TEKA Kom. Mot. i Energ. Roln. – OL PAN, 2011, 11c, 126–133

AN APPLICATION OF BUTANOL AS A DIESEL FUEL COMPONENT AND ITS INFLUENCE ON EXHAUST EMISSIONS

Miłosław Kozak*

*Poznań University of Technology, Poland

Summary. The influence of oxygenated diesel fuel containing n-butanol on a passenger car exhaust emissions was tested over the NEDC transient cycle. The tests showed that a diesel fuel/butanol blend, containing 10% of n-butanol, caused a significant decrease in PM and smoke emissions, had no effect on NO_x and CO_2 emissions and brought about higher CO and HC emissions. The most favourable fact resulting from the butanol application as diesel fuel component is that it produces desirable changes in PM/NO_x trade-off.

Key words: Diesel Engines, Exhaust Emissions, Diesel Fuel, Butanol.

INTRODUCTION

It is well known that fuel composition as well as its parameters have a significant influence on the exhaust emissions. The environmentally oriented changes in diesel fuel parameters boil down mainly to an increase in cetane number, decrease of density, sulphur and PAH content, and lower temperatures of fuel distillation. More unconventional, but also environmentally oriented diesel fuel modification is the oxygenation of the fuel. The process of oxygenation occurs by addition of oxygenated compounds to diesel fuel. The author carried out some research with oxygenated diesel fuels containing glycol ethers, maleates and carbonates. In most cases oxygenated fuels gave significant reductions in PM emissions, in some cases reductions in CO, HC, and NO_x emissions were also achieved [1-3].

Alcohols also can be used as oxygenated compounds. Ethanol is commonly used as a gasoline component and there are also successful examples of its application in diesel engines. However ethanol, because of its very high octane number, low boiling temperature, low density, only partial miscibility with hydrocarbons, etc. is not actually the best candidate for oxygenation of diesel fuel. Another alcohol, which can be used as fuel component is butanol. Because of its high octane number (RON/MON = 96/78), butanol is a good fuel for spark-ignition engines. That is why the majority research deal with butanol application as a fuel for spark-ignition engines. The most recent examples of such works are items: [4-8]. Butanol can be also used as a diesel fuel component, and in this application it is significantly better than ethanol. It should be noticed that butanol has physical properties (density, viscosity) quite similar to those of diesel fuel and in contrast to ethanol, is very well miscible with hydrocarbons. High calorific value is another butanol advantage over ethanol. According to [9]: 1% of butanol decreases the diesel fuel's cetane number by 0.5 units only.

There are not many publications concerning the application of butanol as a diesel fuel component. Rakpulos et al. recently published some articles [10-12] on the application of diesel fuel/butanol blends. They tested exhaust emissions of a diesel engine, operating in stationary conditions, fuelled with different mixtures of diesel fuel and n-butanol. They generally noticed reductions in CO, NO_x and smoke emissions but an increase in HC emissions. Similar changes in emissions of a small diesel engine were observed by Dogan [13]. Miers et al. [14] tested diesel fuel/butanol blends containing 20% and 40% by volume of n-butanol. Emission tests were carried out on a chassis dynamometer over the UDDS and HWFET dynamic cycles and during steady-state operation of a Euro 3 diesel passenger car. During the UDDS cycle a significant increase in CO and HC emissions, but also a reduction in NO_x emissions was noticed. During highway drive cycle they observed 25% increase in NO_x emissions when fuel contained 40% of butanol but CO and HC emissions remained unchanged. Neither PM nor smoke emissions were measured over dynamic cycles. During steady-state tests with different vehicle speeds and loads, the CO and NO_x emissions remained at very similar level regardless of a fuel type, whereas smoke emissions decreased as butanol content increased. HC emissions were traditionally higher for fuels containing butanol.

RESEARCH APPARATUS AND PROCEDURES

The New European Driving Cycle (NEDC) was selected as a representative test for this study. The test was Urban Driving Cycle (UDC) (cold start), followed by the high-speed Extra Urban Drive Cycle (EUDC) (hot start).

The tests were conducted on a passenger car equipped with a direct injection (Common Rail) turbocharged diesel engine, representing the latest technology in production at the start of the research program. Major data on the vehicle are shown in table 1.

Table 1. Specifications of the test vehicle

Vehicle Type	Passenger Car
Dry Weight	950 kg
Engine Type	Diesel, 4-cylinder in-line
Displacement	1.3 dm^3
Max. Power	51 kW @ 4000 rpm
Max. Torque	145 Nm @ 1500 rpm
Injection / Combustion Type	Direct injection Common Rail, turbocharged (intercooled)
Exhaust Gas Recirculation EGR	Electronically controlled (closed-loop)
Emission Control	Oxidation catalyst DOC
Calibrated to	EURO 4

The test vehicle was fuelled with two fuels: conventional Euro 5 diesel fuel (DF) and the Bu10 fuel blend consisting of 90% by volume of DF and 10% of n-butanol. The properties of diesel fuel and n-butanol are given in table 2 and 3 respectively. The majority of properties of Bu10 blend can be calculated from properties of DF and n-butanol. An exception is cetane number. The cetane number for Bu10 blend had been measured at a value of 47.2.

Table 2. Diesel fuel (DF) specifications

		Unit	Value
Cetane number		–	52.8
Cetane index		–	53.4
Density @ 20°C		kg/m^3	827.7
Sulfur content		ppm	8.8
Oxygen content		%(m/m)	0.0
Viscosity	@ 20°C	mm^2/s	4.096
	@ 40°C	mm^2/s	2.607
Distillation	E250	%(v/v)	38.1
	E350	%(v/v)	–
	T95	°C	332.3
	FBP	°C	343.7
Aromatic hydrocarbons	Total aromatics	%(m/m)	20.7
	Monoaromatics	%(m/m)	18.8
	Diaromatics	%(m/m)	1.7
	Tri+ aromatics	%(m/m)	0.2
	Total PAH	%(m/m)	1.9

Table 3. Some properties of n-butanol

	Unit	Value
Molecular weight	amu	74
Oxygen content	%(m/m)	21.6
Boiling point	°C	117
Freezing point	°C	–90
Flash point	°C	34
Autoignition point	°C	343
Density @ 20°C	kg/m^3	810
Viscosity @ 20°C	mm^2/s	3.64
Cetane number	–	25 [14], 18 [15]

The tests were carried out at the Emissions Testing Laboratory using the emissions chassis dynamometer Schenck 500/GS60. The CVS AVL CEC system with full-flow dilution tunnel AVL CET-LD/20 type and particulate sampling system AVL CEP-LD/100 PTS 60 l/min, controlling system CESAR and Sartorius microbalance were used to measure exhaust emissions.

TEST RESULTS AND DISCUSSION

In the first stage of the NEDC, i.e. in the UDC – Bu10 fuel blend caused considerable growth of CO emissions (fig. 1). The analysis of the results of continuous CO emissions measurement in the UDC revealed that the negative influence of Bu10 is mostly manifested during engine operation at high speed and load in steady conditions. Additionally, the analysis showed decreasing CO emissions during the realization of consecutive elementary cycles. The CO emissions drastically decrease in the last, i.e. fourth elementary cycle, which is connected with the start of effective operation of the catalytic converter. At the same time, this elementary cycle is characterized by the greatest relative differences in CO emissions between neat diesel fuel and Bu10.

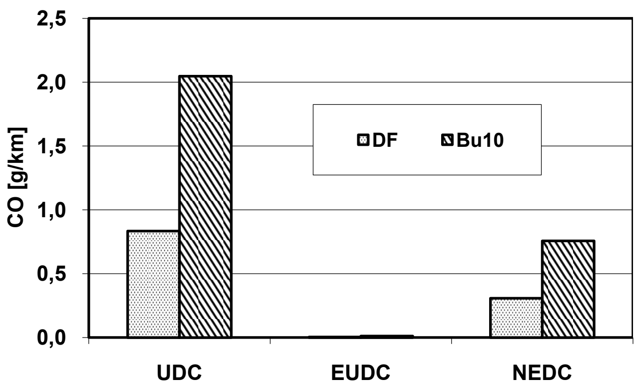

Fig. 1. CO emissions during UDC, EUDC and the whole NEDC for conventional diesel fuel (DF) and diesel fuel/butanol blend (Bu10)

The average CO emissions in the EUDC were over two orders of magnitude lower than in the UDC and amounted to less than 0.01 g/km for the both fuels. This confirms high effectiveness of removing of CO by the catalytic converter. Taking into account such a low emission of CO in the EUDC, the average emission in the entire NEDC is determined mainly by the UDC and the influence of fuel containing butanol is very similar to this in the UDC.

The results of increased CO emissions for diesel fuel/butanol blend described above are consistent with results obtained by Miers et al. [14], however they tested diesel fuel/butanol blends over different transient cycles, i.e. UDDS and HWFET. The results of tests carried out at steady-state conditions [10, 11, 13] show in principle decreases in CO emissions when a diesel fuel/butanol blend is applied.

The influence of the Bu10 fuel blend in the UDC is also unfavourable in the case of HC emissions (fig. 2). The analysis of the results of continuous measurement of HC in the UDC revealed that the negative influence of Bu10 fuel blend is the most evident, similarly to CO, during engine operation at high speed and load in steady conditions. The course of HC emissions during the first three elementary cycles is similar, which means that at that time the catalytic reactor had no influence upon the HC emissions. It is in the last, i.e. fourth elementary cycle that the catalytic converter starts to operate and the level of HC emitted considerably decreases. However, the Bu10 fuel still causes the growth of HC emissions.

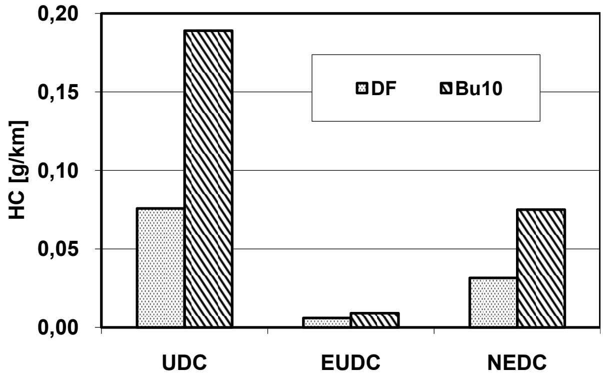

Fig. 2. HC emissions during UDC, EUDC and the whole NEDC for conventional diesel fuel (DF) and diesel fuel/butanol blend

The major benefit expected as a result of the use of oxygenated compounds, including butanol, is the decrease of PM emissions. At the same time it is known that the use of oxygenated compounds (especially those of low autoignition quality) may cause the growth of NO_x emissions as a result of intensification of "prompt NO_x" production. However, most previous studies [10, 11, 12, 13, 14, 15] show, that in case of diesel fuel/butanol blends there is no increase in NO_x emission and possibly even a decrease. Figure 3 shows NO_x emission over the NEDC. One can notice that during the UDC NO_x emissions are lower when the test vehicle is fuelled with Bu10, next during the EUDC this emission is slightly lower when the vehicle is fuelled with neat diesel fuel. For the NEDC analyzed as a whole there is actually no difference in NO_x emissions.

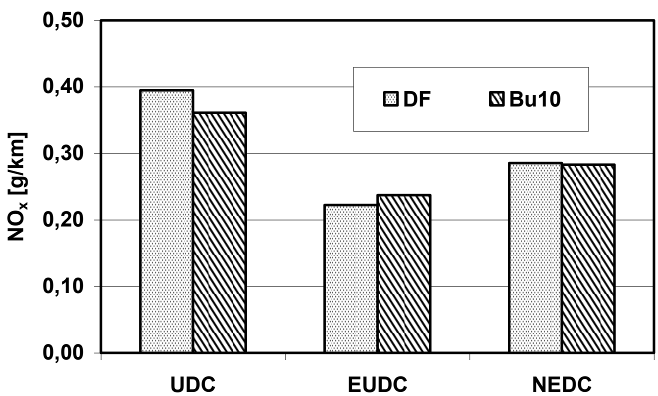

Fig. 3. NO_x emissions during UDC, EUDC and the whole NEDC for conventional diesel fuel (DF) and diesel fuel/butanol blend (Bu10)

The favourable influence of butanol on PM emissions has been confirmed over the whole NEDC (fig. 4). In the UDC – PM emission was lowered by 14%. In the EUDC PM emission reduction was even better and reached 25%. Average reduction in PM emissions in the complete NEDC was at a level of 21%. The analysis of the results of continuous smoke opacity measurement revealed that Bu10 fuel blend causes lower smoke emissions over the whole NEDC. Favourable influence of butanol on smoke emission was especially evident during vehicle's accelerations. In the available literature there are no results of diesel fuel/butanol blends influence on PM emissions during transient cycles. In stationary conditions a reduction in PM/smoke emissions is generally reported [10, 11, 12, 13, 14, 15].

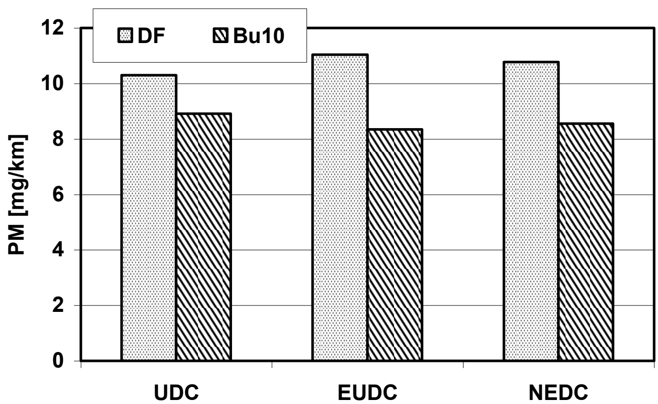

Fig. 4. PM emissions during UDC, EUDC and the whole NEDC
for conventional diesel fuel (DF) and diesel fuel/butanol blend (Bu10)

Bu10 fuel bland has no influence on CO_2 emissions, neither in the UDC phase nor in the EUDC phase of the NEDC cycle (fig. 5).

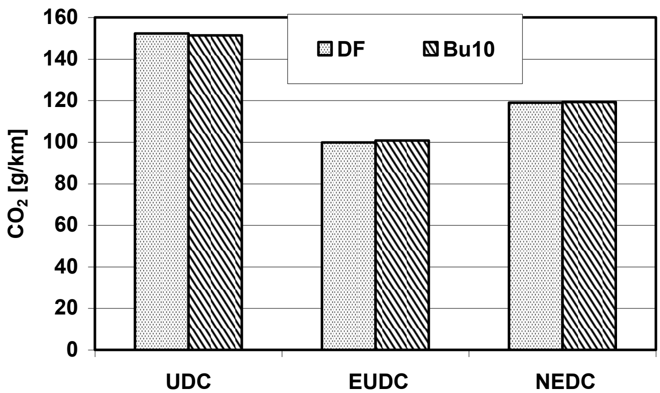

Fig. 5. CO_2 emissions during UDC, EUDC and the whole NEDC
for conventional diesel fuel (DF) and diesel fuel/butanol blend (Bu10)

CONCLUSIONS

Exhaust emissions from a diesel passenger car fuelled by diesel fuel/butanol blend (Bu10) were tested over the NEDC transient cycle. The test revealed a favourable influence of Bu10 fuel on the PM/NO_x trade-off. Namely, a significant (by 21%) reduction of PM emissions was achieved with no change in NO_x emissions. The reduction in PM emissions was confirmed by a considerable decrease in smoke emission. Application of Bu10 fuel had also some unfavourable effects, that are increases in CO and HC emissions. However, it should be emphasized, that after catalyst's light-off, which generally took place at the end of the UDC phase, the CO and HC emissions decreased to a very low level and then fuel type was of little importance. Bu10 fuel had no effect on CO_2 emissions.

The butanol can be regarded as a universal fuel component since it is applicable to gasoline and diesel fuel. In case of both fuels, butanol offers some favourable reductions in exhaust emissions. It can be expected that the role of butanol as a fuel component will be growing. Especially if butanol will be produced on a mass scale as a renewable fuel (second generation biofuel).

REFERENCES

1. Kozak M., Merkisz J., Bielaczyc P. and Szczotka A.: The Influence of Oxygenated Diesel Fuels on a Diesel Vehicle PM/NO_x Emission Trade-Off. SAE Technical Paper 2009-01-2696. 2009 SAE Powertrains, Fuels and Lubricants Meeting, San Antonio, Texas, USA, 02-05.11.2009.
2. Kozak M., Merkisz J., Bielaczyc P. and Szczotka A.: Low-Emissions Diesel Fuels Based on Oxygenated Compounds. APAC 15 Proceedings Vol. 1. 15th Asia Pacific Automotive Engineering Conference (APAC), Hanoi, Vietnam, 26-28.10.2009.
3. Kozak M., Merkisz J., Bielaczyc P. and Szczotka A.: Exhaust Emissions from a Diesel Passenger Car Fuelled with Oxygenated Fuels. Combustion Engines 2009-SC1.
4. Yang J., Wang Y. and Feng R.: The Performance Analysis of an Engine Fuelled with Butanol-Gasoline Blend. SAE Paper 2011-01-1191.
5. Wigg B., Coverdill R., Lee C. and Kyritsis D.: Emissions Characteristics of Neat Butanol Fuel Using a Port Fuel-Injected, Spark-Ignition Engine. SAE Paper 2011-01-0902.
6. Wallner T. and Frazee R.: Study of Regulated and Non-Regulated Emissions from Combustion of Gasoline, Alcohol Fuels and their Blends in a DI-SI Engine. SAE Paper 2010-01-1571.
7. Yang J., Yang X., Liu J., Han Z. and Zhong Z.: Dyno Test Investigations of Gasoline Engine Fueled with Butanol-Gasoline Blends. SAE Paper 2009-01-1891.
8. He X., Ireland J.C., Zigler B.T., Ratcliff M.A., Knoll K.E., Alleman T.L. and Tester J.T.: The Impacts of Mid-level Biofuel Content in Gasoline on SIDI Engine-out and Tailpipe Particulate Matter Emissions. SAE Paper 2010-01-2125.
9. Zöldy M., Hollo A. and Thernesz A.: Butanol as a Diesel Extender Option for Internal Combustion Engines. SAE Paper 2010-01-0481.
10. Rakopoulos D.C., Rakopoulos C.D., Giakoumis E.G., Dimaratos A.M. and Kyritsis D.C.: Effects of Butanol–Diesel Fuel Blends on the Performance and Emissions of a High-Speed DI Diesel Engine. Energy Conversion and Management no. 51 (2010).
11. Rakopoulos D.C., Rakopoulos C.D., Hountalas D.T., Kakaras E.C., Giakoumis E.G. and Papagiannakis R.G.: Investigation of the Performance and Emissions of Bus Engine Operating on Butanol/Diesel Fuel Blends. Fuel no. 89 (2010).

12. Rakopoulos D.C., Rakopoulos C.D., Papagiannakis R.G. and Kyritsis D.C.: Combustion heat release analysis of ethanol or n-butanol diesel fuel blends in heavy-duty DI diesel engine. Fuel no. 90 (2011).
13. Dogan O.: The Influence of n-butanol/Diesel Fuel Blends Utilization on a Small Diesel Engine Performance and Emissions. Fuel no. 90 (2011).
14. Miers S. A., Carlson R. W., McConnell S. S., Ng H. K., Wallner T. and LeFeber J.: Drive Cycle Analysis of Butanol/Diesel Blends in a Light-Duty Vehicle. SAE Paper 2008-01-2381.
15. Weiskirch C., Kaack M., Blei I. and Eilts P.: Alternative Fuels for Alternative and Conventional Diesel Combustion Systems. SAE Paper 2008-01-2507.

ZASTOSOWANIE BUTANOLU JAKO SKŁADNIKA PALIWA DIESEL I JEGO WPŁYW NA EMISJĘ SPALIN

Streszczenie. Badano wpływ utlenionego oleju napędowego zawierajacego n-butanol na emisję spalin w samochodzie osobowym. Testy przebiegały w zmiennym cyklu NECD w warunkach nieustalonych. Badania wykazały, że zawartość 10% n-butanolu w oleju napędowym powodowała znaczny spadek emisji cząstek stałych i dymu, natomiast nie miała wpływu na emisję NO_x i CO_2 oraz powodowała wyższą emisję CO i HC. Najkorzystniejszy aspekt zastosowania butanolu w składzie oleju napędowego to pożądane zmiany w wymianie cząstek stałych na NO_x.

Słowa kluczowe: silniki wysokoprężne, emisja spalin, olej napędowy, butanol.