ISSN: 1231-4005
e-ISSN: 23540133
DOI: 10.5604/01.3001.0010.3092

WATER EMULSIONS OF HYDROCARBONS AS DIESEL ENGINES FUEL

Lech J. Sitnik

Wroclaw University of Science and Technology
Department of Vehicle Engineering
Wybrzeze Stanislawa Wyspianskiego 27; 50-370 Wroclaw, Poland
tel./fax: +48 71 347 79 18
e-mail: lech.sitnik@pwr.edu.pl

Abstract

Testing of internal combustion engine engines with hydrocarbon emulsions with water has its tradition. Previous attempts have been made using emulsions obtained chemically. This article presents similar results with the fact that emulsions of water and fuel were obtained using the cavitation phenomenon. The studies included standardized tests and non-standard measurements of polycyclic aromatic hydrocarbons (PAHs) emissions. The author, at the Wroclaw University of Science and Technology (Department of Vehicle Engineering) has developed a specific cavitator, which has been used to make emulsions of mineral and synthetic hydrocarbons. Both fuels (mineral and synthetic hydrocarbons) and their emulsions, with a water content of twenty percent (by volume), were used for testing. The engine ESC test conditions were developed. The engine was tested under the conditions of this test. Emissions of exhaust gas components (including polycyclic aromatic hydrocarbons) and fuel consumption were determined. It has been found that the use of emulsions leads to a reduction in the consumption of hydrocarbons. It has also been found that the engine power emulsion leads to a significant reduction in the emission of carcinogenic aromatic hydrocarbons, the highest concentrations of which in the exhaust gas are determined when the engine is powered by mineral diesel. Concentrations of other, considered "neutral", polycyclic aromatic hydrocarbons changed with respect to some as they rose, others diminished, and others remained at a constant level. The "neutrality" of these hydrocarbons is due to the fact that the effects on living organisms were evaluated for each hydrocarbon separately. In exhaust gas, however, they always occur in groups, which mean that it is necessary to explain their influence when they are in coincidence.

Keywords: *cavitation, emulsions, IC engines, fuel consumption, emissions*

1. Introduction

The aim of the study was to evaluate the fuel consumption and emission of toxic components of exhaust gases especially polycyclic aromatic hydrocarbons (PAH), of compression ignition engines fuelled with hydrocarbon fuels and water emulsions of these fuels.

Diesel emulsions with water [1-4, 6, 7] can be chemically added – by adding detergents (adjuvants) or physically e.g. using cavitation. In this work hydrocarbon, water emulsions were obtained by the second method.

Two types of diesel fuel – mineral (MDF) and synthetic (SDF) – were used. In addition, aqueous emulsions (20% v / v) of these fuels, i.e. mineral water diesel (MDF + H2O) and synthetic (SDF + H2O) water diesel emulsions were used.

To prepare emulsions used cavitator special design

The obtained emulsions were homogeneous, but they were delaminated:

- after about ten minutes for mineral diesel,

and

- about seven minutes for synthetic diesel.

The MF PERKINS – AD3.152UR compression-ignition engine has been tested for use with mineral oil fuel. PROUDE DPX 4 water brake motor was used. During testing, standard engine settings were maintained.

The test that the study was conducted was the ESC test [9].

Test conditions require the determination of the load characteristics of the motor based on the external characteristics [8]. Since it was expected that the engine power and the fuel emulsions would be expected to result in different engine performance, including the nature of the engine, the characteristics of the first stage were determined.

On this basis, a substitute external characteristic was designated. It is the bottom envelope of all the characteristics of the fuelled engines and their emulsions when they are powered by the engine. It was done to get the engine to get the right parameters, regardless of the fluid it was powered on. As a result of the measurements, the engine fuel consumption was determined and the emissions of polycyclic aromatic hydrocarbons (PAH) were determined at idle.

2. The results of test stand investigations by the ESC test

The ESC test cycle (also known as OICA/ACEA cycle) has been introduced, together with the ETC (European Transient Cycle) and the ELR (European Load Response) tests, for emission certification of heavy-duty diesel engines in Europe starting in the year 2000 *(Directive 1999/96/EC of December 13, 1999)*.

The ESC is a 13-mode, steady-state procedure that replaces the R-49 test.

The engine is tested on an engine dynamometer over a sequence of steady-state modes. The engine must be operated for the prescribed time in each mode, completing engine speed and load changes in the first 20 seconds. The specified speed shall be held to within ±50 rpm and the specified torque shall be held to within ±2% of the maximum torque at the test speed. Emissions are measured during each mode and averaged over the cycle using a set of weighting factors.

Engine test was carried out using engine dyno. The values of engine speed and load corresponding shown in Fig. 1. The size of the circles in the figure corresponds to the share of the load in the total load in the assay.

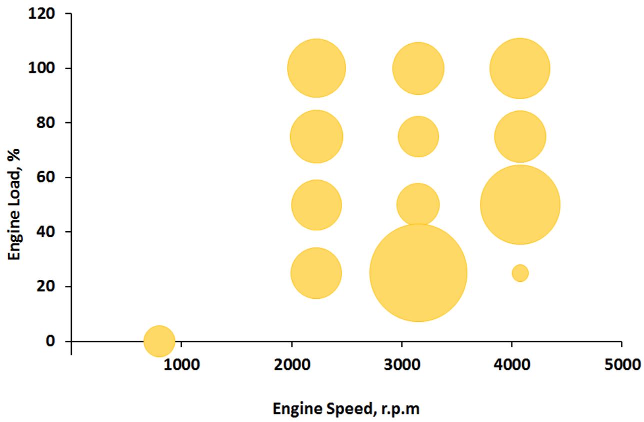

Fig. 1. Points motor characteristics corresponding to the requirements of the ESC test

The table below sets the percentage differences in fuel (liquid) consumption relative to mineral oil consumption.

Tab. 1. Difference in fuel (liquid) consumption in relation to mineral oil consumption

Fuel (fluid)	Difference in fuel consumption with respect to mineral oil consumption,%
MDF	0.00
SDF	-5.64
MDF+H2O	-6.90
SDF+H2O	-11.75

From the data in this table, it follows that the power supply to the synthetic diesel engine leads to a reduction in its volume consumption due to the volume of mineral diesel fuel consumption. It is interesting to note that synthetic diesel is characterized by lower density and lower heating value at the same time. The explanation of this phenomenon is the fact of better preparation of the fuel-air mixture and apparently fuller combustion of synthetic diesel fuel.

The data in Tab. 1 illustrates Fig. 2.

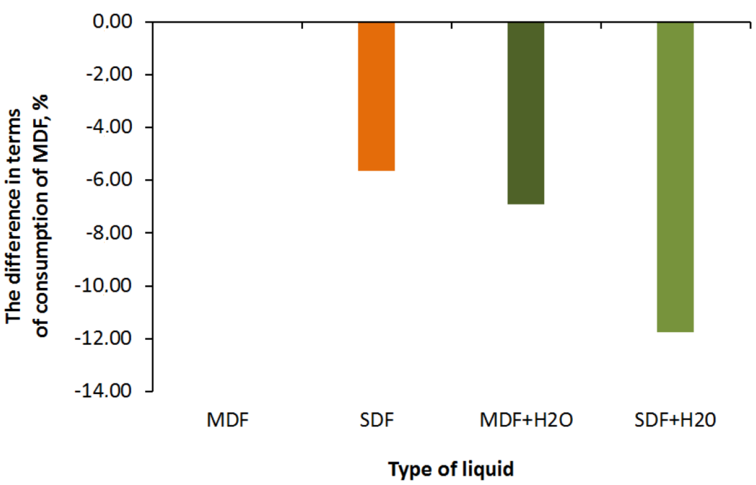

Fig. 2. Difference in fuel consumption with respect to mineral oil consumption

It is also interesting considerably to reduce the consumption of diesel when delivered to the engine in the water emulsion. The potential reduction in consumption by almost 7% for mineral and almost 12% of synthetic diesel seems to be encouraging further work in this direction.

It has been found that the power supply of the diesel engine emulsion leads to an increase in the emissions of carbon monoxide (CO) and hydrocarbons (HC). This raises the question whether increasing carbon dioxide emissions is associated with simultaneous increase of carcinogenic hydrocarbon emissions. To investigate this issue, a study on the emission of polycyclic aromatic hydrocarbons (PAHs) was conducted

The emission of PAH has been determined in the Department of Vehicle Engineering of Wroclaw University of Science and Technology.

3. Laboratory analysis of the PAH content in the exhaust gas

Determination of PAH content in the sample was made by capillary gas chromatography with purification and enrichment of the sample [5]. The PAH extraction on activated carbon was carried out with methylene chloride in an ultrasonic bath. The Solid Phase Extraction (SPE) method, recommended by modern analytical rules, was used to purify the extract from interfering substances. The extraction agent was a broad silica gel with 18-carbon alkyl chains bonded on its surface (C-18).

These groups give the surface a hydrophobic character that interacts with organic compounds in the sample.

Retarded compounds, including PAH, were eluted with organic solvents that were more potent with PAH than the solid alkyl phase. The mechanism of action in this case is similar to reversed-phase liquid chromatography.

Chromatographic analysis was performed on a $% VARIAN gas chromatograph) GC, with a flame ionization detector enabling quantitative and qualitative determination of adsorbed PAHs. Temperatures were programmed in the range of 333-555 K (60-280°C) with an increase of 15 K/min.

The calibration of the apparatus was based on an approved mixture of 16 PAH standards recommended by EPA (USA) with a concentration of 10 ng/µl.

During engine tests, the following results were obtained for the content of PAH in the exhaust gas of the engine fuelled with the tested fuels and their aqueous emulsions.

Tab. 2. Concentration of polycyclic aromatic hydrocarbons in the exhaust gas of the engine fed with the tested fuels and their aqueous emulsions

Chemical compound(s) (PAH)	Liquid			
	MDF	SDF	EMON	ESON
	Concentration of PAH $\mu g/m^3$ of exhausts gas			
Naphthalene	0.00	4.76	0.00	2.24
Acenaphtylene	3.08	0.00	2.52	3.36
Acenaphtene	5.04	3.36	3.08	7.84
Fluorene	14.28	0.00	4.20	7.84
Phenanthrene	6.44	8.12	11.76	4.76
Anthracene	3.92	5.04	9.80	3.64
Fluoranthene	1.40	0.28	0.56	0.84
Pyrene	1.12	0.00	0.00	0.56
Benzo(a)anthracene	0.56	0.00	0.28	0.00
Chrysenes	0.28	0.28	0.00	0.00
Dibenzo(a,h)anthracene	19.04	0.00	0.00	0.00

The data in Tab. 2 is illustrated in Fig. 3.

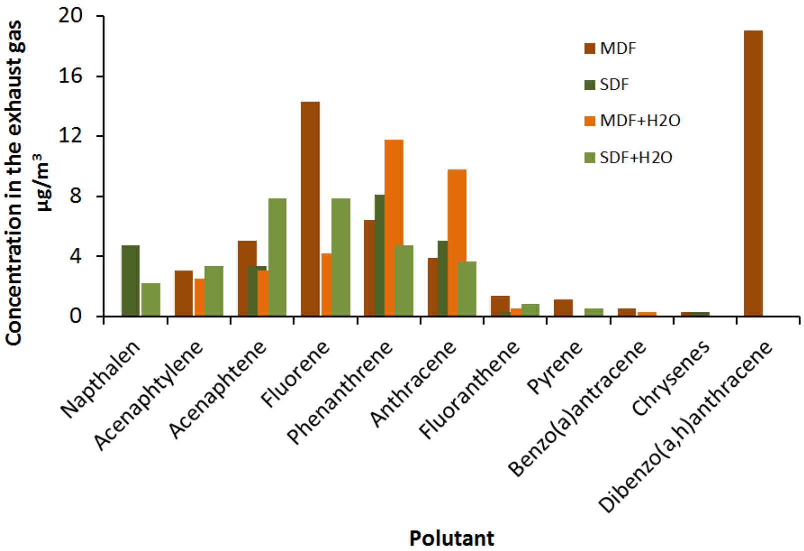

Fig. 3. Illustration of concentrations of emitted aromatic hydrocarbons (PAH) when engine is fuelled by different fuels

The data show that the emission of polycyclic aromatic hydrocarbons fuelled by the tested fuels and their aqueous emulsions differs substantially. This difference concerns both, what hydrocarbons are emitted and the concentration of individual hydrocarbons in the engine exhaust.

In general, the concentrations of the marked aromatic hydrocarbons are higher in the exhaust gas of a mineral diesel engine (MDF). Powering the engine with the water-based emulsion of this oil leads to a reduction in emissions while simultaneously increasing the concentration in the exhaust gas of other designated hydrocarbons.

Of the identified aromatic hydrocarbons, according to U.S. The Environmental Protection

Agency (EPA) carcinogenic aromatic hydrocarbons are:
- Benz(a)anthracene,
- Dibenzo(a,h)anthracene.

According to the International Agency for Research on Cancer (IARC), carcinogenic aromatic hydrocarbons are:
- Benz(a)anthracene.

According to U.S. Department of Health and Human Services (HHS) carcinogenic aromatic hydrocarbons are:
- Benz(a)anthracene,
- Dibenz(a,h)anthracene.

Other PAHs are considered neutral as e.g. EPA:
- Acenaphtylene,
- Fluorene,
- Anthracene,
- Fluoranthene.

It can therefore be assumed that among the identified aromatic hydrocarbons
- Benz(a)anthracene,
- Dibenz(a,h)anthracene,

are carcinogenic hydrocarbons.

From the data in Tab. 2, it is clear that diesel engine power is associated with severe emissions of dibenz(a,h)anthracene (19.04 μg/m^3) and benzene(a)anthracene emissions (0.56 μg/m^3). In the case of diesel engine power, the emissions of both of these polycyclic aromatic hydrocarbons were not found.

It is interesting that the power supply of the engine water emulsions of both fuels leads to the reduction of the benzene(a)anthracene concentration (up to 0.28 μg/m^3) in the case of mineral oil diesel emulsions and to the total elimination of the dibenz(a,h)anthracene emission. At the same time, for some hydrocarbons (chrysanthemums), there was no difference in engine power from diesel or its emulsion.

At the time of the engine power supply, the synthetic diesel fuel had no content of both carcinogenic aromatic hydrocarbons.

Interestingly (and unexpectedly) is that for some aromatic hydrocarbons, when the engine is powered by water emulsions of the tested fuels, both the increase and the reduction of the "neutral" aromatic hydrocarbons concentration in the exhaust gas are reported, it is sufficient to compare the data from the table referring to acenaphthene, fluoren, phenanthrene or anthracene.

The term “neutral” for aromatic hydrocarbons is taken in quotation marks because the data provided by the various agencies relate to the study of the effects on living organisms only of individual hydrocarbons, so they do not cover the problem of coincidentally of the hydrocarbon group – such studies are currently carried out at the Department of Vehicle Engineering at the Wroclaw University of Science and Technology. Preliminary results of these studies seem to confirm the perception of the coincidence of the influence of many components of fumes on the cells of the human body. Research is in progress and confirmation of their results will have to wait.

4. Conclusions

After analysing the results of the research, it seems that improving the economical and ecological performance of modern compression ignition engines can be achieved by supplying them with synthetic diesel or water emulsions of diesel fuel.

It has been found that the diesel engine power supply leads to a reduction in the fuel consumption determined by the ESC test, by about 5.6% for mineral oil consumption. Power supply to the engine's synthetic diesel fuel emulsion leads to a further reduction in its volumetric wear to almost 12% v / v. These are significant results.

Powering the engine with an emulsion of mineral diesel leads to a reduction in its volume consumption by approximately 7% – which is also a significant result.

Powering engines with water-based emulsions of diesel fuels leads to changes in emissions of toxic exhaust gas components. In general, emissions of toxic exhaust gas components such as hydrocarbons (HC) are increasing. It is positive, however, that practically eliminates the hydrocarbon emissions considered chancellial.

Presented research was carried out using a non-advanced, self-ignition engine. In future work, it would be appropriate to carry out such research but using the latest generation engine.

In further research, it would be appropriate to explain how the use of emulsions affects the durability and reliability of the engines.

Relatively fast delamination of the emulsions (obtained by physical means using cavitation) makes these fuels mainly used for propulsion of stationary motors or engines of vehicles with a mass of more than 3.5 Mg.

References

[1] Abu-Zaid, M., *Performance of single cylinder, direct injection Diesel engine using water fuel emulsions. Energy Conversion and Management*, Vol. 45, Iss. 5, pp. 697-705, 2004.

[2] Alahmer, A., Yamin, J., Sakhrieh, A., Hamdan, M. A., *Engine performance using emulsified diesel fuel, Energy Conversion and Management*, Vol. 51, Iss. 8, pp. 1708-1713, 2010.

[3] Armas, O., Ballesteros, R., Martos, F. J., Agudelo, J. R., *Characterization of light duty Diesel engine pollutant emissions using water-emulsified fuel*, Fuel, Vol. 84, Iss. 7-8, pp. 1011-1018, 2005.

[4] Crookes, R. J., Kiannejad, F., Nazha, M. A., *Systematic assessment of combustion characteristics of biofuels and emulsions with water for use as diesel engine fuels*, Energy Conversion and Management, Vol. 38, Iss. 15-17, pp. 1785-1795, 1997.

[5] Janicka, A., *Emisja związków toksycznych z silnika o zapłonie samoczynnym z katalizatorem wewnętrznym*, Wroclaw 2008.

[6] Kolanek, C., Kułażyński, M., Sroka, Z., Walkowiak, W., *The effect of water addition in emulsion fuel on nitric oxides concentration in diesel engine exhausts,* Journal of KONES, Vol. 16, No. 4, pp. 227-232, 2009.

[7] Lif, A., Holmberg, K., *Water-in-diesel emulsions and related systems*, Advances in Colloid and Interface Science, Vol. 123-126, pp. 231-239, 2006.

[8] Sitnik, L. J., *Ekopaliwa silnikowe,* Oficyna Wydawnicza Politechniki Wrocławskiej, ISBN 83-7085-767-1,Wrocław 2004.

[9] http://www.dieselnet.com/standards/cycles/esc.php.