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Dynamic parameters of a car with a SI engine fueled with LPG/DME blends

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The paper presents an analysis of the dynamic parameters of a compact class passenger car powered by LPG/DME blends. The presented results are part of the research cycle of this vehicle, the purpose of which was to check the possibility of using DME (dimethyl ether) as an additive in the fuel mixture with LPG. In the presented part of the experimental research, the acceleration times of the vehicle under specific conditions were measured. On the basis of the obtained results, the relations between the average acceleration in the tested speed ranges, the fuel composition, and the degree of engine load were developed. The results of the analysis indicate that in the examined range of changes in the DME share in the fuel, comparable or higher acceleration values were obtained for all engine load levels. This confirms the usefulness of DME as a fuel component used to power SI engines.

Key words: *LPG/DME, fuel blend, dynamic parameters, acceleration, SI engine*

1. Introduction

The analysis of scientific research on the use of DME clearly shows that it is used in many branches of the economy. Dimethylether is considered one of the best alternative fuels for internal combustion engines. It owes this to its physico-chemical properties, as an environmentally friendly, non-toxic, biodegradable product. DME can be produced from natural gas, coal or biomass. As a synthetic fuel, it is considered an excellent substitute for conventional diesel and LPG.

Many research units have started researching the use of DME in diesel engines [3, 15, 17, 21]. The properties of this fuel allow it to be used in a diesel engine due to its high cetane number and low auto-ignition temperature. Due to the very low PM emission during DME combustion, a high rate of exhaust gas recirculation (EGR) is possible in order to reduce the emission of nitrogen oxides [11, 22, 23]. Specific application solutions mainly concern CI engines [10, 12], but in the last few years, attempts have been made to power the SI engine. The high cetane number prevents the use of DME as a substitute fuel, but it is suitable for fueling the engine in the form of a mixture with gasoline [1, 8, 13, 18–20, 24] or with LPG [4, 5].

Research on the use of LPG/DME gaseous fuel mixtures has also been conducted for over 10 years at the Faculty of Transport and Aviation Engineering at the Silesian University of Technology. The results of these studies were published on an ongoing basis. The completed project included several research cycles, which included:

– preliminary tests on a chassis dynamometer at full engine load, in the range of mixtures with DME content up to 26% by weight [7]
– experimental tests on a chassis dynamometer at partial engine loads, in the range of mixtures with DME content up to 30% by weight [9]
– experimental tests on a chassis dynamometer at partial engine loads, in the range of mixtures with DME content up to 30% by weight, with correction of the ignition advance [14]
– simulation studies of thermodynamic processes occurring in the engine cylinder, based on the results of experimental studies (approved for publication)
– tests of vehicle dynamics parameters when fueled with LPG/DME mixtures.

This article elaborates on the research results obtained in the last of the above-mentioned stages. The assessment of the dynamic parameters of the vehicle is aimed at determining the impact of the composition change on the acceleration values achieved during acceleration. In fact, it is one of the factors of comfort of use. Users take this aspect into account and consider it one of the criteria for assessing the possibility of widespread use of fuel. These types of tests approximate actual operating conditions and may also be conducted to determine fuel consumption or exhaust emissions [2, 16].

2. Experimental studies

2.1. Measurement set-up

The popular passenger car powered by 1.6 liter engine, naturally aspirated with a compression ratio of 9.6, port fuel injection, two valves per cylinder, flat pistons and without external EGR was used in the experiments (Fig. 2). The engine has been adapted to run on LPG gas fuel and LPG and DME blends. The main features of the engine of the tested vehicle are presented in Table 1.

Table 1. Engine specification

Parameter	Value
Engine code	X16SZR
Cylinder number and layout	4 R
Maximum power	55 kW@5200 rpm
Maximum torque	128 N·m@2800 rpm
Displacement	1598 cm^3
Bore × stroke	79.0 × 81.5 mm
Compression ratio	9.6

The experiments were performed on a MAHA MSR500 chassis dynamometer. While examining the dynamic parameters of the vehicle, the acceleration time was measured using the built-in module ‘Driving simulation’. The driving simulation reenacts a road drive and/or a certain load, which can be set with the drive cycles based on specific drive resistances. The measurement was performed by running the research procedure in the dynamometer software (Fig. 1).

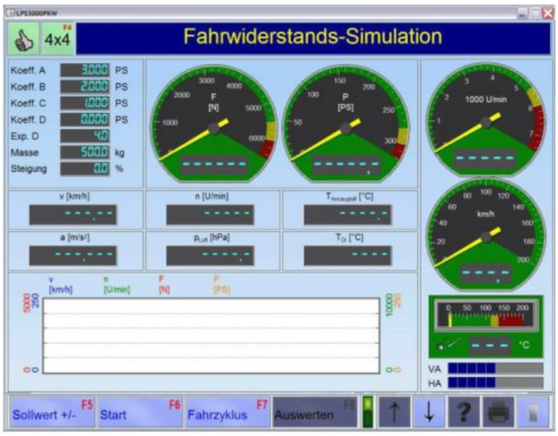

Fig. 1. View of the engine compartment of the tested vehicle on the dynamometer chassis

Then, the vehicle was accelerated to a speed that enabled it to drive at the given gear ratio (3 or 4). The test started when the lower speed range was reached. The dyno software measured the time to reach the upper driving speed range.

The vehicle-specific drive resistance characteristic including mass simulation is described by the following simulation model [17]:

$$F = \frac{C_A}{v_{ref}} + \frac{C_A \cdot v}{v_{ref}^2} + \frac{C_C \cdot v^2}{v_{ref}^3} + \frac{C_D \cdot v^{Exp\,D}}{v_{ref}^{Exp\,D+1}} + (M - m_{mech})\frac{dv}{dt} + (M \cdot g \cdot \sin\alpha)$$

where: F – tractive force target value, C_A – rolling resistance coefficient (constant), C_B – flexing resistance coefficient (linear), C_C – drag coefficient (square with n ≅ 2), C_D – drag coefficient (exp. with n being variable), Exp D – exponent D ($1 \le n \le 3$, one decimal place), M – vehicle mass, m_{mech} – mechanical mass, V – roller speed, V_{ref} – reference speed, α – gradient angle (±), dv/dt – roller acceleration, g – gravitational acceleration.

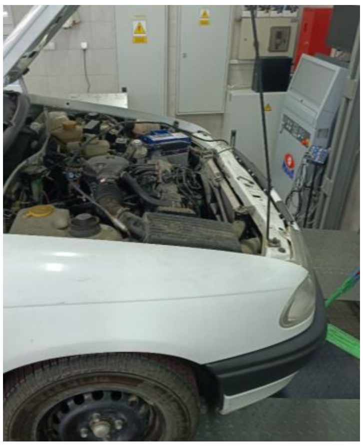

Fig. 2. View of the engine compartment of the tested vehicle on the dynamometer chassis

2.2. Methodology of research

Two series of tests were carried out:
- acceleration from 40 to 70 km/h in 3rd gear
- acceleration from 60 to 90 km/h in 4th gear.

Each series included 48 measurements; for eight fuels with different DME content and six engine load levels. The fuels used for the tests contained from 0% (LPG only) to 30% DME. The proportions of fuel components were determined by the gravimetric method. The gas fuel blend was produced immediately before a given measurement series. For this purpose, a fuel blend preparation station was used. (Fig. 3).

Fig. 3. Station for producing fuel blends

Physicochemical properties of the tested fuels are given in the Table 2. The selected engine load stages: 21%, 33%, 48%, 69%, 90% and 100% correspond to the position of the accelerator pedal and are determined by the TPS signal. An original device was used to apply partial loads to the engine, designed universally for the selected test object. The load was adjusted using replaceable washers that were mounted in the base of the device under the accelerator pedal.

Acceleration of the vehicle at a given degree of throttle opening was started below the starting speed to ensure stable engine load during the measurement. Time measurement was started at the moment of reaching the start speed and turned off simultaneously with reaching the final speed in the assumed range.

Table 2. Physicochemical properties of the tested fuels [6]

Properties	DME $(CH_3)_2O$	Propane C_3H_8	n-butane C_4H_{10}	Unit
Density of liquefied gas	667	582	579	kg/m^3
Molecular weight	46.07	44.1	58.12	g/mol
Evaporation pressure	530	830	210	kPa
Heat of vaporization	467	370	358	kJ/kg
Boiling point	–25	–42	–0.5	°C
Air to fuel ratio	9	15.7	15,46	kg/kg
Lower heating value (LHV)	28.8	46.4	48	MJ/kg
Cetane number	55–60	5	10	–
Octane number	–	112	88.9	–

3. Discussion of results

In order to test the dynamic properties of a car fueled with DME fuel blends, the acceleration times of the vehicle on a chassis dynamometer were measured. The dynamometer operating mode simulated an additional load, corresponding to the resistance to motion, which the vehicle must overcome in road conditions. The results of the measurement of the acceleration time in the adopted measurement ranges are presented in the tables (Table 3 and 4). In order to show the influence of the DME share on the vehicle dynamics, the obtained results were presented on graphs (Fig. 4 and 6). An alternative form was also introduced to the visualization of the results, which shows the changes in the acceleration time grouped for the tested engine load levels (Fig. 5 and 7).

Table 3. Acceleration time in 3rd gear in the speed range of 40–70 km/h

WOT	Acceleration time [s]							
	Mass percentage of DME in the blend							
	0%	7%	11%	14%	17%	21%	26%	30%
21%	13.22	14.17	12.76	12.63	12.30	12.02	12.67	12.74
33%	10.37	10.25	10.35	10.43	10.36	10.28	9.37	10.34
48%	6.06	5.96	6.17	6.63	6.40	6.19	6.57	6.75
69%	5.68	4.96	5.57	5.92	6.19	5.31	5.47	6.00
90%	5.05	5.08	5.68	5.7	5.67	6.03	6.11	5.96
100%	4.46	5.00	4.98	5.31	5.40	5.58	5.38	5.46

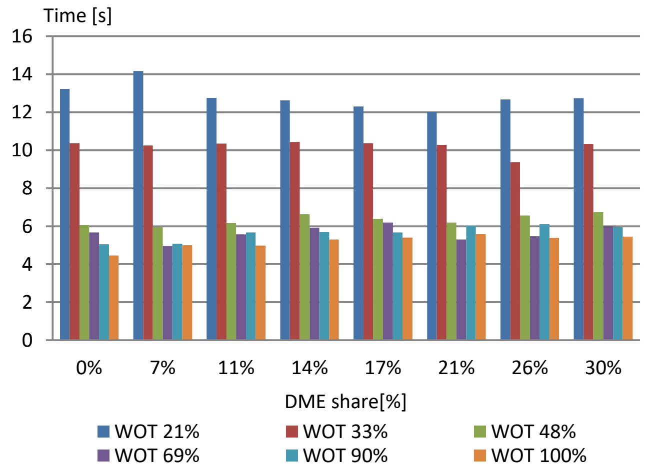

Fig. 4. Acceleration time depending on DME share, speed 40–70 km/h

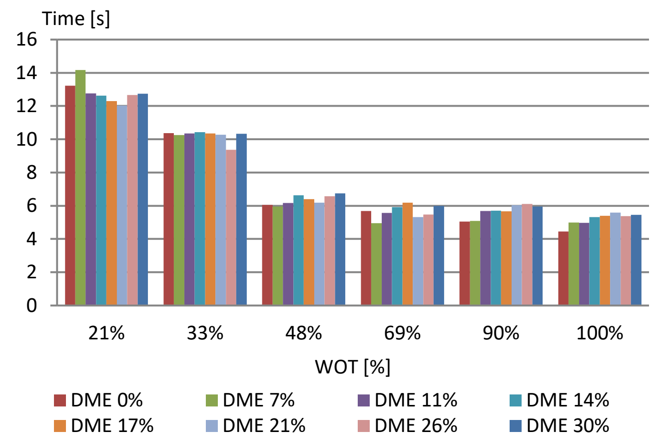

Fig. 5. Acceleration time depending on WOT, speed 40–70 km/h

Table 4. Acceleration time in 4th gear in the speed range of 60–90 km/h

WOT	Acceleration time [s]							
	Mass percentage of DME in the blend							
	0%	7%	11%	14%	17%	21%	26%	30%
21%	30.85	32.00	30.91	29.90	27.51	28.86	29.18	30.99
33%	22.14	20.55	19.44	19.35	19.62	20.36	20.04	20.33
48%	14.13	10.44	11.09	11.47	12.16	11.79	12.66	14.27
69%	10.81	9.97	9.78	9.93	10.84	9.84	11.18	12.91
90%	9.19	9.76	9.31	9.37	10.16	10.13	10.60	10.73
100%	8.99	9.41	9.54	9.21	9.38	10.93	10.19	10.91

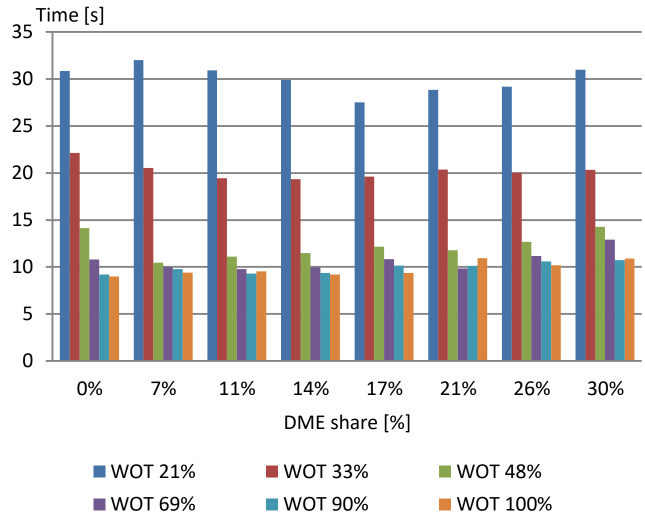

Fig. 6. Acceleration time depending on DME share, speed 60–90 km/h

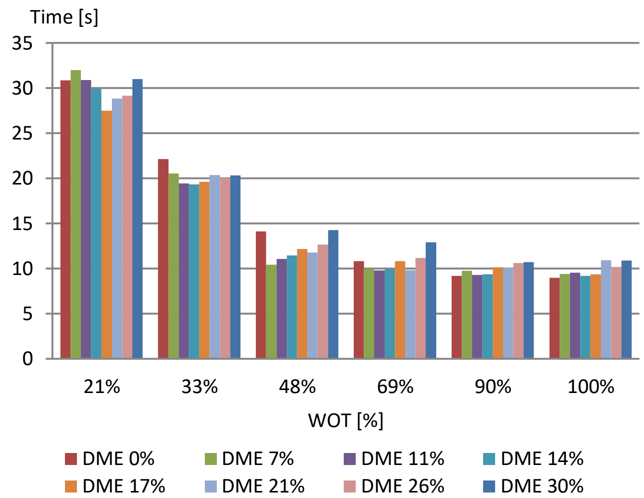

Fig. 7. Acceleration time depending on WOT, speed 60–90 km/h

Selected, exemplary ranges of speeds in gears 3rd and 4th correspond to the middle range of engine revolutions, which means that this is the area of the engine's performance characteristics, where a sufficiently high engine torque is available, which ensures smooth acceleration.

Next, specific acceleration values were calculated, based on the measured acceleration times in the assumed speed ranges. The accelerations are presented in three-dimensional graphs (Fig. 8 and 10), which allow to observe both the effect of the degree of engine load and the fuel composition. Increasing the share of DME, which has a much lower heating value than LPG (Table 2), undoubtedly also reduces the calorific value of the fuel blend. However, the presence of oxygen in the chemical structure of DME also causes a decrease in the A/F ratio. Thanks to this, the energy value of the stoichiometric mixture remains quite constant. This is confirmed by the results obtained. Observation of the results allows, among other things, to conclude that, in general, increasing the share of DME blended with LPG, does not entail a significant reduction in dynamic parameters. The obtained results show a similar picture for both tested speed ranges.

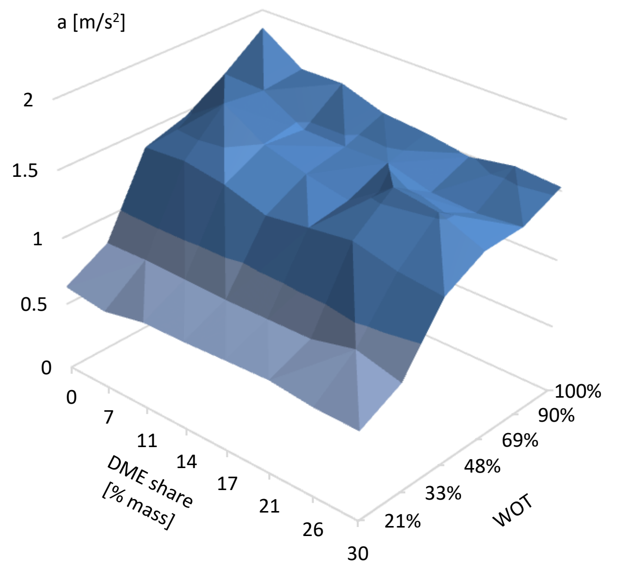

Fig. 8. Acceleration in 3rd gear in the speed range of 40–70 km/h

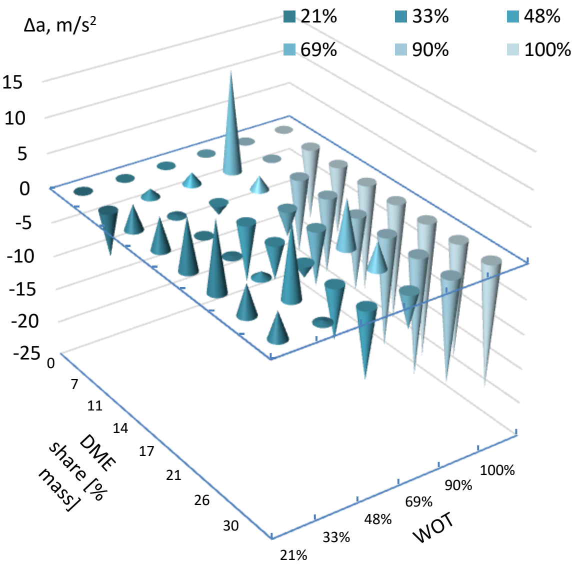

Fig. 9. Comparison of accelerations in 3rd gear in relation to LPG

Of course, the overarching goal of the conducted analyzes is to compare the results obtained when fueling with DME blends, with the dynamics of a vehicle powered only by LPG. This is the base fuel in this case. Therefore, in the further elaboration of the results, the differences in the achieved accelerations were presented in detail, in the form of changes Δa, expressed in [%]. They express the percentage increase/decrease in acceleration on a given fuel in relation to the value obtained for LPG without DME admixture. Changes in these values, in 3rd (Fig. 9) and 4th gear (Fig. 11), respectively, lead to interesting observations, as they allow to isolating areas where the vehicle dynamics improves or deteriorates. In addition, these areas are repeated in both measurement series. Namely, in the range of medium engine loads (33–69% WOT), the acceleration values increase. However, in the range of maximum loads, above 90%, the acceleration values are lower in relation to LPG-only operation. These trends are maintained for all tested mixtures with the participation of DME.

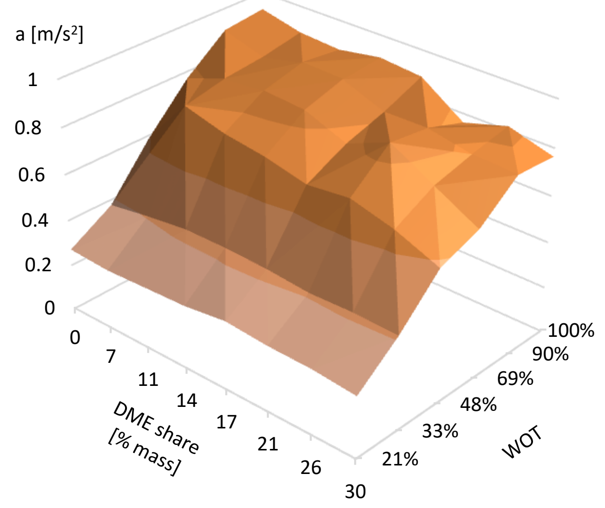

Fig. 10. Acceleration in 4th gear in the speed range of 60–90 km/h

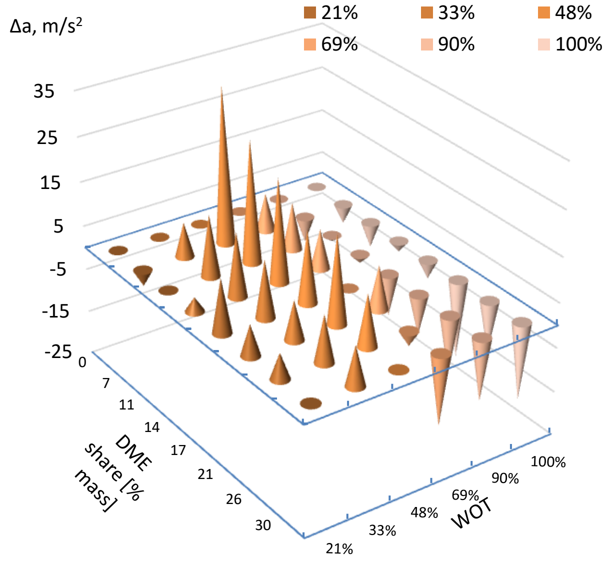

Fig. 11. Comparison of accelerations in 4th gear in relation to LPG

4. Conclusions

The conducted experimental studies complement the results obtained during the implementation of a wider cycle devoted to the use of LPG/DME mixtures in a spark-ignition engine. They make it possible to observe the influence of the DME share on the dynamic parameters of the tested engine.

Summing up the conducted research, the following conclusions can be drawn:

1. Similar physical and chemical properties enable the production of a mixture of LPG+DME fuels, its storage in standard tanks, and its use in LPG fueling systems. Such a solution is very important due to the utility aspect, which gives the opportunity to use existing and functioning installations.
2. Extending the research methodology with measurements at partial engine loads made it possible to compare the most useful areas of engine operation, most often used during vehicle operation.
3. As shown by vehicle acceleration measurements (on a chassis dynamometer), the dynamics of a vehicle powered by LPG+DME increases in the range of low and medium engine loads. The observed increase in vehicle dynamics occurs when fueled with mixtures containing DME from 7 to 26%. It amounted to an average of 4% in 3rd gear and approx. 8–12% in 4th gear.
4. At maximum loads, a decrease is observed, while maintaining the factory settings of the ignition timing. For a mixture containing 30% DME, the acceleration values decrease significantly. The recorded decrease was respectively: 17% in 3rd gear and 14.2% in 4th gear.
5. The results of the obtained research are complementary to a wide series of research, the results of which have been published in separate works. The use of the DME additive in a mixture with LPG is, from the point of view of observation of dynamic parameters and the combustion process, a fully valuable and useful fuel, which does not impair the performance of an engine fueled only with LPG.

Nomenclature

CA	crank angle
COV_{imep}	cyclic variation of indicating mean effective pressure
DME	dimethyl ether
EGR	exhaust gas recirculation
Exp.	exponential
HR	heat released
LPG	liquified petrolum gas
PM	particulate matter
SI	spark ignition
WOT	width opening of the throttle

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