.02	3.52 ± 0.00	3.49 ± 0.04	3.33 ± 0.00	3.08 ± 0.07	2.23 ± 0.39
	3500	4.10 ± 0.01	4.16 ± 0.04	4.21 ± 0.15	4.11 ± 0.03	3.67 ± 0.25	2.33 ± 0.12
	4000	4.54 ± 0.03	4.85 ± 0.04	4.68 ± 0.03	4.67 ± 0.06	4.13 ± 0.14	2.75 ± 0.35
high (9.44:1)	2000	2.24 ± 0.04	2.32 ± 0.02	2.28 ± 0.02	2.38 ± 0.03	2.08 ± 0.14	2.16 ± 0.02
	2500	2.91 ± 0.06	3.14 ± 0.05	3.20 ± 0.05	3.18 ± 0.02	2.85 ± 0.16	2.87 ± 0.06
	3000	3.51 ± 0.01	3.64 ± 0.04	3.77 ± 0.00	3.74 ± 0.02	3.19 ± 0.39	3.32 ± 0.01
	3500	4.14 ± 0.00	4.36 ± 0.00	4.53 ± 0.02	4.47 ± 0.10	4.42 ± 0.09	4.09 ± 0.08
	4000	4.80 ± 0.08	5.03 ± 0.02	5.09 ± 0.06	5.10 ± 0.12	5.05 ± 0.07	3.93 ± 0.11

- Power (kW) – Mechanical power generated by the engine, measured in kilowatts (kW)
- Specific fuel consumption (g/kWh) – Amount of fuel consumed by the engine to produce one kilowatt-hour (kWh) of mechanical energy output, measured in grams per kilowatt-hour (g/kWh)
- Efficiency (%) – Ratio of useful work output to the total energy input from the fuel mixture, expressed as a percentage.
- CO (%), CO2 (%), and O2 (%) – Percentage of carbon monoxide, carbon dioxide, and oxygen emissions, respectively, produced by the engine relative to the total exhaust gas volume.
- HC (ppm) and NOx (ppm) – Concentration of hydrocarbon and nitrogen oxide emissions, respectively, in the exhaust gases, measured in parts per million (ppm).

The test results are presented in Figs 1 and 2 and detailed in Tables 1–14. In the figures, the points represent the average values for each measured condition, accompanied by error bars that indicate the standard deviation. Fig. 1 highlights the main engine performance data, while Fig. 2 covers information regarding exhaust gas emissions. Tables 1–14 present the average and standard deviations corresponding to each evaluated condition.

Fig. 3 presents the engine head and oil after operation with the mixture containing 50% water, showing corrosion points in the engine head and the condition of the engine lubricating oil.

Table 3
Fuel consumption (g/s): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
low (7.44:1)	2000	0.227 ± 0.005	0.258 ± 0.010	0.295 ± 0.015	0.352 ± 0.013	0.440 ± 0.030	0.573 ± 0.015
	2500	0.280 ± 0.009	0.332 ± 0.017	0.378 ± 0.008	0.445 ± 0.021	0.558 ± 0.010	0.722 ± 0.023
	3000	0.352 ± 0.020	0.403 ± 0.015	0.478 ± 0.026	0.557 ± 0.018	0.707 ± 0.049	0.853 ± 0.025
	3500	0.412 ± 0.012	0.487 ± 0.022	0.557 ± 0.015	0.643 ± 0.027	0.793 ± 0.028	1.052 ± 0.046
	4000	0.487 ± 0.016	0.568 ± 0.023	0.647 ± 0.037	0.800 ± 0.049	0.915 ± 0.034	1.123 ± 0.078
high (9.44:1)	2000	0.217 ± 0.008	0.243 ± 0.038	0.288 ± 0.004	0.342 ± 0.008	0.438 ± 0.016	0.573 ± 0.010
	2500	0.273 ± 0.014	0.327 ± 0.056	0.373 ± 0.005	0.453 ± 0.022	0.557 ± 0.019	0.717 ± 0.030
	3000	0.332 ± 0.004	0.395 ± 0.097	0.435 ± 0.028	0.535 ± 0.018	0.673 ± 0.029	0.880 ± 0.043
	3500	0.387 ± 0.012	0.460 ± 0.038	0.525 ± 0.005	0.627 ± 0.010	0.822 ± 0.044	1.030 ± 0.042
	4000	0.450 ± 0.011	0.487 ± 0.075	0.623 ± 0.014	0.728 ± 0.018	0.907 ± 0.012	1.088 ± 0.077

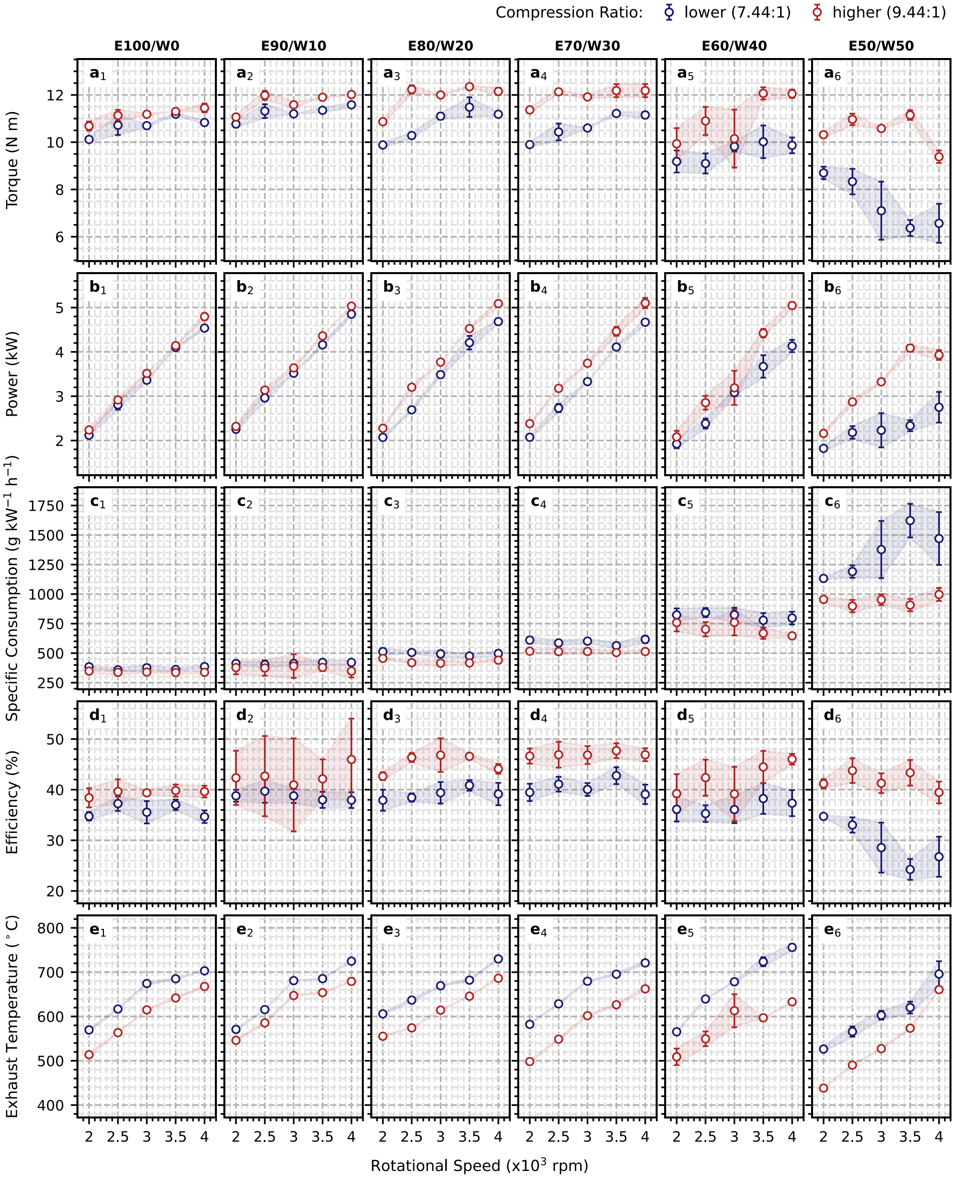

Fig. 1. Data for torque, power, specific consumption, efficiency, and exhaust gas temperature as a function of rotational speed and fuel composition.

4. Experimental Design, Materials and Methods

The adopted approach involved experiments on a stationary mono-cylinder Otto cycle engine, operating at different speed values and water concentrations. During these tests, adjustments were made to the ignition advance and fuel injection to maximize the torque generated and maintain the mixture in its stoichiometric condition (with a lambda factor equal to 1). This study refers to the mixture of ethanol and water simply as fuel. Details about the test bench, preparation procedures, and the conduction of the experiments are described below.

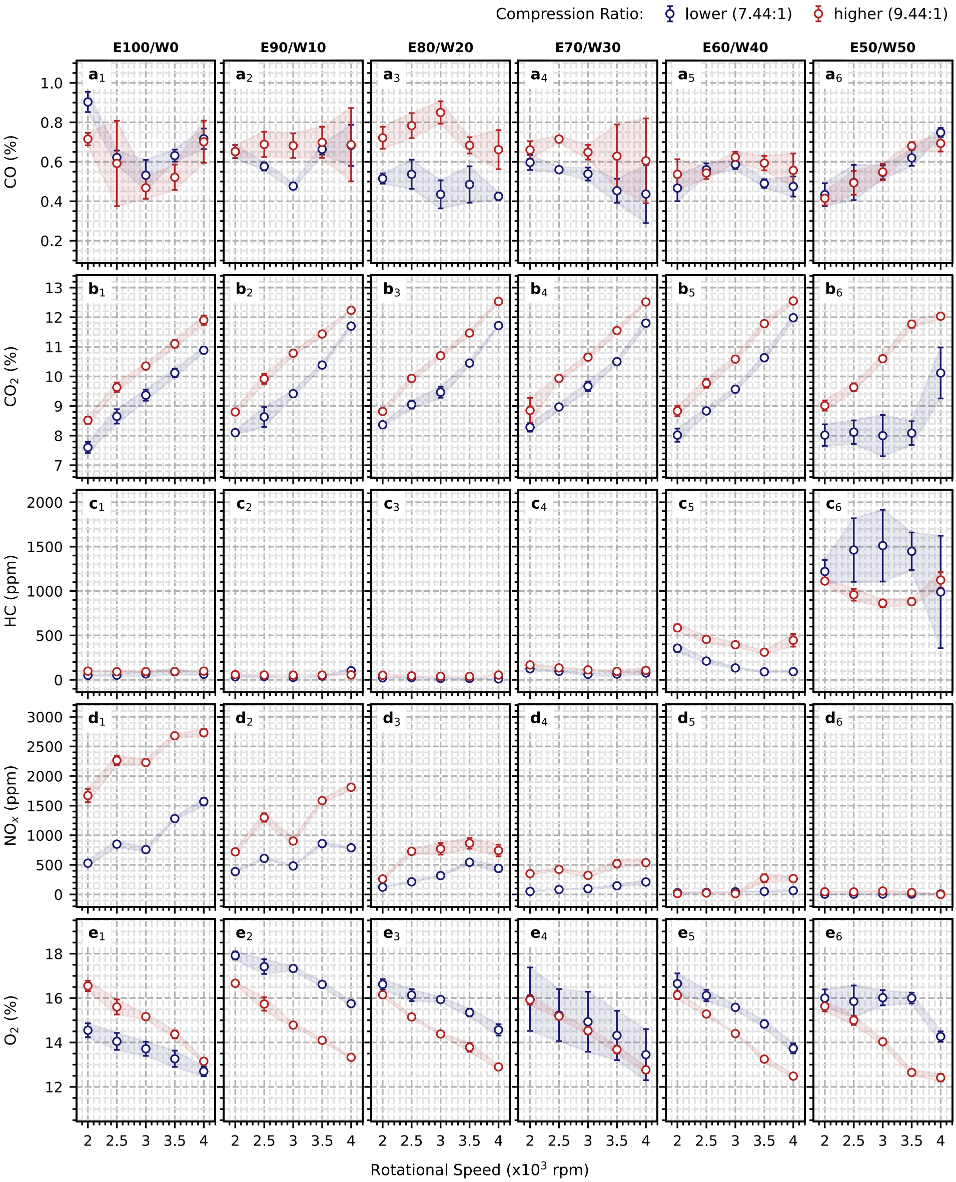

Fig. 2. Measurements of the fraction of CO, CO_2, HC, NO_x and O_2 in exhaust gases as a function of rotation and fuel composition.

4.1. Test bench

The dynamometer bench used at the Mauá Institute of Technology Motor Laboratory consists of a cantilevered electric motor connected to a cardan shaft. This shaft was coupled to the engine shaft through a flange. A load cell was mounted on the side of the engine to measure the load applied during operation. Furthermore, an encoder was installed to record the rotation of the electric motor shaft, and two fans were positioned next to the motor to assist in heat

Table 4
Specific fuel consumption (g/kWh): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
low (7.44:1)	2000	385 ± 9	412 ± 13	513 ± 29	611 ± 27	824 ± 55	1133 ± 9
	2500	360 ± 15	403 ± 23	506 ± 11	587 ± 21	845 ± 39	1193 ± 53
	3000	377 ± 24	413 ± 15	494 ± 29	602 ± 19	825 ± 60	1412 ± 242
	3500	362 ± 10	421 ± 17	476 ± 13	563 ± 22	781 ± 62	1628 ± 142
	4000	386 ± 14	422 ± 17	497 ± 28	616 ± 31	798 ± 54	1491 ± 224
high (9.44:1)	2000	349 ± 17	378 ± 57	456 ± 8	517 ± 16	763 ± 74	955 ± 21
	2500	338 ± 20	375 ± 65	420 ± 8	514 ± 28	705 ± 61	899 ± 52
	3000	340 ± 4	392 ± 100	415 ± 27	515 ± 20	771 ± 110	953 ± 46
	3500	336 ± 11	380 ± 31	418 ± 5	505 ± 15	670 ± 47	908 ± 53
	4000	338 ± 10	348 ± 53	441 ± 10	514 ± 14	647 ± 15	996 ± 55

Table 5
Efficiency (%): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
low (7.44:1)	2000	34.76 ± 0.83	38.83 ± 1.17	38.00 ± 2.08	39.52 ± 1.70	36.23 ± 2.41	34.72 ± 0.28
	2500	37.27 ± 1.44	39.79 ± 2.29	38.46 ± 0.80	41.12 ± 1.46	35.27 ± 1.64	33.01 ± 1.51
	3000	35.64 ± 2.21	38.81 ± 1.41	39.49 ± 2.13	40.07 ± 1.27	36.22 ± 2.68	28.56 ± 4.93
	3500	37.04 ± 1.04	38.05 ± 1.60	40.86 ± 1.05	42.83 ± 1.67	38.30 ± 3.04	24.31 ± 2.06
	4000	34.70 ± 1.24	37.99 ± 1.56	39.25 ± 2.21	39.17 ± 1.92	37.41 ± 2.57	26.87 ± 3.95
high (9.44:1)	2000	38.45 ± 1.89	43.03 ± 5.35	42.66 ± 0.79	46.66 ± 1.50	39.34 ± 3.83	41.18 ± 0.91
	2500	39.74 ± 2.41	43.82 ± 7.93	46.36 ± 0.89	47.00 ± 2.55	42.47 ± 3.56	43.85 ± 2.44
	3000	39.38 ± 0.47	42.76 ± 9.20	47.01 ± 3.33	46.89 ± 1.78	39.25 ± 5.36	41.36 ± 1.96
	3500	39.85 ± 1.20	42.40 ± 3.84	46.59 ± 0.59	47.71 ± 1.47	44.63 ± 3.17	43.43 ± 2.53
	4000	39.64 ± 1.15	47.00 ± 8.06	44.13 ± 0.97	46.92 ± 1.28	46.03 ± 1.06	39.57 ± 2.14

Table 6
– Ignition Advance Angle (°BTDC).

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
low (7.44:1)	2000	25.0	25.0	20.0	26.5	33.5	50.5
	2500	31.1	30.0	27.0	31.5	33.5	54.0
	3000	30.0	28.0	32.0	33.0	37.5	56.0
	3500	35.0	35.0	37.0	37.0	40.0	52.0
	4000	40.0	35.0	40.0	41.0	41.5	52.0
high (9.44:1)	2000	32.0	32.0	23.0	40.0	42.0	75.0
	2500	35.0	32.0	34.0	42.5	49.0	70.0
	3000	35.0	33.0	35.0	40.0	53.2	75.0
	3500	38.0	35.0	37.0	45.0	55.0	63.1
	4000	40.0	38.0	43.0	45.0	55.0	63.0

dissipation. Fig. 4 presents an image of the dynamometer bench used to conduct the tests, and Table 15 provides technical details about the equipment.

The test was carried out with a mono-cylinder spark ignition internal combustion engine. Initially, this engine was equipped with a factory carbureted injection system. However, an electronic injection system was adapted to carry out the experiments. Detailed technical information about the engine is presented in Table 16. The engine assembly included a coil, cable, spark plug, an intake manifold with an injection nozzle close to the engine head's air intake, a vari-

Table 7
Fuel temperature (°C): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
low (7.44:1)	2000	31.60 ± 0.49	32.30 ± 0.55	30.80 ± 0.15	32.07 ± 2.78	33.07 ± 1.03	32.20 ± 0.06
	2500	31.88 ± 0.46	32.02 ± 1.00	30.78 ± 0.20	32.08 ± 2.68	33.05 ± 0.93	32.23 ± 0.12
	3000	31.73 ± 0.25	32.53 ± 0.26	30.80 ± 0.21	31.78 ± 2.21	33.08 ± 0.75	32.30 ± 0.13
	3500	31.02 ± 0.17	32.92 ± 0.50	31.28 ± 0.13	31.83 ± 1.79	33.77 ± 0.59	32.73 ± 0.37
	4000	30.48 ± 0.73	32.35 ± 0.42	30.90 ± 0.19	31.65 ± 1.81	33.42 ± 0.08	32.55 ± 0.42
high (9.44:1)	2000	34.27 ± 0.66	37.08 ± 0.37	34.97 ± 1.63	29.65 ± 0.05	30.13 ± 0.08	29.77 ± 0.20
	2500	33.60 ± 0.74	36.83 ± 0.42	35.57 ± 1.04	29.88 ± 0.15	30.37 ± 0.14	30.15 ± 0.21
	3000	33.50 ± 0.69	36.73 ± 0.31	35.98 ± 0.68	30.55 ± 0.16	30.82 ± 0.08	30.57 ± 0.08
	3500	32.47 ± 1.07	36.23 ± 0.30	35.92 ± 0.64	30.45 ± 0.14	30.88 ± 0.35	30.63 ± 0.15
	4000	31.87 ± 1.55	35.68 ± 0.73	36.00 ± 0.48	30.18 ± 0.04	30.32 ± 0.16	30.50 ± 0.17

Table 8
Exhaust temperature (°C): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
low (7.44:1)	2000	569.7 ± 2.7	570.9 ± 1.3	605.9 ± 1.4	582.2 ± 0.9	565.5 ± 2.1	526.5 ± 6.0
	2500	616.8 ± 1.2	615.6 ± 1.0	637.0 ± 4.4	628.6 ± 1.5	639.4 ± 0.9	565.9 ± 11.5
	3000	674.5 ± 2.8	680.9 ± 1.0	669.4 ± 0.9	679.5 ± 1.1	678.4 ± 1.3	602.8 ± 10.1
	3500	685.2 ± 2.1	685.4 ± 1.0	682.0 ± 2.6	695.5 ± 2.5	723.6 ± 10.1	620.1 ± 13.3
	4000	703.0 ± 0.8	724.9 ± 1.3	729.9 ± 1.8	720.8 ± 3.1	756.0 ± 7.5	695.8 ± 28.9
high (9.44:1)	2000	513.8 ± 4.9	546.2 ± 1.4	555.3 ± 1.3	498.3 ± 2.0	508.9 ± 18.7	438.4 ± 1.8
	2500	563.5 ± 1.1	585.6 ± 2.8	574.3 ± 1.1	548.8 ± 2.0	549.6 ± 16.7	490.1 ± 1.3
	3000	614.9 ± 1.4	647.4 ± 1.5	614.3 ± 1.3	601.8 ± 2.1	613.0 ± 37.3	527.5 ± 2.0
	3500	641.9 ± 2.1	653.8 ± 1.6	645.7 ± 0.9	626.6 ± 2.3	597.0 ± 0.9	573.5 ± 2.5
	4000	667.8 ± 1.9	679.2 ± 1.0	686.2 ± 2.2	662.4 ± 3.3	633.0 ± 1.9	660.6 ± 1.1

Table 9
Oil temperature (°C): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
low (7.44:1)	2000	142.1 ± 1.4	125.3 ± 5.7	115.4 ± 0.9	106.6 ± 6.5	90.7 ± 2.7	67.4 ± 1.0
	2500	148.0 ± 2.3	128.6 ± 8.2	122.5 ± 1.8	111.2 ± 5.0	93.7 ± 3.2	67.4 ± 0.6
	3000	154.1 ± 1.3	143.7 ± 1.0	128.0 ± 0.6	116.0 ± 5.2	97.0 ± 3.2	67.6 ± 0.9
	3500	159.5 ± 6.3	144.6 ± 2.0	132.4 ± 0.5	118.2 ± 4.7	101.6 ± 4.7	69.0 ± 1.0
	4000	162.2 ± 2.9	136.7 ± 3.8	132.8 ± 3.3	118.1 ± 5.6	104.1 ± 5.7	74.5 ± 2.7
high (9.44:1)	2000	148.2 ± 2.8	138.9 ± 1.1	123.9 ± 3.5	103.3 ± 2.0	82.3 ± 2.3	64.7 ± 0.6
	2500	155.8 ± 1.3	143.0 ± 0.6	128.9 ± 1.9	105.0 ± 1.8	84.1 ± 4.1	66.2 ± 0.7
	3000	161.0 ± 2.7	146.6 ± 1.6	130.4 ± 2.9	108.1 ± 2.1	86.2 ± 4.3	68.7 ± 0.4
	3500	158.7 ± 2.1	148.4 ± 2.5	130.4 ± 2.9	111.7 ± 1.8	90.0 ± 1.8	70.2 ± 0.8
	4000	150.9 ± 2.9	145.3 ± 5.2	125.2 ± 3.5	110.4 ± 0.5	86.2 ± 1.4	69.3 ± 0.9

able throttle valve, and a phonic wheel with 19 teeth and one missing tooth. Fig. 5 illustrates the engine assembly components.

The fuel injection line was configured with a Becker placed on a gravimetric scale. These components were positioned outside the test room for safety reasons due to the need for fuel refill. The fuel transfer from the Becker occurred through an electric pump operating at a pressure of 3 bar, passing through a filter before reaching the injection nozzle.

Table 10
CO fraction in exhaust gases (%): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
low (7.44:1)	2000	0.903 ± 0.051	0.652 ± 0.033	0.515 ± 0.026	0.597 ± 0.038	0.467 ± 0.066	0.433 ± 0.058
	2500	0.622 ± 0.035	0.577 ± 0.021	0.537 ± 0.074	0.560 ± 0.013	0.560 ± 0.032	0.495 ± 0.089
	3000	0.532 ± 0.078	0.477 ± 0.015	0.435 ± 0.071	0.538 ± 0.033	0.587 ± 0.023	0.547 ± 0.035
	3500	0.632 ± 0.031	0.663 ± 0.027	0.485 ± 0.092	0.453 ± 0.061	0.490 ± 0.022	0.620 ± 0.040
	4000	0.717 ± 0.052	0.683 ± 0.104	0.425 ± 0.019	0.437 ± 0.147	0.475 ± 0.051	0.748 ± 0.023
high (9.44:1)	2000	0.715 ± 0.031	0.652 ± 0.033	0.722 ± 0.056	0.660 ± 0.045	0.537 ± 0.077	0.415 ± 0.036
	2500	0.592 ± 0.216	0.688 ± 0.064	0.783 ± 0.063	0.715 ± 0.016	0.543 ± 0.031	0.493 ± 0.061
	3000	0.468 ± 0.056	0.682 ± 0.063	0.850 ± 0.057	0.648 ± 0.037	0.623 ± 0.027	0.548 ± 0.042
	3500	0.522 ± 0.065	0.698 ± 0.079	0.683 ± 0.041	0.628 ± 0.161	0.593 ± 0.037	0.680 ± 0.020
	4000	0.702 ± 0.107	0.687 ± 0.186	0.662 ± 0.099	0.605 ± 0.215	0.557 ± 0.085	0.693 ± 0.041

Table 11
CO_2 fraction in exhaust gases (%): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
low (7.44:1)	2000	7.60 ± 0.19	8.10 ± 0.06	8.37 ± 0.05	8.28 ± 0.15	8.02 ± 0.22	8.02 ± 0.37
	2500	8.65 ± 0.24	8.63 ± 0.34	9.05 ± 0.14	8.97 ± 0.10	8.83 ± 0.10	8.12 ± 0.40
	3000	9.37 ± 0.19	9.42 ± 0.10	9.47 ± 0.19	9.67 ± 0.16	9.57 ± 0.08	8.00 ± 0.70
	3500	10.12 ± 0.15	10.38 ± 0.08	10.45 ± 0.08	10.50 ± 0.06	10.63 ± 0.10	8.08 ± 0.40
	4000	10.88 ± 0.08	11.70 ± 0.06	11.72 ± 0.04	11.80 ± 0.11	11.98 ± 0.10	10.12 ± 0.86
high (9.44:1)	2000	8.52 ± 0.12	8.80 ± 0.06	8.82 ± 0.08	8.85 ± 0.42	8.83 ± 0.18	9.02 ± 0.17
	2500	9.63 ± 0.16	9.92 ± 0.17	9.93 ± 0.10	9.93 ± 0.08	9.77 ± 0.15	9.63 ± 0.14
	3000	10.35 ± 0.08	10.78 ± 0.08	10.70 ± 0.06	10.65 ± 0.10	10.58 ± 0.10	10.60 ± 0.11
	3500	11.10 ± 0.13	11.43 ± 0.08	11.47 ± 0.08	11.55 ± 0.08	11.78 ± 0.10	11.77 ± 0.12
	4000	11.90 ± 0.15	12.23 ± 0.05	12.53 ± 0.05	12.52 ± 0.04	12.55 ± 0.05	12.03 ± 0.08

Table 12
O_2 fraction in exhaust gases (%): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
low (7.44:1)	2000	14.55 ± 0.31	17.92 ± 0.18	16.62 ± 0.23	15.95 ± 1.43	16.65 ± 0.46	16.00 ± 0.39
	2500	14.05 ± 0.38	17.42 ± 0.33	16.13 ± 0.27	15.23 ± 1.18	16.12 ± 0.26	15.85 ± 0.72
	3000	13.72 ± 0.32	17.33 ± 0.10	15.93 ± 0.10	14.93 ± 1.35	15.58 ± 0.12	16.02 ± 0.34
	3500	13.27 ± 0.37	16.62 ± 0.12	15.35 ± 0.18	14.32 ± 1.11	14.83 ± 0.16	16.00 ± 0.24
	4000	12.70 ± 0.22	15.75 ± 0.10	14.57 ± 0.26	13.45 ± 1.15	13.73 ± 0.23	14.27 ± 0.23
high (9.44:1)	2000	16.55 ± 0.23	16.67 ± 0.05	16.15 ± 0.08	15.92 ± 0.21	16.13 ± 0.18	15.63 ± 0.23
	2500	15.60 ± 0.34	15.73 ± 0.30	15.15 ± 0.08	15.18 ± 0.12	15.28 ± 0.10	15.00 ± 0.21
	3000	15.17 ± 0.12	14.78 ± 0.10	14.38 ± 0.04	14.53 ± 0.15	14.40 ± 0.00	14.03 ± 0.12
	3500	14.37 ± 0.18	14.10 ± 0.06	13.78 ± 0.20	13.68 ± 0.17	13.25 ± 0.14	12.65 ± 0.12
	4000	13.15 ± 0.08	13.33 ± 0.05	12.90 ± 0.09	12.77 ± 0.15	12.48 ± 0.08	12.42 ± 0.17

Table 13
HC fraction in exhaust gases (ppm): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
low (7.44:1)	2000	51.3 ± 6.7	34.5 ± 6.1	23.8 ± 2.3	125.2 ± 11.9	356.0 ± 40.3	1220.0 ± 130.5
	2500	51.8 ± 12.5	38.0 ± 7.0	26.2 ± 6.8	97.0 ± 7.4	211.3 ± 24.1	1461.8 ± 357.5
	3000	67.8 ± 27.5	27.5 ± 2.1	15.8 ± 6.1	62.0 ± 14.6	134.3 ± 7.1	1511.5 ± 404.5
	3500	91.2 ± 31.1	42.0 ± 4.4	16.3 ± 6.3	65.5 ± 20.6	90.5 ± 3.1	1447.8 ± 212.0
	4000	62.8 ± 11.2	102.8 ± 25.8	10.3 ± 1.8	77.3 ± 21.8	92.0 ± 8.3	989.7 ± 633.2
high (9.44:1)	2000	98.3 ± 2.7	58.3 ± 4.8	51.3 ± 2.7	167.7 ± 12.4	585.8 ± 39.1	1112.5 ± 30.9
	2500	91.5 ± 6.2	54.2 ± 3.6	45.3 ± 3.9	134.7 ± 7.8	455.3 ± 35.0	958.0 ± 66.1
	3000	93.2 ± 6.5	52.5 ± 2.1	39.7 ± 2.6	112.0 ± 6.6	395.5 ± 27.0	863.0 ± 41.9
	3500	93.8 ± 5.1	53.0 ± 1.5	38.5 ± 1.4	94.8 ± 9.9	310.5 ± 15.2	880.8 ± 36.4
	4000	98.7 ± 2.7	55.7 ± 2.0	53.7 ± 2.7	105.5 ± 34.9	445.5 ± 71.3	1123.3 ± 89.3

Sensors were installed in the engine assembly to monitor various parameters. A Bosch rotation sensor, model 0261210, was placed to record the phonic wheel's rotation and the crankshaft's position. Throttle position sensors, model Magneti Marelli PF1C/00, and intake air temperature sensors, model Delphi WC 10079, were fixed to the intake manifold. Furthermore, two oil temperature sensors were installed, one from the Delphi 801 model and the other a thermocouple (ECIL, type K, error limit of 2.2°C or 0.75% of the measured value), both in the engine crankcase. A lambda probe was positioned close to the exhaust manifold outlet. Addi-

Table 14
NO_x fraction in exhaust gases (ppm): average ± standard deviation.

Compression Ratio	Rotational Speed (rpm)	Fuel Composition					
		E100/W0	E90/W10	E80/W20	E70/W30	E60/W40	E50/W50
Low (7.44:1)	2000	528.2 ± 50.8	386.3 ± 12.2	123.7 ± 1.5	51.3 ± 8.5	30.2 ± 4.8	5.3 ± 5.9
	2500	849.7 ± 48.9	610.2 ± 10.9	213.8 ± 15.7	83.2 ± 2.1	34.7 ± 3.7	5.7 ± 5.9
	3000	758.0 ± 34.6	481.8 ± 10.3	318.7 ± 8.3	97.3 ± 3.5	45.8 ± 4.6	6.8 ± 7.5
	3500	1282.0 ± 22.1	860.0 ± 22.1	543.2 ± 31.4	146.8 ± 13.8	51.3 ± 10.6	5.8 ± 6.4
	4000	1568.5 ± 60.7	789.0 ± 13.0	441.2 ± 56.8	211.2 ± 36.2	64.5 ± 14.5	8.7 ± 9.5
High (9.44:1)	2000	1671.8 ± 113.7	721.0 ± 33.6	262.2 ± 22.9	352.0 ± 23.5	15.3 ± 1.9	45.3 ± 8.7
	2500	2263.7 ± 79.2	1299.7 ± 71.7	729.2 ± 40.3	423.3 ± 26.2	25.3 ± 1.2	42.7 ± 7.3
	3000	2228.8 ± 48.2	902.3 ± 49.4	770.5 ± 98.1	322.7 ± 36.1	13.8 ± 1.5	58.0 ± 13.7
	3500	2681.7 ± 30.0	1585.7 ± 32.5	864.3 ± 91.3	520.5 ± 65.6	274.5 ± 66.9	32.3 ± 17.5
	4000	2733.2 ± 60.9	1810.3 ± 48.8	742.0 ± 97.9	537.3 ± 37.9	268.2 ± 37.5	0.0 ± 0.0

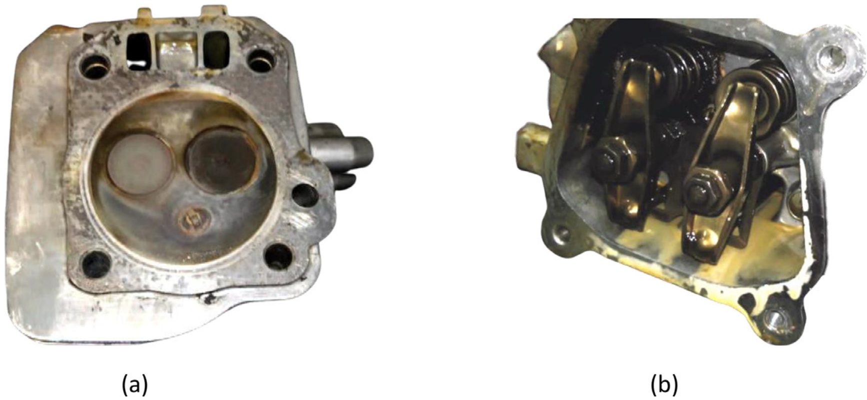

Fig. 3. (a) Corrosion points presented after carrying out all tests, and (b) condition of the engine lubricating oil after using E50/W50.

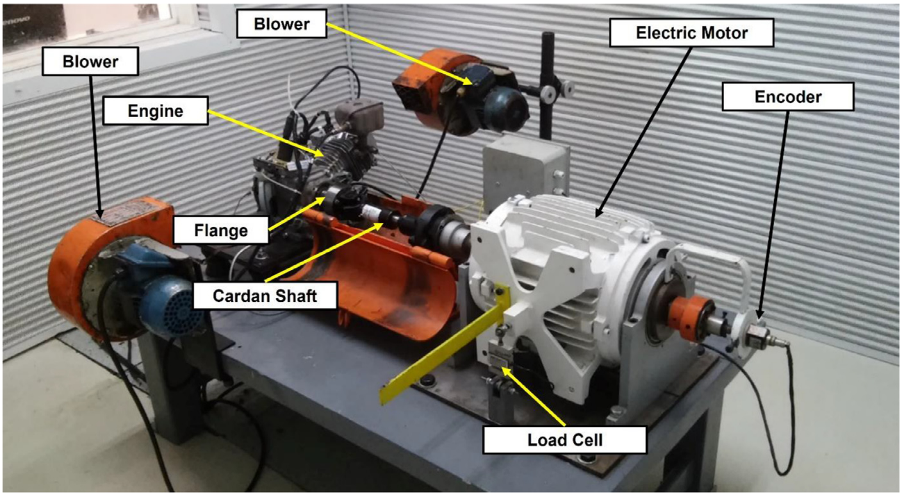

Fig. 4. Overview of the dynamometric test bench.

Table 15
Technical information on the test bench.

Equipment	Description
Engine	Honda GX160 OHV
Electric motor	WEG 15 kW
Cardan shaft	DANA Spicer
Flange	Machined steel/keyway transmission
Fans	Flow 20 m^3/min
Encoder	Tecmot 098039. 360 pulses per revolution
Load cell	Alfa Instrumentos SV 50 / Capacity 50 kg, Sensitivity 2.000 mV/V ± 10%
Electric fuel pump	Delphi
Fuel filter	FRAM G5738
Gravimetric scale	Weblabor / Resolution 0.01 g
Graduated cylinder	Deltex 1.586-D. Capacity 1,000 ml / Resolution 50 ml

Table 16
Technical information on the engine.

Item	Description
Net power / rpm	4.8 / 3600 hp/rpm (SAE J1349)
Net torque / rpm	1.05 / 2500 kgf m/rpm (SAE J1349)
Cylinders	1
Displacement	163 cm^3
Diameter x Stroke	68 × 45 mm
Compression ratio	8.5:1
Lubrication	Splash
Cooling system	Forced air
Valves per cylinder	2
Intake manifold	Machined steel / Cylindrical internal profile
Phonic wheel	19 teeth / one missing tooth. The angle between teeth is 18°
Variable butterfly valve	Spring return butterfly
Injector nozzle	Magneti Marelli IWP 176 / Flow 141 cm^3
Spark plug	NGK
Ignition cable	NGK / 5kΩ
Ignition coil	Bosch 9 220 087 034 / F 000 ZS 104

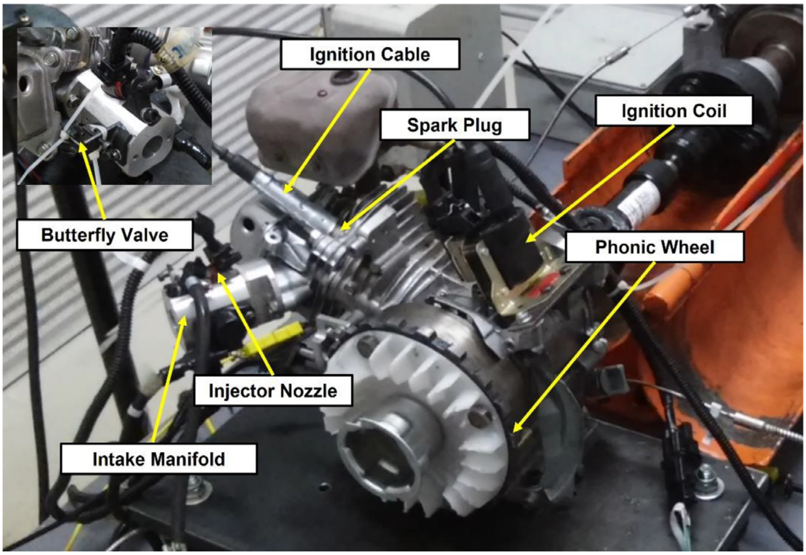

Fig. 5. Engine components.

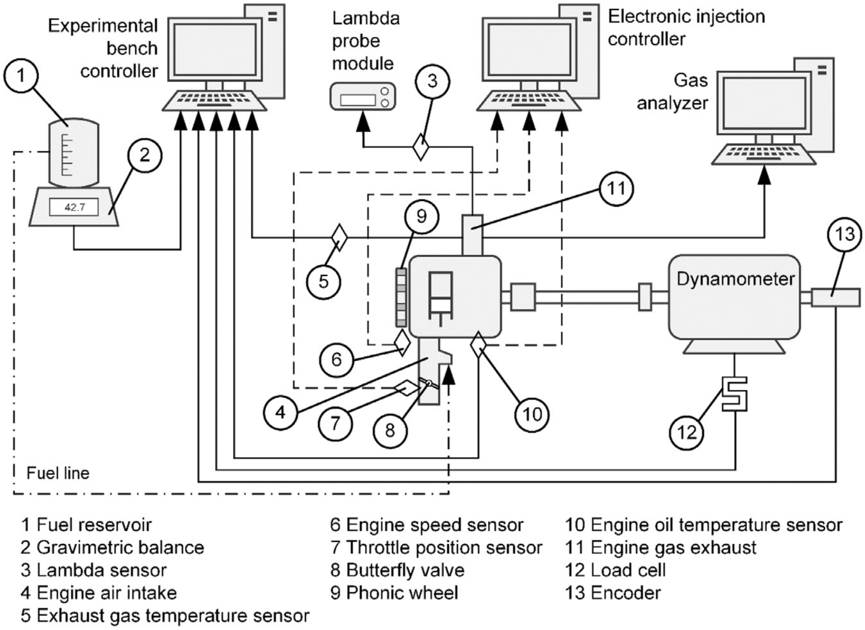

Fig. 6. Schematic of the experimental bench.

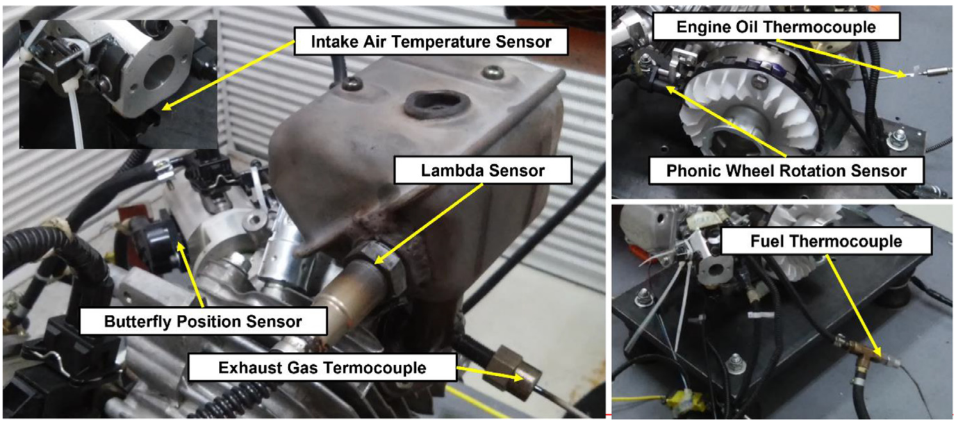

Fig. 7. Location of the sensors.

tionally, two thermocouples were included (ECIL, type K, error limit of 2.2°C or 0.75% of the measured value), one in the fuel injection line and the other in the exhaust manifold, close to the exhaust gas exit from the combustion chamber. Fig. 6 shows a schematic of the experimental bench with the sensors and the acquisition and control systems, and Fig. 7 shows details of the sensor's location.

The MegaSquirt® electronic fuel injection controller was used to calibrate the amount of fuel injected and the ignition timing advance. In addition to calibration, it was possible to instantly monitor several parameters, such as engine speed, throttle position, and ignition timing advancement.

Table 17
Air/fuel ratio and LHV.

Fuel	Air/fuel ratio	LHV [MJ/kg]
E100/W0	8,91:1	26,9
E90/W10	7,81:1	22,5
E80/W20	6,77:1	18,51
E70/W30	5,78:1	14,94
E60/W40	4,83:1	12,1
E50/W50	3,93:1	9,15

Motor rotation control was implemented using software developed in LabVIEW. With the data acquisition system connected to the gravimetric scale, it was possible to measure the fuel consumption, the engine's torque, the fuel's temperature, engine oil, and exhaust gases in real-time.

The amount of oxygen emitted by the exhaust gases was measured using the lambda probe. An ETAS LA4 Version 2.4 lambda meter module (0-25% O_2) was used to receive the sensor signal and show the actual air/fuel ratio. With the information detailed by the module, it was possible to vary the amount of fuel injected into the intake and, together with adjusting the ignition timing advance, obtain stoichiometric combustion.

The gas analyzer used for the test was the NAPRO PC-MULTIGÁS, a universal gas analyzer based on the infrared and non-dispersive measurement method capable of measuring the concentration of O_2 (0-25.0%), CO (0-15.0%), CO_2 (0-20.0%), HC (0-20,000 ppm, Hydrocarbons referenced to Hexane), and NO_x (0-5,000 ppm) in gases (Table 17).

4.2. Test preparation

The fuel's lower heating value (LHV) was obtained from typical literature data considering the proportion of water in the mixture. The main parameters are summarized in Table 5.

The head cavity and gasket volumes were measured using a 50 ml glass burette with an uncertainty of 0.1 ml, together with a 2.5 mm thick acrylic plate with five holes. Four of these holes were used to fix the head, while the fifth was 5 mm in diameter and was used for injecting distilled water. After assembling the head with the spark plug, valves, and gasket, the acrylic plate was fixed with four screws, and the burette was installed on the support. The engine was supported on the same base, and water from the burette was injected into the head cavity, observing the presence of bubbles and leaks. Three measurements resulted in an average volume of 23.7 ml.

To determine the volume of the piston head, its geometry was considered, which included a central circle of 25.50 mm in diameter and 0.50 mm in height. Three measurements were taken using an analog caliper with a reading of 150 mm and a resolution of 0.05 mm resulting in an average volume of 1.55 ml. The dead volume was obtained by adding the volume of the piston head to the volume of the head cavity and gasket, totaling 25.25 ml. The volume displaced by the piston was calculated based on measurements of the cylinder's internal diameter and stroke, resulting in 162.78 ml. The calculated engine compression ratio was 7.44:1.

The cylinder head was machined using a milling machine to increase the engine's compression ratio. A 1.5 mm layer was removed from the head face region. This height was chosen to avoid structural problems related to the cylinder head and the collision between the top of the piston and the spark plug. Subsequently, the procedure to determine the cavity volume formed by the head and the gasket was repeated. The new dead volume was quantified as 19.28 cm^3, resulting in a new engine compression ratio of 9.44:1. The tests with the increased compression rate strictly followed the same procedures previously adopted for the original factory compression rate.

The load cell installed on the dynamometer bench was calibrated using six standard weights hanging from a known lever arm. This way, the voltage measured by the acquisition system can be converted into torque. Each torque value shown by the acquisition system during the tests corresponded to the average torque in 15 engine revolutions. For every 15 engine rotations, the acquisition system showed a torque value, making it possible to verify how the torque variation occurred during each test.

The reading of the variation in fuel consumption was automated, with the system receiving data directly from the gravimetric scale and displaying the consumption in grams per second (g/s). To validate this fuel consumption measurement, we calculated the fuel mass flow rate as indicated by the gravimetric scale and compared it with the value provided by the acquisition system. The fuel mass flow rate was also manually calculated using a stopwatch to measure the time required to consume approximately 10 g of fuel. This measurement used anhydrous ethanol as fuel, maintaining a calibration that ensured the engine's failure-free operation.

The gas analyzer was calibrated using compressed gas supplied by the White Martins company, containing C_6H_{14}, CO_2, CO, and N_2. According to the White Martins certificate, the ratio of CO_2/CO gas was established as equal to 4.958. This relationship was determined by measuring two samples using the analyzer, resulting in a deviation of less than 0.1%. Additionally, when reading the ambient air, a maximum deviation of 0.1% was observed for the O_2 concentration.

4.3. Test procedure

Before conducting the tests, a detailed analysis was carried out of the engine's peripheral elements, the components of the dynamometer bench, the sensors, and the fluids. This analysis involved a thorough visual inspection of the structural integrity of each component and an assessment of its functional performance. The verification aimed to prevent operational issues and ensure the safety of the individuals carrying out the experiments.

The fuels were prepared from anhydrous ethanol, to which proportions of distilled water were added. Mixtures of anhydrous ethanol and distilled water were prepared under room temperature conditions. For this purpose, a Becker-type container with a capacity of 1,000 ml, with a measurement resolution of 50 ml, and a graduated cylinder with a capacity of 50 ml and a resolution of 1 ml for the precise dosage of anhydrous ethanol and distilled water were used, respectively.

To validate the use of this trace as a reference, a gravimetric balance was zeroed with an empty Becker cup and then filled with anhydrous ethanol until the liquid reached the level corresponding to the 900 ml trace of the cup. The reading indicated by the scale was 711.63 g, which was compared with the theoretical value of 711.144 g, calculated as the product of the measured specific mass of anhydrous ethanol (0.79016 g/cm^3) by the volume of 900 ml. The variation found was less than 0.1%.

The angle of rotation of the crank at the moment of spark in relation to the engine's top dead center (TDC) was checked using a strobe lamp and used to adjust the MegaSquirt® controller appropriately. To validate the calibration of the ignition advance, a test was carried out in which the ignition point was advanced by up to 40° before TDC by the controller, and this advance was confirmed and verified using the stroboscopic lamp.

For the engine to obtain the highest torque per rotation in a stoichiometric combustion condition, the ignition timing advance and the fuel injection amount were adjusted using the MegaSquirt® controller with wide open throttle (WOT). The standard calibration of the butterfly valve position was previously carried out. The mapping of the best ignition point advance and the stoichiometric combustion condition was carried out following the following steps:

1. First, the temperature of the exhaust gases was stabilized.
2. Fuel injection was adjusted until the lambda factor measuring module indicated 1.000 ± 0.015.
3. Torque values and exhaust gas and engine oil temperatures were recorded.

4. The ignition timing advance was adjusted to maximize torque, varying the advance value upwards and downwards in relation to TDC.
5. The new torque and lambda factor values were recorded.
6. If necessary, the fuel injection was adjusted to maintain the lambda factor equal to 1 if this was changed due to the ignition timing advance adjustment.
7. The new torque value was recorded.
8. Steps 4 and 7 were repeated iteratively until the highest torque and a lambda factor equal to 1 were reached simultaneously through successive attempts.

The tests were conducted with varying engine rotation, water concentration, and compression ratio:

- Engine rotation: from 4,000 rpm to 2,000 rpm in steps of 500 rpm
- Water concentration: from E100/W0 to E50/W50 in steps of 10% increase of water concentration
- Compression ratio: 7.44:1 (low) and 9.44:1 (high)

All permutations of these parameters were tested according to the following procedure:

- The engine was operated with wide open throttle condition (WOT).
- Each test lasted three minutes, starting when the exhaust gas temperature stabilized within a tolerance range of ±10°C.
- During each test, three measurements were taken, with one taken approximately every minute.
- Each test was repeated twice, with the repetition occurring before changing the type of fuel used.

The testing phase started from the highest speed, 4,000 rpm, and continued until the lowest speed, 2,000 rpm. The choice of 2,000 rpm was justified by the manufacturer's specification, which establishes the engine's idle speed at 1,500 rpm. Furthermore, it was considered that, given the nature of the engine, intended for operation with gasoline, the use of ethanol and water at low speeds could result in potential ignition problems. The 4,000 rpm was chosen because, above this value, the torque curve could present a significant drop. It was decided to start the tests at the highest speed so that data acquisition occurred with the engine operating at high temperatures, similar to typical operating conditions.

For each test conducted, the following engine operational data were collected:

- Fuel consumption rate in grams per second (g/s)
- Exhaust gas temperature in degrees Celsius (°C)
- Engine oil temperature in degrees Celsius (°C)
- Fuel temperature in degrees Celsius (°C)
- Torque in Newton-meters (N m)
- Value of the Lambda Factor
- Gas emissions (CO, CO_2, HC, O_2, NO_x)

4.4. Indicators

The engine power (kW) is calculated as

$$W = \frac{2\pi \ N \ T}{60,000}$$

where N is the crank shaft angular speed (RPM) and T is the engine torque (N m).

The specific fuel consumption (g/kWh) is calculated as

$$C_{ec} = \frac{m_c \ 3,600}{W}$$

where m_c is the mass fuel flow (g/s), i.e., fuel consumption.

The fuel conversion efficiency of an engine can be expressed as

$$\eta_c = \frac{3,600}{C_{ec} P_{c,inf}}$$

where $P_{c,inf}$ is the LHV (kJ/kg).

Limitations

We observed considerable dispersion in the fuel consumption values measured during operations with E90/W10 fuel and a high compression ratio in all speed ranges. This variability is evidenced by the high standard deviations of specific fuel consumption and efficiency, as illustrated in graphs c2 and d2 in Fig. 1. This phenomenon was only noticed after all tests were completed, and the origin of this variability is yet to be identified.

Ethics Statement

The authors have read and follow the ethical requirements for publication in Data in Brief. The current work does not involve human subjects, animal experiments, or any data collected from social media platforms.

Data Availability

Performance and emissions data of an internal combustion engine operating with different ethanol/water mixtures and compression ratios (Original data) (Mendeley Data)

CRediT Author Statement

Darlan Jorge Gil Torres: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft; **André de Souza Mendes:** Validation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization; **Cyro Albuquerque:** Conceptualization, Methodology, Validation, Formal analysis, Writing – review & editing, Visualization, Supervision.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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