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Complex Analysis of Power Output and Emission Parameters of High-Power Motorcycles at Application of Advanced and Sustainable Fuels and Their Mixtures

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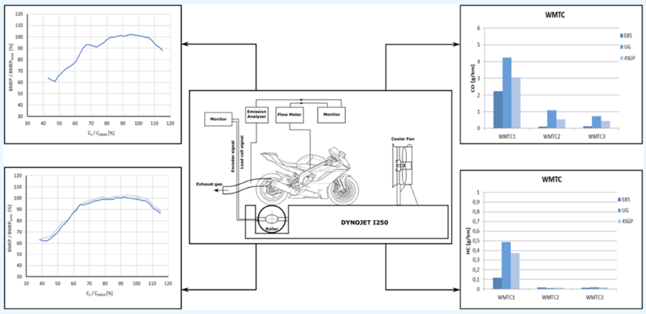
ABSTRACT: The presented scientific study is focused on a complex analysis of power output and emission parameters concerning an experimental motorcycle. In spite of the fact that there are at disposal considerable theoretical and experimental results, which include also matters of the L-category vehicles, there is, in general, a lack of data covering the experimental tests and power output characteristics of racing, high-power engines that represent a technological peak in the given segment. This situation is caused by an aversion of motorcycle producers to publicize their newest information, especially in the case of the latest high-tech applications. The given study is focused on all the main results obtained from the operational tests performed on the motorcycle engine in two testing cases: first with the original arrangement of the installed piston combustion engine series produced and second with the modified engine configuration proposed in order to increase the combustion process efficiency. Three kinds of engine fuel were tested and mutually compared within the performed research work: the first was the experimental top fuel used in the world motorcycle competition 4SGP, the second was the sustainable experimental fuel, the so-called superethanol e85 developed for maximum power output and minimum emission, and the third was the standard fuel, which is commonly available at gas stations. Applicable fuel mixtures were also created with the aim to analyze their power output and emission parameters. Finally, these fuel mixtures were compared with the top technological products available in the given area.



1. INTRODUCTION

Complex analysis of the power output parameters in the case of high-power motorcycles is always a theme of speculations because these are the subject of competition on racing circuits and it is fully understandable that the producers of motorcycles do not like to disclose real potential of their technological innovations. Therefore, there is a general lack of information concerning engines that technologically top in this area. It is well known that under pressure to achieve carbon neutrality, all the top motorsport disciplines, including F1, MotoGP, or WORLDSBK, are gradually switching to application of sustainable fuels. For example, in the year 2021, F1 racing cars were powered by E5 gasoline, whereby the designation E5 refers to a 5-percent content of ethanol. In 2022, motorcar sport switched to E10 fuel, and from the year 2026, the fuel should be 100% bioethanol. Motorcycle races should switch to a sustainable fuel one year later, that is, in 2027. There are, at disposal, in the professional literature, many detailed descriptions of modifications proposed in order to increase the specific power output of the series-produced engines, but only a little information deals with modifications determined for application of the sustainable fuel. Constructional adjustments of the intake and exhaust systems, intended for improvement of the engine volumetric efficiency, are very effective in obtaining a specific power output. Many common professional books present theoretical and experimental data about aerodynamics of engine head manifolds. Although the theory and practice of engine testing are closely connected with technical progress in the area of internal combustion engines, there are only few references relating to testing of high-speed racing engines. This article presents an experimental study[1−3] focused on the high-speed series-produced motorcycle engine,[4,5] which was modified in accordance with the FIM regulations for the 600 STOCK category in order to obtain specific power output and to compare the output parameters after application of sustainable fuels and their mixtures.[6−10]

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2. EXPERIMENTAL CONDITIONS AND TECHNICAL EQUIPMENT

2.1. Experimental Model. A Yamaha R6 motorcycle was used as an experimental model, which was equipped with a complete GYTR racing kit in accordance with the valid FIM regulations for the 600 STOCK class. This is a racing class determined for the series-produced motorcycles. The basic technical specifications of the tested motorcycle engine are summarized in Table 1.

Table 1. Tested Engine Data

type	four-stroke, inline four-cylinder, DOHC, 4 valves per cylinder
capacity	599 cm^3
bore × stroke	67 × 42.5 mm
compression ratio	13.1:1
ignition and injection	GYTR technology
max. power output	87.1 kW/116.7 hP (14,500 rpm)
max. torque	61.7 Nm/45.5 lb-ft (10,500 rpm)
exhaust system	AKPRAPOVIC racing GYTR

All the modifications of the original engine are focused on increasing the engine power output within the limits given by the regulations. The shape and volume of the engine combustion chamber is changed by the constructional modification of the cylinder head in order to increase the compression ratio, whereby, in this case, a special fuel is used to prevent detonation combustion.[11,12] The fuel injection engine control unit (ECU) is replaced and the ignition advance as well as the injection timing, and the length duration maps are experimentally tuned as the functions of the engine operational regime and load. No changes in the mechanical components, which can reduce mechanical friction, are allowed, so the only way for improvement of organic efficiency (except for surface treatment), is through application of a better lubricant. Only minor adjustments were made in the arrangement of the intake system in accordance with the FIM rules. The secondary throttles remained at their maximum value since their role is not important within the required engine speed range. The original air filter was replaced with a 3 mm sponge filter to reduce pressure losses.

To perform the power output analyses, the exhaust system situated behind the engine head is completely replaced according to the FIM (International Motorcycling Federation) regulations with the AKPAROVIC GYTR exhaust system. The exhaust pipe behind the engine head is made from titanium tubes, and it is a classic ″4 into 2 into 1″ pipe. Two intermediate secondary branches collect the primary exhaust gases from the cylinders 1−2 or cylinders 3−4, and they discharge the exhaust gases through Y-coupling into a common exhaust pipe, which ends in the exhaust silencer. This arrangement increases power output in a high range of engine speed for engines with combustion order 1−2−4-3.[13−15] The silencer is of the absorption type, due to low back-pressure of the exhaust gases. Minor adjustments were realized in the layout of the intake system, with regards to the FIM rules. Contrarily, a standard exhaust system equipped with a catalyzer was used for the emission analyses.[16]

2.2. Experimental Fuels. The most important characteristics of three different fuels used for the experimental analysis are summarized in Table 2.

Table 2. Specifications of the Test Fuels

specification	E85	UG (EN 228)	4SGP
octane numbers, RON (Mon)	108 (89)	95 (85)	100 (88)
density [kg/L at 15 °C]	0.79	0.72	0.725
oxygen [% m/m]	32	2.7	2.6
air/fuel ratio	9.32	14.7	14.33
vapor pressure [bar at 37.8 °C]	0.400	0.592	0.530
sulfur [mg/kg]	<30	2.9	<10
lead content [g/L]	<0.001	0.0025	<0.005
benzene [vol %]	0.1	0.83	<0.1

The first applied is the E85 fuel from ELF company. This fuel is a leader in the given segment. It was developed differently from superethanol and E 85 fuels, which are already on the market, in terms of its stable quality and composition, improved combustion rate, and significantly higher calorific value. The ELF E85 fuel provides optimal knocking resistance and excellent fuel reactivity, thanks to its exceptional RON number. Therefore, this fuel enables optimized ignition timing and it increases the engine power output. The second experimental fuel is unleaded gasoline (UG), which fulfills the valid European standards EN 228 and it is standardly available at gas stations.[17] The third tested fuel, namely, the 4S GP fuel from the ELF company, is based on ELF's experiences in MotoGP. It offers maximum power output within the limits of FIM regulations. The ELF MOTO 4S GP fuel regularly wins the WSBK and WSS championships. Its specific content of olefins gives the ELF MOTO 4S GP very fast combustion rate, which is particularly effective at high engine speeds. At the same time, also the fuel mixtures are the subject of the performed power output analyses. They were created by mixing of the above-mentioned fuels using the following mixing ratios: E85_UG (50:50), E85_4SGP (50:50), and UG_4SGP (50:50).

2.3. Measuring Equipment. The motorcycle engine was tested in an acoustically isolated chamber equipped with a cooler fan, which supplies air for cooling and intake of the engine, and with an exhaust gas extractor, which removes exhaust gases from the room.[18−20] Inside the chamber was installed the dynamometer Dynojet i250 (Figure 1), which was dimensioned to a maximum power output value of 373 kW, maximum speed of 200mph (322 kph), timing accuracy of +/−1 microsecond, drum speed accuracy of +/−1/100th kph, and rpm accuracy of +/−1/10th rpm. The measuring equipment also includes sensors of ambient air temperature, pressure, and humidity. Measuring of the engine speed is based on the pulses sent from the ECU into the ignition coil of the cylinder. Resolution, that is, accuracy of this measuring, is 1 rev/min. According to the data given by the manufacturer, the accuracies of other quantities concerning the undercarriage dynamometer are as follows: the timing accuracy is 1 ms, the drum speed accuracy is 1/100 mph, and the engine speed accuracy is 1/10 rev/min. Accuracy of the measured torque values can be estimated to 0.2% of the full torque range, i.e., ±2 Nm during the tests performed in a stable state using an electric dynamometer. The fuel consumption is obtained by measuring the weight. The acquisitions are supplemented with measuring the air-fuel ratio, which is derived from the lambda probe signal.[21,22] Most of the tests are performed with the engine clutch in 4th gear in order to ensure operational stability over almost the whole engine speed range, what is useful under engine load.[23] The exhaust gas emissions were

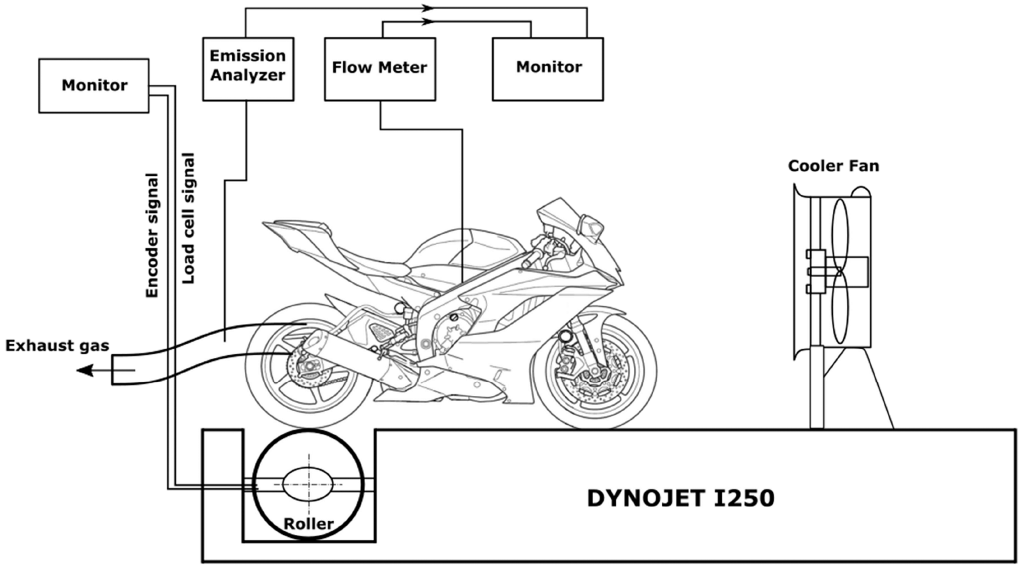

Figure 1. Testing system with experimental motorcycle.

measured using a mobile measuring system determined for emission testing (TEXA).

2.4. Testing Cycles. The following driving cycles were used for emission analysis of the experimental motorcycle:

- European driving cycle of type approval (ECE and EUDC),
- World Motorcycle Test Cycle (WMTC).

The cycle ECE and EUDC consists of an urban (ECE) and an extra-urban part (EUDC). The specifications of ECE and EUDC test cycles are presented in Table 3. The urban part is divided into two phases: ECE1—cold testing and ECE2—testing at operational temperature. The full test starts with four repetitions of the ECE cycle (Figure 2, left). ECE is an urban driving cycle, also known as UDC. This cycle was proposed to represent the urban driving conditions, for example, in Paris or Rome. It is characterized by low speed of vehicle, low level of engine load, and low temperature of exhaust gas. The EUDC (Extra-Urban Driving Cycle) segment was added after the fourth ECE cycle in order to take into consideration also more aggressive driving modes with high speed of the vehicle. The maximum speed limit of the EUDC cycle is 120 km/h. An alternative EUDC cycle was defined for low power output vehicles with a maximum speed limited to 90 km/h (Figure 2, right).[24−31]

Table 3. Specifications of ECE and EUDC Test Cycles

characteristics	ECE	EUDC
distance [km]	0.9941	6.9549
total time [s]	195	400
tdle (standing) time [s]	57	39
average speed (incl. stops) [km/h]	18.35	62.59
average driving speed (excl. stops) [km/h]	25.93	69.36
maximum speed [km/h]	50	120
average acceleration [m/s^2]	0.599	0.354
maximum acceleration [m/s^2]	1.042	0.833

The World Motorcycle Test Cycle (WMTC) is a system of driving cycles used to measure fuel consumption and emissions of motorcycles. The methods are set out as a part of global technical regulation established by the UN World Forum for the Harmonization of Vehicle Regulations, also known as WP.29. Testing according to WMTC is carried out for the motorcycle with the maximum speed higher than 140 km/h, and it is performed in three phases: cold WMTC1 (Part 1), WMTC2 (Part 2), and WMTC3 (Part 3), Table 4.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Analysis of Engine Power Output and Fuel Consumption. Analysis of the engine power output was performed on a motorcycle with racing modification using the

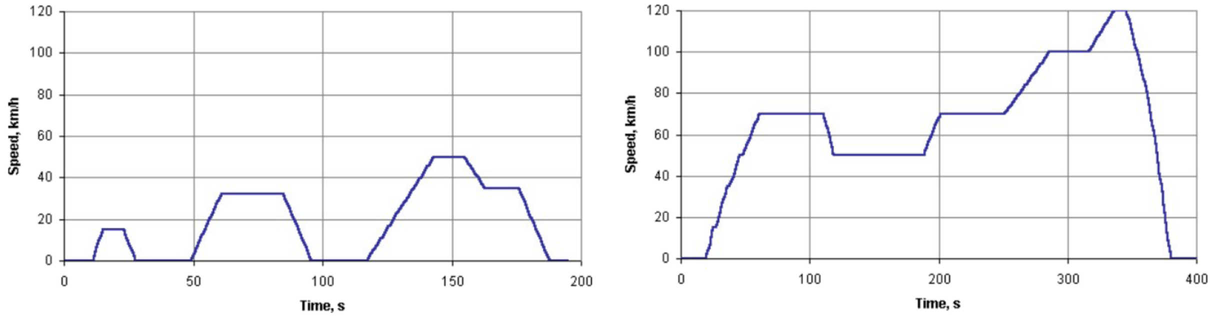

Figure 2. Characteristics of ECE testing (left) and EUDC testing (right); the vertical axis shows the speed of motorcycle [km/h] and the horizontal axis shows the time [s].

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Table 4. Specifications of the WMTC Test Cycle

specification WMTC	part 1	part 2	part 3
distance [km]	4.07	9.11	15.74
total time [s]	600	600	600
idle time ratio [%]	17.0	7.3	2.5
average speed [km/h]	24.4	54.7	94.4
maximum speed [km/h]	60	94.9	125.3
average acceleration [m/s^2]	0.685	0.582	0.468
maximum acceleration [m/s^2]	2.51	2.68	1.56

GYTR kit and the motorcycle dynamometer Dynojet i250. The result obtained from measuring on the given device is a dependence of the engine power output and torque on the engine speed.[31−45] However, for scientific purposes, the results are presented in the form of the dependence of the brake mean effective pressure (BMEP) on the relative mean piston speed (Cs). This dependence is expressed in a dimensionless form, applying the maximum values of the above-mentioned quantities ($BMEP_{max}$ = 1.29 MPa; Cs_{max} = 20.54 m/s), whereas it was measured in the steady state at maximum engine power on 4th gear.

Figure 3 shows the measured dependence of the relative brake mean effective pressure ($BMEP/BMEP_{max}$) on the relative mean piston speed (Cs/Cs_{max}) for the unleaded fuel E85. Parameters of this fuel are listed in Table 2. This fuel tops among the sustainable fuels. It provides a significant resistance to engine knocking as well as excellent reactivity. This fact is also reflected in the output characteristics of the experimental engine, where it is possible to note a continuous increase and only minimal decreases of BMEP in the whole spectrum of relative mean piston speed. The highest BMEP values are quite stable and the engine is characterized by excellent flexibility within the maximally possible usable working range.

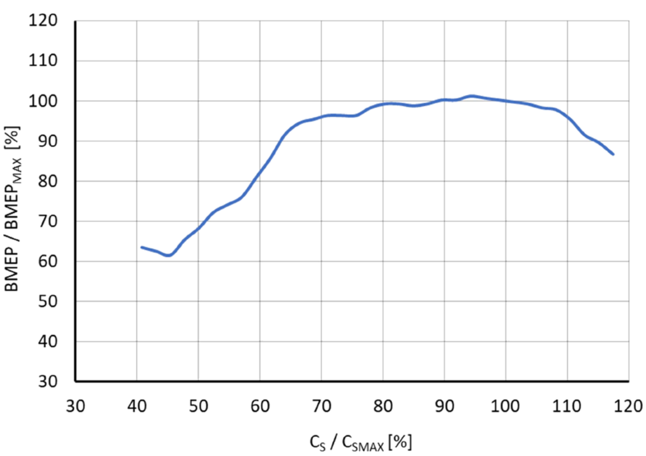

Figure 3. Analysis of dependence of relative brake mean effective pressure on relative mean piston speed for E85 fuel.

Figure 4 presents the measured dependence of the relative brake mean effective pressure on the relative mean piston speed for unleaded gasoline (UG). Parameters of this fuel are in Table 2. This fuel is standardly available at gas stations and used in common transport. From the analysis, it can be stated that in the case of this fuel, the increase of BMEP is relatively smooth but less distinctive than using E85 fuel and there are two significant decreases in the area of 60% and 75% Cs/Cs_{max}. The maximum values of BMEP are relatively stable, and the engine is characterized by limited flexibility since the usable range of its operation is limited by the decrease at 75% Cs/Cs_{max}.

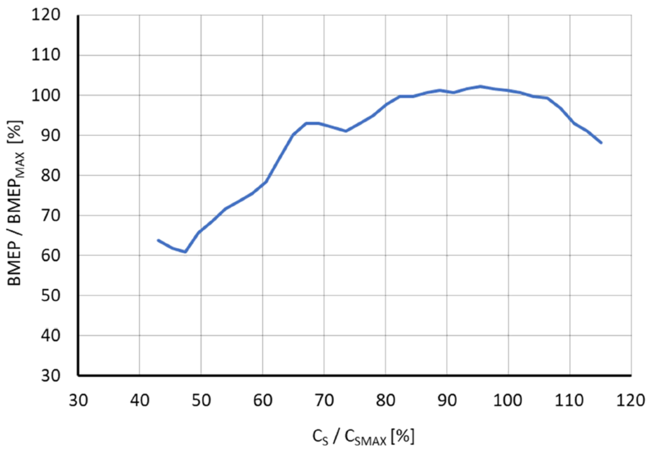

Figure 4. Analysis of dependence of relative brake mean effective pressure on relative mean piston speed for unleaded gasoline (UG).

Figure 5 illustrates an experimental output presenting a dependence of the relative brake mean effective pressure on the relative mean piston speed for the 4S GP fuel, which is the best fuel available on the market. This fuel offers maximum power output within the limits of FIM regulations, together with a very high combustion rate, which is especially effective at high engine speeds. The increase of BMEP is the most distinctive compared to that of the other tested fuels that are characterized by the best acceleration of the tested vehicle. This fuel enables a much faster achievement of the maximum engine power output parameters that are maintained for a long time and in a wide spectrum of the applied medium piston speed. The maximum engine power parameters are also the best, even if the changes in the area of maximum power are moderate. However, much more important is a benefit in the engine speed range.

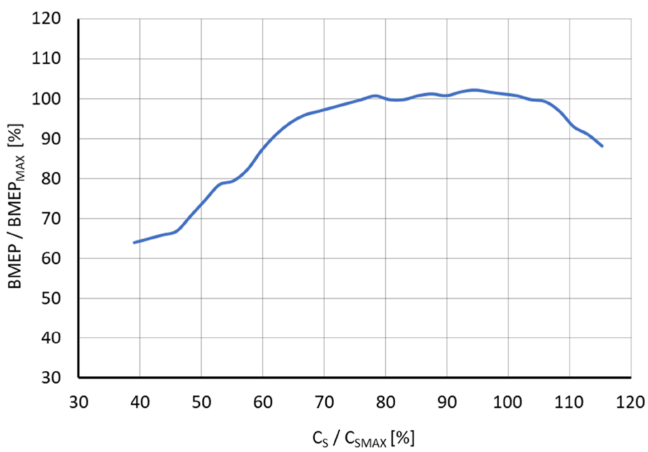

Figure 5. Analysis of dependence of relative brake mean effective pressure on relative mean piston speed for 4SGP fuel.

As it follows from a mutual comparison of the parameters among the individual fuels, the BMEP curve maintains approximately the same shape, but, according to expectation, it differs especially in the area of power increase. Hence, the engine power increases mainly during acceleration and in the case of 4SGP fuel also in the maximum operational regime. This fact can be considered as a potential disadvantage for the standard engines, but the racing car engines are only rarely exploited below 60% of their maximum power. On the other hand, the standard fuel is not suitable for racing purposes.

Figure 6 illustrates the specific fuel consumption depending on the relative mean piston speed. These values were more or less stable for all three tested fuels, and they correspond to setting of engine mapping. This figure clearly shows a visibly higher fuel demand in the area of the critical engine speed spectrum (50%). Consequently, after 60%, the fuel consumption is stable and the combustion is significantly more efficient below this value. This fact is caused by the so-called engine flexibility, which defines the range of engine speed between the maximum engine torque value and the maximum engine power value. In this range of engine speed, the engine is working optimally.

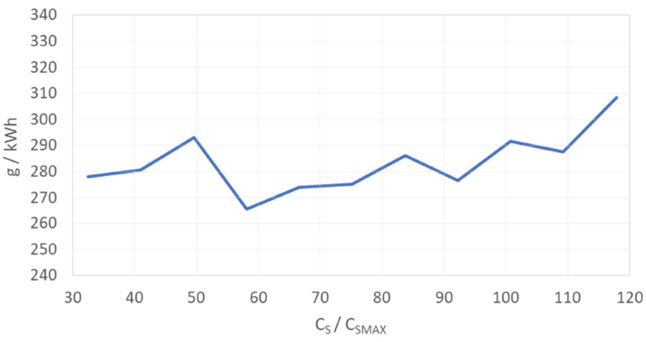

Figure 6. Dependence of specific fuel consumption on relative mean piston speed in [%].

3.2. Emission Analysis. Emission analysis was carried out for CO, NOx, and HC emissions (Figures 7, 8, and 9). These emissions were measured for all 3 kinds of the applied fuel using the EUDC and WMTC driving cycles. The individual emissions of a regulated pollutant are expressed in weight per kilometer traveled. As it follows from the emission analysis, parameters of the E85 fuel are more favorable concerning the CO and HC polluting substances. It can be assumed that due to the higher oxygen content, the combustion process runs better. Conversely, NOx emissions are moderately higher compared to the 4S GP fuel. Thus, it seems that the fuel management system and also the catalyzer capacity were not proposed appropriately for application of biofuels with regard to a fact that these fuels require a richer mixture composition. In spite of this, there is a possibility for the newest high-power motorcycles to apply a variable fuel map, which would ensure a better combustion of the bio-component.

It is evident from the NOx analysis that in the case of the applied E85 fuel, the emissions are increasing mainly on a long straight route (WMTC3). Due to rapid vehicle acceleration and dynamic driving style under these operational conditions, the impact of combustion temperature at high-level engine load and with high volume of exhaust gas flow reduces effectiveness of the catalyzer.

The analyzed results indicate that in the case of the tested fuels, a cold start (ECE1) clearly increases the CO and HC emissions compared to the values obtained at warmed up engine (ECE2). This situation can be caused by various factors. First, the engine during a cold start needs a rich fuel-air mixture that is outside the catalyzer optimal range. An increased amount of the fuel condenses on the cold inner walls of the engine or has not yet been evaporated. Second, during the first moments of cold transition, the efficiency of the catalyzer is too low due to rich AFR values.

3.3. Power Output Analysis of the Experimental Fuel Mixtures. This experiment was performed in connection with the actual trend in the field of motorsport (F1, MotoGP), where the world's vehicle manufacturers are constantly working on the improvement of driving units. In 2021, racing cars were powered by E5 gasoline. This designation means that the fuel contains 5% of ethanol. In 2022, the sport switched to E10 fuel, and during next years, the portion of bio-component will be increased. According to the results obtained from the experimental analyses described in Section 3.1, the best power output parameters were obtained in the case of the 4SGP fuel. For this reason, in the following experiment, the 4SGP fuel was chosen as a comparative fuel determined for comparison with the experimental fuel mixtures, which were created by mixing of E85 with 4SGP in different ratios (30, 60, and 90%). The main task was to create such a fuel mixture, which would be similar to 4SGP fuel in terms of power output parameters; at the same time, it would have a significantly higher content of bio-components and thus a potential for future application in the motorsport area.[31]

Figure 10 shows a dependence of the relative brake mean effective pressure on the relative mean piston speed. The comparative fuel is the pure 4SGP fuel (dashed line), and the full-line curve represents characteristics of the engine when using fuel, which was created by mixing 30% E85 with 70% of 4SGP. With regard to the comparative fuel, this fuel has a higher content of bio-components what is in accordance with

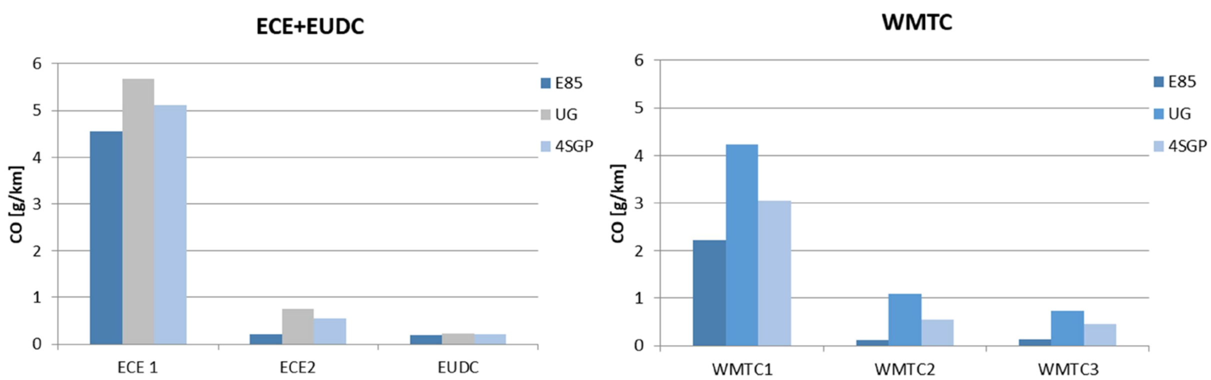

Figure 7. CO emissions analyzed for the applied three fuels at various driving cycles.

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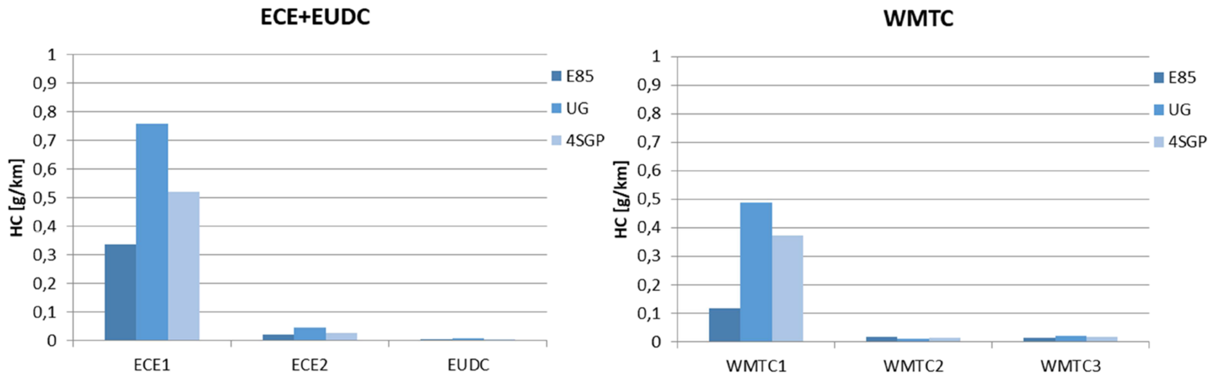

Figure 8. HC emissions analyzed for the applied three fuels at various driving cycles.

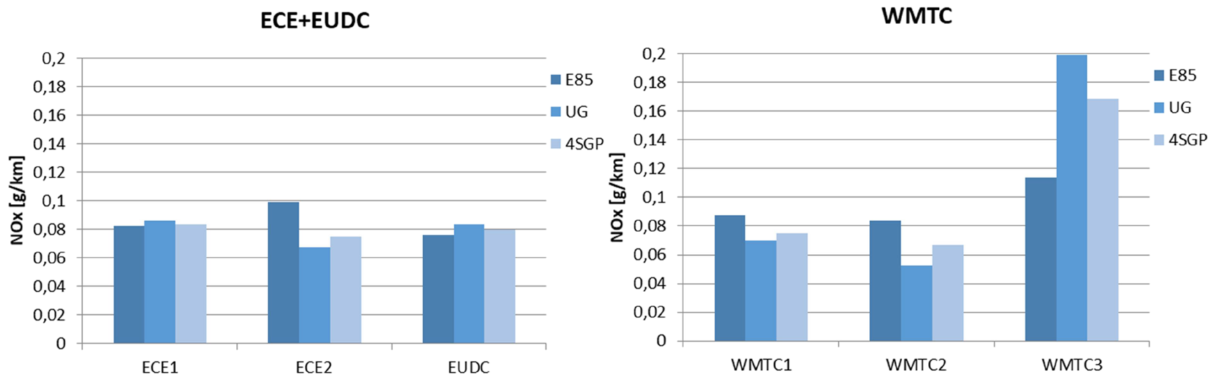

Figure 9. NOx emissions analyzed for the applied three fuels at various driving cycles.

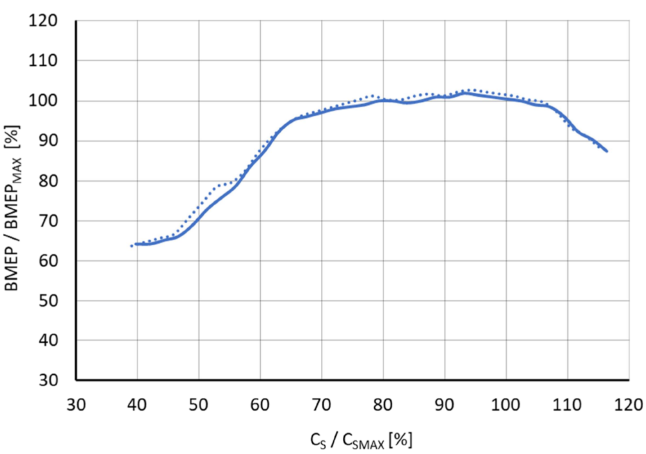

Figure 10. Comparison of output characteristics for pure 4SGP (dashed line) and for fuel mixture 30% E85/70% 4SGP (full line).

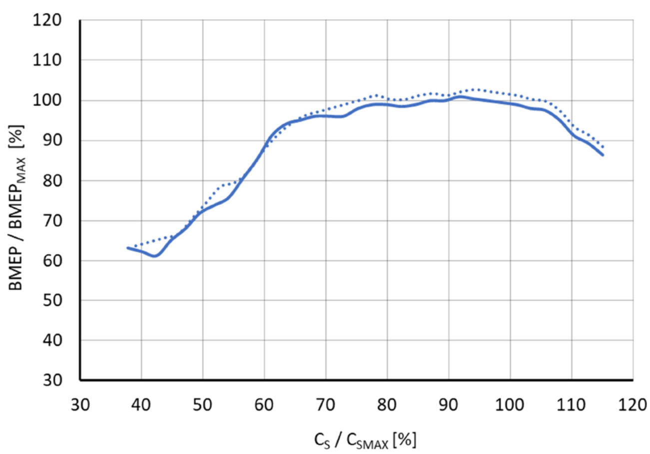

Figure 11. Comparison of output characteristics for pure 4SGP (dashed line) and for fuel mixture 60% E85/40% 4SGP (full line).

the future regulations valid in motorsport. The analysis shows that the bio-component had a moderate effect on the increase of BMEP, especially in the areas about 45−50% of the relative mean piston speed. The area of maximum BMEP is slightly lower, too. The overall analysis discovers that influence caused by this percentage of E85 was acceptable from the point of view of the output parameters.

In the next part of experimental investigation, the fuel ratio was adjusted and the fuel mixture, which was compared to pure 4SGP, had a composition of 60% E85 and 40% 4SGP (Figure 11). Analysis of the results proves that there was a more distinctive decrease of BMEP in the area of 50−55% Cs. There was also visible decrease of the maximum BMEP in the range of 70% Cs and more. The BMEP curve for the given fuel mixture basically copies the curve for pure 4SGP, but the problem is the missing maximum power output.

The last experimental fuel mixture, which was compared with pure 4SGP, is the mixture of 90% E85 and 10% 4SGP (Figure 12). The main task was to find out the influence of a relatively small amount of 4SGP added to E85. Experimental analysis confirmed a decrease of BMEP in the range 45−55% of the relative mean piston speed. At the same time, a significant decrease of BMEP was recorded in the whole range of the maximum relative mean piston speed. However, when this curve is compared with the curve valid for pure E85, it can be stated that the 10% share of 4SGP represents an interesting benefit for the output characteristics.

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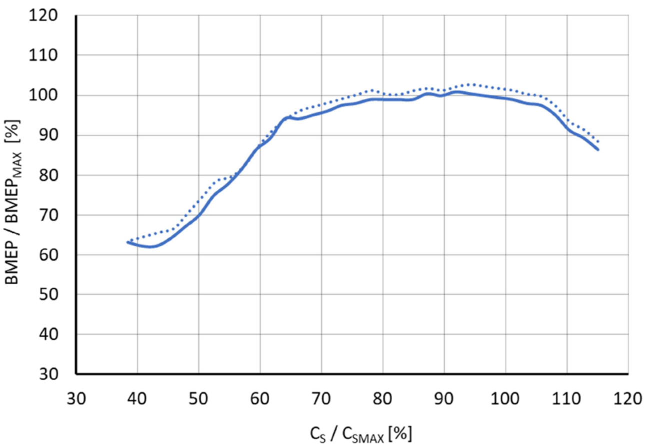

Figure 12. Comparison of output characteristics for pure 4SGP (dashed line) and for fuel mixture 90% E85/10% 4SGP (full line).

The experimental analyses were performed with a constant setting of motor management in order to ensure an objective comparison process. However, it is possible to assume that an appropriate adjustment of engine mapping and compression ratio could bring an improvement in application of the biofuels.

4. CONCLUSIONS

This scientific research work was focused on the experimental research of power output concerning the motorcycle racing engine. There were described experimentally tested modifications of a standard engine using a GYTR kit in accordance with the valid regulations. For scientific purposes, the results were presented in the form of a dependence of the brake mean effective pressure on the relative mean piston speed. This dependence was expressed in a dimensionless form, using the maximum values of the above-mentioned quantities. The results obtained from the performed engine experimental tests indicate an increase of engine power output parameters when using advanced fuels. The best power output parameters were achieved in the case of the top fuel 4SGP. At the same time, superethanol e85 also had significantly better power output parameters than the standard fuel available at gas stations.

In terms of engine gaseous emissions, the superethanol e85 clearly dominates. This fuel had 10 to 20% better emission parameters than the 4SGP fuel and, on average, 30% better results compared to the standard UG fuel. Therefore, it is possible to assume that due to higher oxygen content in E85, combustion of this fuel is more perfect. At the same time, for all the tested motorcycles, there is an evident fundamental difference between the emissions during the cold start of the engine and in the engine operational regime. This fact is mainly caused due to the fact that when the engine is warmed up, it co-works optimally with the operational catalyzer.

In the third part of this work, the experimental fuel mixtures were analyzed with the aim to create a fuel mix usable in the motorsport area according to the regulations valid during the following years. It can be stated that the addition of a lower percentage (30%) of E85 has no significant effect on the engine power parameters. Using a higher ratio of E85 (90%), the deviations are significant and the engine would require a complete change of mapping in this case.

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) Pachiannan, T.; Zhong, W.; Rajkumar, S.; He, Z.; Leng, X.; Wang, Q. A literature review of fuel effects on performance and emission characteristics of low-temperature combustion strategies. *Appl. Energy* **2019**, *251*, No. 113380.

(2) Kokjohn, S. L.; Hanson, R. M.; Splitter, D. A.; Reitz, R. D. Experiments and modeling of dual-fuel HCCI and PCCI combustion using in-cylinder fuel blending. *SAE Int. J. Engines* **2009**, *2*, 24−39.

(3) Long, Q.; Wu, C.; Wang, X.; Jiang, L.; Li, J. A. Multiobjective genetic algorithm based on a discrete selection procedure. *Math. Probl. Eng.* **2015**, *2015*, No. 349781.

(4) Eichmeier, J. U.; Reitz, R. D.; Rutland, C. A. Zero-dimensional phenomenological model for RCCI combustion using reaction kinetics. *SAE Int. J. Engines* **2014**, *7*, 106−119.

(5) Engeländer, K.; Duchowny, A.; Blümich, B.; Adams, A. Analysis of aging products from biofuels in long-term storage. *ACS Omega* **2022**, *7*, 26256−26264.

(6) Kokjohn, S. L.; Hanson, R. M.; Splitter, D. A.; Reitz, R. D. Fuel reactivity controlled compression ignition (RCCI): A pathway to controlled high-efficiency clean combustion. *Int. J. Engine Res.* **2011**, *12*, 209−226.

(7) Yang, B.; Yao, M.; Cheng, W. K.; Li, Y.; Zheng, Z.; Li, S. Experimental and numerical study on different dual-fuel combustion modes fueled with gasoline and diesel. *Appl. Energy* **2014**, *113*, 722−733.

(8) Li, J.; Yang, W. M.; An, H.; Zhao, D. Effects of fuel ratio and injection timing on gasoline/biodiesel fueled RCCI engine: A modeling study. *Appl. Energy* **2015**, *155*, 59−67.

(9) Hanson, R.; Curran, S.; Wagner, R.; Kokjohn, S.; Splitter, D.; Reitz, R. D. Piston Bowl optimization for RCCI combustion in a light-duty multi-cylinder engine. *SAE Int. J. Engines* **2012**, *5*, 286−299.

(10) Zhou, D.; Yang, W.; Li, J.; Tay, K. L.; Kraft, M. Combustion modeling in RCCI engines with a hybrid characteristic time combustion and closed reactor model. *Appl. Energy* **2018**, *227*, 665−671.
(11) Romero-Perez, J. C.; Vergara, L.; González-Delgado, Á. D. Development of a methodology for the synthesis of biorefineries based on incremental economic and exergetic return on investment. *ACS Omega* **2021**, *6*, 6112−6123.
(12) Benajes, J.; Molina, S.; García, A.; Belarte, E.; Vanvolsem, M. An investigation on RCCI combustion in a heavy duty diesel engine using in-cylinder blending of diesel and gasoline fuels. *Appl. Therm. Eng.* **2014**, *63*, 66−76.
(13) Puškár, M.; Fabian, M.; Kádárová, J.; Blišt'an, P.; Kopas, M. Autonomous vehicle with internal combustion drive based on the homogeneous charge compression ignition technology. *Int. J. Adv. Robot. Syst.* **2017**, *14*, No. 172988141773689.
(14) Pal, S.; Gubeljak, N.; Bončina, T.; Hudák, R.; Toth, T.; Zivcak, J.; Lojen, G.; Leben, N.; Drstvenšek, I. The effects of locations on the build tray on the quality of specimens in powder bed additive manufacturing. *Int. J. Adv. Manuf. Technol.* **2021**, *112*, 1159−1170.
(15) Doosje, E.; Willems, F.; Baert, R. *Experimental demonstration of RCCI in heavy-duty engines using diesel and natural gas*. SAE Technical Paper Series, 2014.
(16) Li, Y.; Jia, M.; Chang, Y.; Liu, Y.; Xie, M.; Wang, T.; Zhou, L. Parametric study and optimization of a RCCI (reactivity controlled compression ignition) engine fueled with methanol and diesel. *Energy* **2014**, *65*, 319−332.
(17) Li, Y.; Jia, M.; Chang, Y.; Fan, W.; Xie, M.; Wang, T. Evaluation of the necessity of exhaust gas recirculation employment for a methanol/diesel reactivity controlled compression ignition engine operated at medium loads. *Energy Convers. Manage.* **2015**, *101*, 40−51.
(18) Han, X.; Divekar, P.; Reader, G.; Zheng, M.; Tjong, J. Active Injection Control for Enabling Clean Combustion in Ethanol-Diesel Dual-Fuel Mode. *SAE Int. J. Engines* **2015**, *8*, 890−902.
(19) Fang, W.; Fang, J.; Kittelson, D.; Northrop, W. An Experimental Investigation of Reactivity-Controlled Compression Ignition Combustion in a Single-Cylinder Diesel Engine Using Hydrous Ethanol. *J. Energy Resour. Technol.* **2014**, *137*, No. 031101.
(20) Wang, H.; DelVescovo, D.; Yao, M.; Reitz, R. Numerical Study of RCCI and HCCI Combustion Processes Using Gasoline, Diesel, iso-Butanol and DTBP Cetane Improver. *SAE Int. J. Engines* **2015**, *8*, 831−845.
(21) Benajes, J.; Molina, S.; García, A.; Monsalve-Serrano, J. Effects of direct injection timing and blending ratio on RCCI combustion with different low reactivity fuels. *Energy Convers. Manage.* **2015**, *99*, 193−209.
(22) Zhou, D.; Yang, W.; An, H.; Li, J. Application of CFD-chemical kinetics approach in detecting RCCI engine knocking fueled with biodiesel/methanol. *Appl. Energy* **2015**, *145*, 255−264.
(23) Zhou, D.; Yang, W.; An, H.; Li, J.; Shu, C. A numerical study on RCCI engine fueled by biodiesel/methanol. *Energy Convers. Manage.* **2015**, *89*, 798−807.
(24) Fang, T.; Lin, Y.; Foong, T.; Lee, C. Biodiesel combustion in an optical HSDI diesel engine under low load premixed combustion conditions. *Fuel* **2009**, *88*, 2154−2162.
(25) Kuric, I.; Tlach, V.; Císar, M.; Ságová, Z.; Zajačko, I. Examination of industrial robot performance parameters utilizing machine tool diagnostic methods. *Int. J. Adv. Robot. Syst.* **2020**, *17*, No. 172988142090572.
(26) Pavlenko, I.; Ivanov, V.; Kuric, I.; Gusak, O.; Liaposhchenko, O. *Ensuring vibration reliability of turbopump units using Artificial Neural Networks*. Lecture Notes Mechanical Engineering, 2019; pp 165 −175.
(27) Píštěk, V.; Klimeš, L.; Mauder, T.; Kučera, P. Optimal design of structure in rheological models: an automotive ap-plication to dampers with high viscosity silicone fluids. *J. Vibroengineering.* **2017**, *19*, 4459−4470.
(28) Ojstersek, R.; Acko, B.; Buchmeister, B. Simulation study of a flexible manufacturing system regarding sustainability. *Int. J. Simul. Model.* **2020**, *19*, 65−76.
(29) Puškár, M.; Kopas, M.; Sabadka, D.; Kliment, M.; Šoltésová, M. Reduction of the gaseous emissions in the marine diesel engine using biodiesel mixtures. *J. Mar. Sci. Eng.* **2020**, *8*, 330.
(30) Puškár, M.; Živčák, J.; Tarbajovský, P. Complex analysis of combustion and emission parameters of bio-renewable fuel mixtures in dual-fuel mode. *Biofuels, Bioprod. Biorefin.* **2022**, *16*, 1744−1760.
(31) Hudák, R.; Schnitzer, M.; Králová, Z. O.; Gorejová, R.; Mitrík, L.; Rajťúková, V.; Tóth, T.; Kovačević, M.; Riznič, M.; Oriňaková, R.; Živčák, J. Additive Manufacturing of porous ti6al4v alloy: Geometry Analysis and mechanical properties testing. *Appl. Sci.* **2021**, *11*, 2611.
(32) Xue, J.; Grift, T.; Hansen, A. Effect of biodiesel on engine performances and emissions. *Renewable Sustainable Energy Rev.* **2011**, *15*, 1098−1116.
(33) An, H.; Yang, W.; Chou, S.; Chua, K. Combustion and emissions characteristics of diesel engine fueled by biodiesel at partial load conditions. *Appl. Energy* **2012**, *99*, 363−371.
(34) An, H.; Yang, W.; Maghbouli, A.; Li, J.; Chou, S.; Chua, K. Performance, combustion and emission characteristics of biodiesel derived from waste cooking oils. *Appl. Energy* **2012**, *112*, 493−499.
(35) Li, J.; Yang, W.; An, H.; Maghbouli, A.; Chou, S. Effects of piston bowl geometry on combustion and emission characteristics of biodiesel fueled diesel engines. *Fuel* **2014**, *120*, 66−73.
(36) Mohsin, R.; Majid, Z.; Shihnan, A.; Nasri, N.; Sharer, Z. Effect of biodiesel blends on engine performance and exhaust emission for diesel dual fuel engine. *Energy Convers. Manage.* **2014**, *88*, 821−828.
(37) Gharehghani, A.; Hosseini, R.; Mirsalim, M.; Jazayeri, S.; Yusaf, T. An experimental study on reactivity controlled compression ignition engine fueled with biodiesel/natural gas. *Energy* **2015**, *89*, 558−567.
(38) Cha, J.; Kwon, S.; Kwon, S.; Park, S. Combustion and emission characteristics of a gasoline−dimethyl ether dual-fuel engine. *Proc. Inst. Mech. Eng., Part D* **2012**, *226*, 1667−1677.
(39) Hanson, R.; Kokjohn, S.; Splitter, D.; Reitz, R. Fuel Effects on Reactivity Controlled Compression Ignition (RCCI) Combustion at Low Load. *SAE Int. J. Engines* **2011**, *4*, 394−411.
(40) Dempsey, A.; Walker, N.; Reitz, R. Effect of Cetane Improvers on Gasoline, Ethanol, and Methanol Reactivity and the Implications for RCCI Combustion. *SAE Int. J. Fuels Lubr.* **2013**, *6*, 170−187.
(41) Wu, Y.; Reitz, R. Effects of Exhaust Gas Recirculation and Boost Pressure on Reactivity Controlled Compression Ignition Engine at High Load Operating Conditions. *J. Energy Resour. Technol.* **2015**, *137*, DOI: 10.1115/1.4029866.
(42) Singh, A.; Agarwal, A. Experimental evaluation of sensitivity of low-temperature combustion to intake charge temperature and fuel properties. *Int. J. Engine Res.* **2017**, *19*, 732−757.
(43) Ma, S.; Zheng, Z.; Liu, H.; Zhang, Q.; Yao, M. Experimental investigation of the effects of diesel injection strategy on gasoline/diesel dual-fuel combustion. *Appl. Energy* **2013**, *109*, 202−212.
(44) Puskar, M.; Kopas, M.; Soltesova, M.; Tarbajovsky, P. Simulation model of advanced system for application of sustainable fuels. *Int. J. Simul. Model.* **2022**, *21*, 308−319.
(45) Puškár, M.; Živčák, J.; Kočišová, M.; Šoltésová, M.; Kopas, M. Impact of bio-renewable energy sources on reduction of emission footprint from vehicles. *Biofuels, Bioprod. Biorefin.* **2021**, *15*, 1385−1394.