THE INFLUENCE OF FUEL AROMATICS ON DIESEL EXHAUST EMISSION

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Abstract

Current and future air quality is a worldwide concern, which has resulted in both a continuous tightening of emissions legislation for vehicles and a parallel tightening of fuel specifications.

The automotive and oil industry across the globe especially in EU, USA and Japan have in each case made considerable efforts to understand the relationship between vehicle emissions, urban air quality, engine technologies and fuels, and to meet the more and more stringent legislation.

The supply of automotive fuels today is based almost entirely on petroleum.The quality requirements of diesel fuels become more and more stricter and it will continue in the next decades, because the clean engines need clean fuels. Therefore, fuels of low emission become significant factor in reducing toxic emission which pollutes the environment. With the introduce of low sulfur diesel fuel, the effect of sulfur become less significant. Other fuel properties such as aromatics content i.e. composition thus becomes more important.

From this aspect it is investigated the affect of simultaneous addition of mono^{+}-, di^{+} - and tri^{+}-aromatics into low-sulfur diesel fuel. Obtained results show that aromatics composition has the effect on diesel exhaust emission.

Keywords: *diesel fuel, aromatics, exhaust emission*

1. Introduction

Today's lifestyle depends greatly on access to a reliable, affordable and sustainable transport system. We all see mobility as a prerequisite for a comfortable life. However, the growth in the number of vehicles worldwide has led to an increase in air pollution from the transport sector.

The vehicle and the fuel are the system, and the transport related air pollutants cannot be reduced unless the vehicle and the fuel are cleaned up together. The introduce of cleaner fuels is a step by step process which is reproduced by countries across the globe.

The immense benefits from the implementation of these clean vehicle and fuel strategies are very significant. Studies across the globe have tried to compare the costs of improving fuel quality alone or with cleaner vehicles with the health and environmental benefits related to the these improvements. The conclusion from all of these studies is that the benefits far outweigh the costs sometime up to 10 fold.

The diversification of future powertrain concepts requires numerous high-quality fuel solutions. There are three main requirements for modern powertrain solutions at the moment (Figure 1) [1].

Growing demand on engine fuels for traffic purposes the finiteness of fossil oil resources and rising environmental concern about health risks of diesel engine exhaust led to intense research activities over the last decades. Because of its efficiency and robustness the diesel engine become the dominating propulsion principle for trucks. The discussion about diesel exhaust related health effects led to a worldwide tightening up of exhaust gas regulations, especially for heavy duty vehicles.

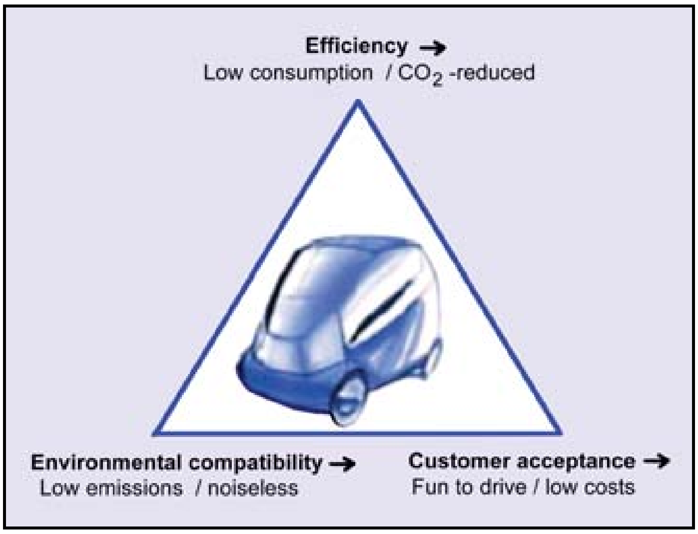

Fig. 1. Requirements for modern powertrain solutions

Now and in the next decades more attention will have to be paid to non-road diesel mashinery emission (Figure 2), tractors especially, due to production of healthy food and cleaner environment

It should say that non-road diesel engines account for about 47% of diesel particulate matter (PM) and 25% of total nitrogen oxides (NOx) emissions from mobile sources.

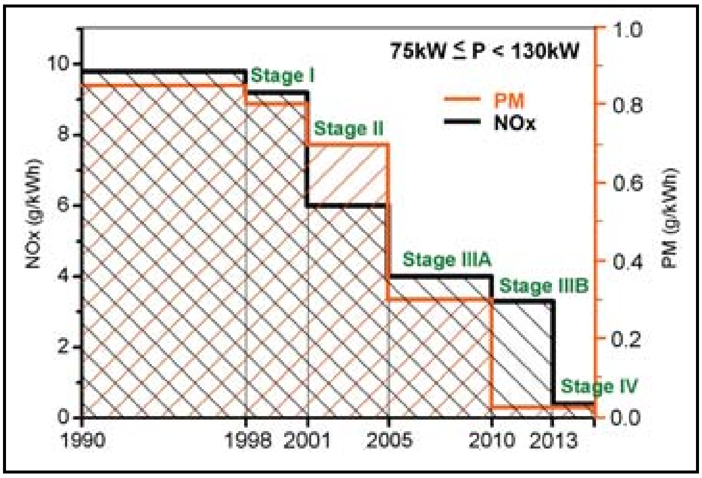

Fig. 2. Emission regulations (g/kWh) for tractors [2]

Diesel fuel specifications are continuously tightening and its demand is also growing in EU as and in US and Japan. In EU sulfur limit of diesel fuel is currently 50 ppm that will be reduced to 10 ppm from 2009. With the introduce of low sulfur (50 ppm) and sulfur free (10 ppm) diesel fuel [3], the effect of sulfur fuel becomes less significant. Other fuel properties such as aromatics content i.e. composition thus becomes more important [4-19]. Reduction of aromatics content in diesel fuel is important because they decrease of the PM, HC and NOx emissions.

From this aspect it is investigated the effect of simultaneous addition of mono, di^+-and tri^+ aromatics into low-sulfur diesel fuel.

2. Experimental

Tests of the effect of simultaneous addition of mono, di^+ and tri^+-aromatics in low sulfur (EI) diesel fuel on diesel exhaust emissions have been performed on a three cylinder tractors DI diesel engine (THDM 33/T~ TD 3.152 Perkins) of rated power 40.5 kW, 2250 R.P.M. swept volume

2.5 m^3 , turbocharged KKK 14 with intercooler. The engine is an older design with an open combustion chamber in the piston, while nozzles have 4 holes with dia. 0.28 mm each. Injection pressure is 210 bar and injection angle 12^0. It is well known that the majority of investigations relating to the effect of fuel quality on diesel emissions are performed on engines of modern design that having considerably higher injection pressures and that have nozzles with greater number of holes.

Four types of diesel fuel, whose properties are shown in table 1, have been used for testing purposes.

In order to realise the effect of aromatics type on diesel engine emissions, as well as to see interaction and interrelation with other fuel characteristics, we added aromatics into low diesel fuel sulfur (EI) as follows:

10% mono + 8% di^+ +2% tri^+- aromatics (EI1),
10% mono + 5% di^+ +1.5% tri^+- aromatics (EI2),
0% mono + 8% di^+ +2% tri^+- aromatics (EI3).

Tab.1. Physical-chemical properties of fuels used for testing

Fuels / Properties	E I	E I1	E I2	E I3
Sulfur (% mm)	0,0248	0,0403	0,0354	0,0342
Aromatics (% m)	16,3	35,8	32,4	26,6
Di-aromatics (%m)	2,1	12,9	9,9	12,8
Tri-aromatics (%m)	0,3	1,0	0,9	1,0
Density at15^{o}C	0,8208	0,844	0,8377	0,836
Viscosity at 20^o mm^2/s	3,70	2,88	3,02	3,40
Cetane index (CI)	54,3	42,9	46,7	48,7
Distillation: IBP	188	155	148	177
FBP (98%)	344	337	338	338

It can be seen from table 1, that addition of mono, di^+ - and tri^+-aromatics aromatics in low sulfur (EI –referent fuel) diesel fuel have produced change of some fuel properties, first of all density and cetane index.

Diesel engine emissions were measured in accordance with ECE R96 Regulation, 8-mode cycle.

3. Results and discussion

The value of specific emissions HC, PM and NOx (g/kWh) for four different types of diesel fuel are shown in Figure 3 and 3a. They are the result of making an average value of an emission for each mode and basic parameters of engine functional characteristics.

It can be seen from Figures 3 that HC, PM and NOx emission level increases with the addition of mono, di^+ -and tri^+ -aromatics. For example, HC emission of fuel EI1(0.665 g/kWh) enriched with 10% mono + 8% di^+ - + 2% tri^+ - aromatics is increased by 59% in relation to referent fuel EI (0.417 g/kWh), whereas PM emission of fuel EI1(0.851 g/kWh), is increased by 2 times in relation to referent fuel EI(0.425 g/kWh) . NOx emission of fuel EI1 is increased by 34% in relation to referent fuel (EI).

Addition of 10% mono + 5% di^+ - + 1.5% tri^+ - aromatics in fuel EI (EI2) causes growth of PM, HC and NOx emissions by 91%, 45% and 27 % respectively. This data show that addition of mono, di^+ and tri^+ -aromatics into referent fuel have stronger effect on PM emission than on HC and NOx emission.

As for PM and HC emission of low sulfur diesel fuel enriched with 0% mono + 8% di^+ - + 2% tri^+ - aromatics (E I3) is increased by 96% 41% and 40% respectively in relation EI fuel.
Having in view that mono, di^+ and tri^+ -aromatics were added to fuels (EI), for the analysis of results showing the influence of type and content of these to engine exhaust emissions we had to use 3D diagrams. Such diagrams consider contents of aromatics type as an independent variable, meaning that, in one case, diagrams show PM, HC and NOx emissions originating from mono and di^+ -,then mono and tri^+ -aromatics content as well as from di^+ and tri^+ -aromatics content.

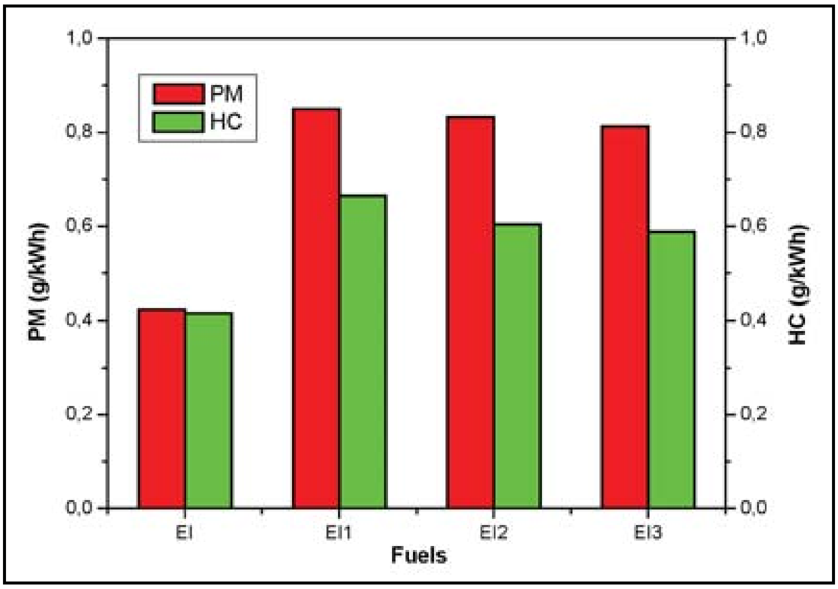

Fig. 3. Specific PM and HC emissions with four types of diesel fuels

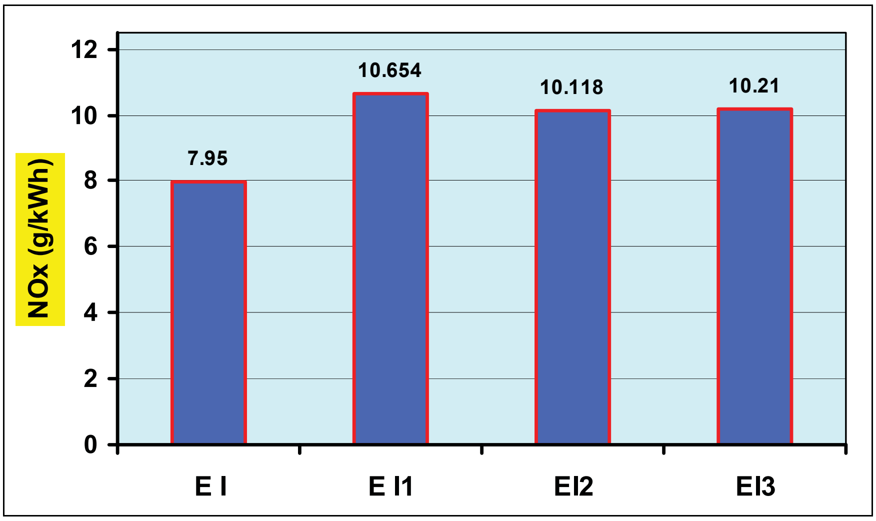

Fig. 3a. Specific NOx emissions with four types of diesel fuels

HC emissions

The dependence of HC emission on added mono and di^+ -aromatics content in EI diesel fuel is shown in Figure 4. It can be seen that the effect of mono-aromatics is noticeable only when the content of di^+ -aromatics is the lowest (1-2%) as well as at the highest (over 10%) content ones. In the region from 2 to 10% di^+ -aromatics, the effect of mono-aromatics is minor. Total contribution to HC emission of mono- and di^+ -aromatics content depend on their ratio. With the constant di^+ -aromatics content, the growth of HC emission in function of mono-aromatics, is moved between 0.022 g/kWh (for low di^+ -aromatics content) to 0.06 g/kWh (for high di^+ -aromatics content). When mono-aromatics content is constant and content of di^+ -aromatics is changeable, the growth of HC emission is considerably higher and amounts from 0.09 g/kWh (for low mono-aromatics content) to 0.131 g/kWh (for high mono-aromatics content).

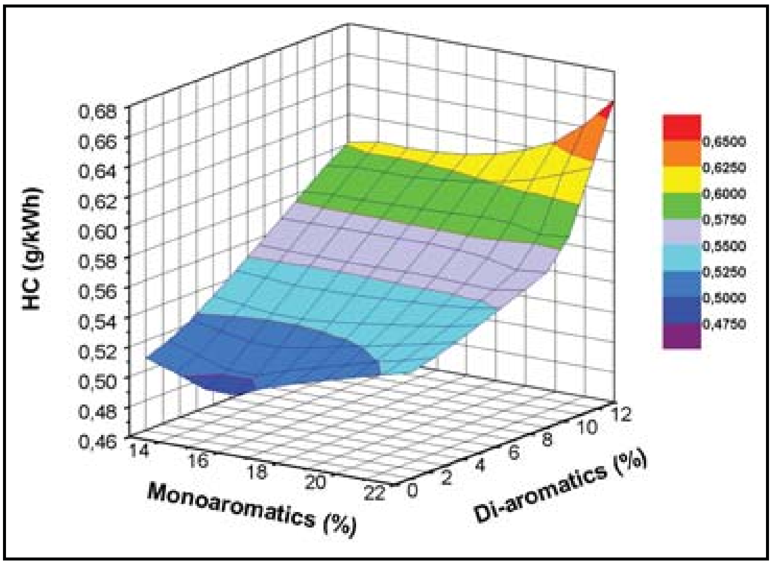

Fig. 4. Dependence of HC emission on the content of mono- and di$^+$ -aromatics into EI diesel fuel

Figure 5 shows how HC emission depends on the content of added mono and tri$^+$ -aromatics into EI diesel fuel. As well as in the case of Figure 4, the effect mono-aromatics is noticeable only when the content of tri$^+$ -aromatics is the lowest (0 - 0.2%), and the highest (approx. 1%). In the rest area the effect mono-aromatics in coupling with tri$^+$ -aromatics is the minor. When tri$^+$ -aromatics content is 0%, the growth HC emission is increased approx. 0.03 g/kWh for mono-aromatics content change from 14 to 22%. If tri$^+$ -aromatics content is approx. 1%, the growth of HC emission amounts approx. 0.06 g/kWh, at the same change of mono-aromatics content.

Considerably the higher growth of HC emission is evident when mono-aromatics content is changed. For example, when mono-aromatics content is low (14 -16%) the influence of tri$^+$ -aromatics is showed in uniform increasing HC emission by 0.1 g/kWh, whereas at high mono-aromatics content, the growth of HC emission amounts approx. 1.2 g/kWh in the region 0 – 1% of tri$^+$ -aromatics content. Strong growth of HC emission is noticeable when tri$^+$ -aromatics content is increased over 0.8 %.

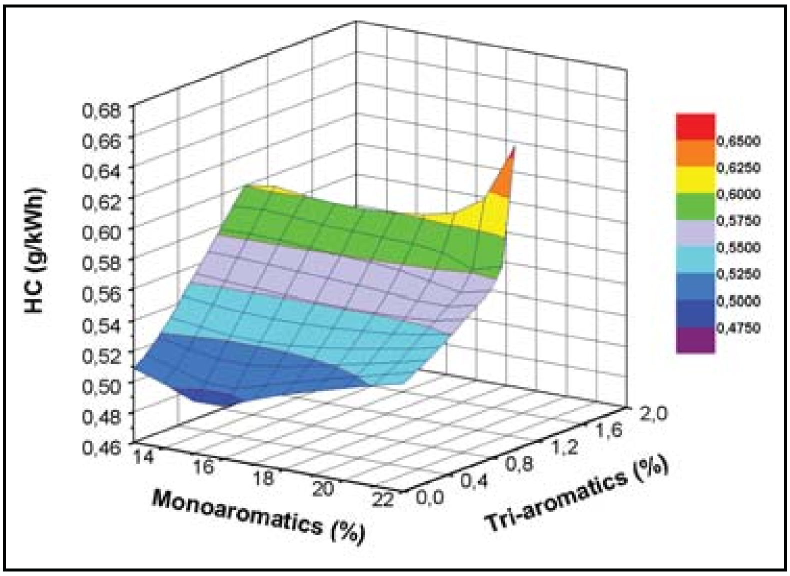

Fig. 5. Dependence of HC emission on the content of mono and tri$^+$ -aromatics into EI diesel fuel

Figure 6 illustrate how HC emission depends on the content of added di+ and tri+ -aromatics into low sulfur (EI) diesel fuel. The growth of HC emission depends on the increasing di+ and tri+ -aromatics content. With low concentration of di+ - (< 10%) and tri+ -aromatics (> 0.6%), the growth of HC emission is uniform in the area from 0.075 g/kWh, whereas at the higher concentration, HC emission is increased strongly by 0.09 g/kWh.

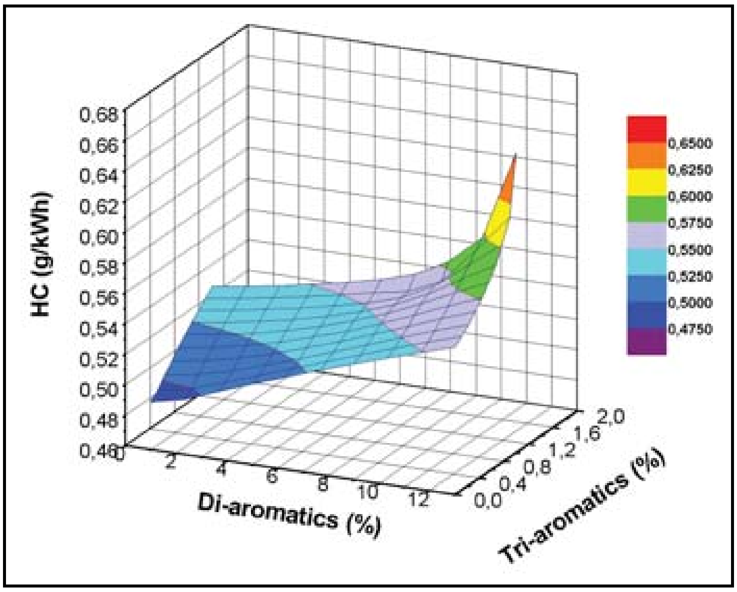

Fig. 6. Dependence of HC emission on the content of di+ - and tri+ -aromatics into EI diesel fuel

PM (PT) emission

Particulate emission will also be shown in 3D diagrams depending on contents of added mono, di+ and tri+ -aromatics content into lover (EI) sulfur diesel fuels.

Figure 7 shows dependence of PM emission on the content of mono and di+ -aromatics into EI fuel.

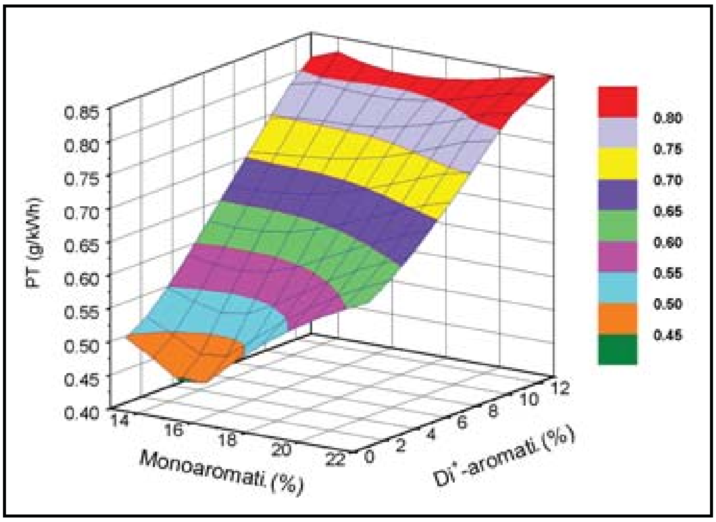

Fig. 7. Dependence of PM emission on the content of mono and di+ -aromatics into EI diesel fuel

From this figure it can be noticed that the growth of PM emission is more sensitive to the increase of di+ -aromatics content than to the increase of mono-aromatics content. The influence of mono-aromatics is noticeable up to approximately 7% of di+ -aromatics. When the content of mono-aromatics reaches 14-22% the growth of PM emission amounts to approx. 0.08 g/kWh.

When di^+ -aromatics content exceeds 7% the effect of mono-aromatics is less visible. But, when di^+ -aromatics content is 1-2% the contribution of mono-aromatics with the content of 14-22%, to PM emission amounts to about 0.11 g/kWh.

Figure 8 illustrates how PM emission depends on the content of added mono and tri^+ -aromatics into EI diesel fuel. As it can be observed tri^+ -aromatics show considerably stronger effect to PM emission than mono-aromatics. As it is assumed that tri^+ -aromatics content is 0.3% then the contribution of mono-aromatics, within the area of 14-22% to particulate emission would be about 0.08 g/kWh.

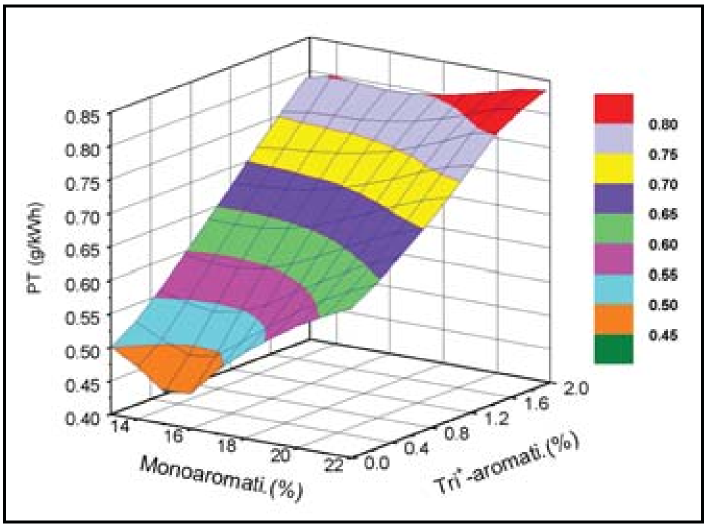

Fig. 8. Dependence of PM emission on the content of mono and tri^+ -aromatics into EI diesel fuel

Dependence of EI diesel fuel particulate emission on the content of di^+ - and tri^+ -aromatics shows Figure 9. It can be observed that PM emission grows with the increase of di^+ - and tri^+ -aromatics content, but it should be under lined that the content of tri^+ -aromatics is considerably lower than the content of di^+ -aromatics. Approximately the same effect to the growth of PM emission has the content of di^+ -aromatics, about 11%, and tri^+ -aromatics, 1%.

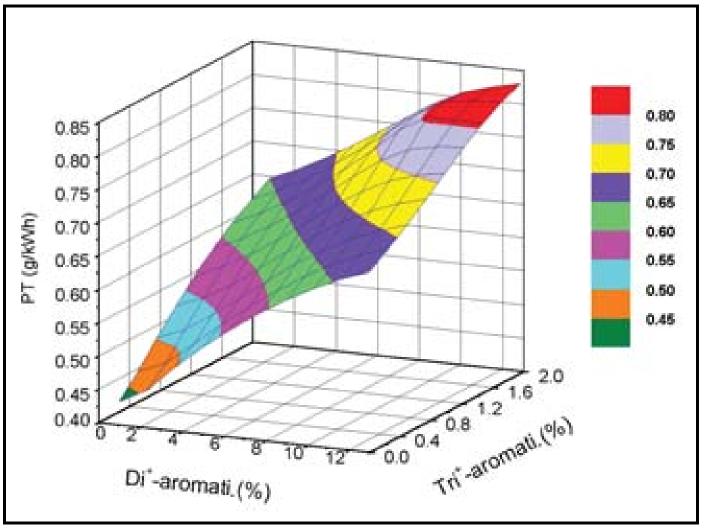

Fig. 9. Dependence of PM emission on the content of di^+ and tri^+ -aromatics into EI diesel fuel

NOx emissions

Figure 10 shows how NOx emission depends on the content of added mono and di^+ -aromatics into EI diesel fuel. It can be seen that the tendency of NOx emission growth is more distinct in the direction of the di^+ -aromatics content increase than in case of mono –aromatics. With lower content of di^+ -aromatics, up to 2%, which is probably, the bottom limit in realistic fuels, and with the increase of mono-aromatics, from 14 to 22%, NOx emission shows growth of 0.7 g/kWh.

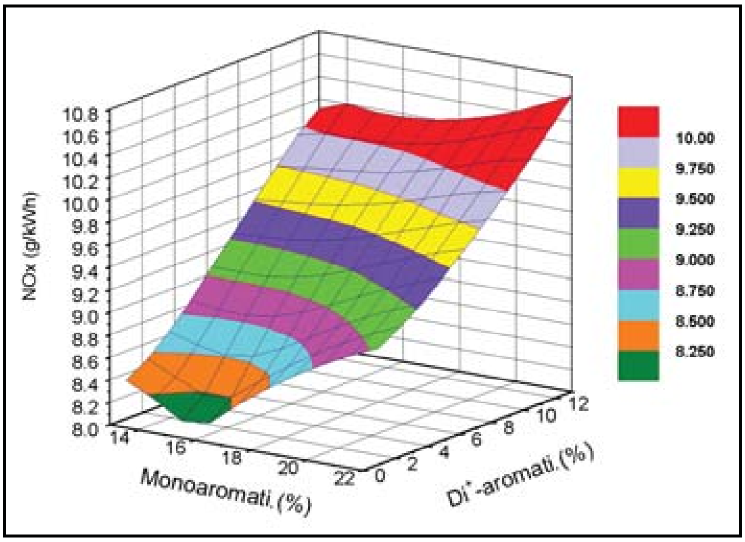

Fig. 10. Dependence of NOx emission on the content of mono and di^+ -aromatics into EI diesel fuel

With increases of di^+ -aromatics content, e.g., by 10%, their effect becomes more significant than of di^+ -aromatics.

The dependence of NOx emission on added mono and tri^+ -aromatics content in EI diesel fuel is shown in Figure 11.

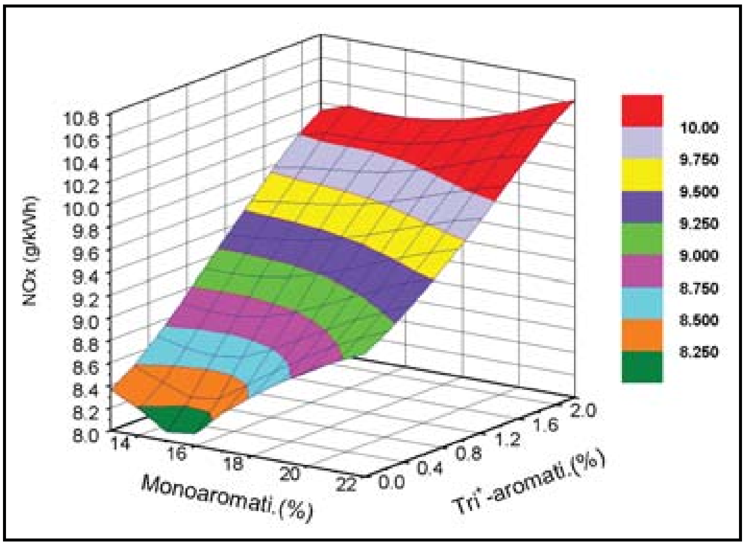

Fig. 11. Dependence of NOx emission on the content of mono and tri^+ -aromatics into EI diesel fuel

It is rather obvious that emission growth is considerably bigger when the tri^+ -aromatics content is higher. Let us consider that tri^+ -aromatics content is 0 % then, as it could be seen, the contribution of mono-aromatics to NOx emission would be 0.6%. NOx area is almost flat and parallel to mono-aromatics axis with inclined slope towards the increase of tri^+ -aromatics content. This goes to prove that even low tri^+ -aromatics content in fuel can affect NOx emission more seriously than mono-aromatics content can do.

Figure 12 shows the dependence of NOx emission on the content of added di^+ and tri^+ -aromatics into EI diesel fuel. In relation to Figures 10 and 11 we can observe the growth of NOx

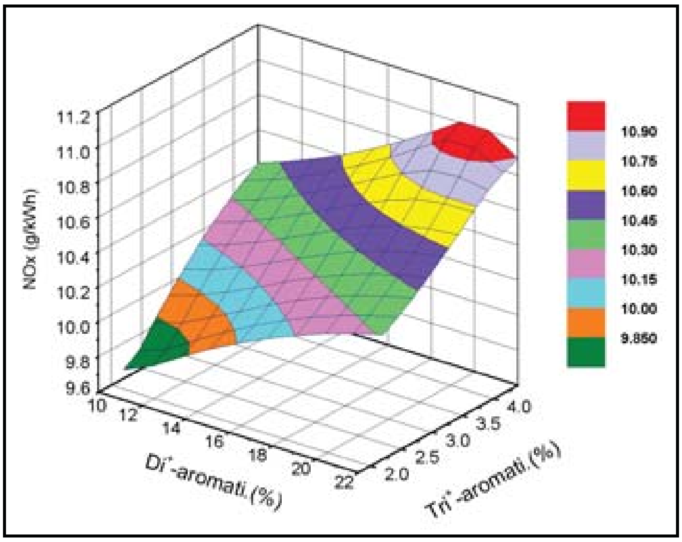

Fig. 12. Dependence of NOx emission on the content of di$^+$ -and tri$^+$ -aromatics into EI diesel fuel

emission both in the direction of di$^+$ -aromatics content increase and in the direction of tri$^+$ -aromatics content increase. When tri$^+$ -aromatics content is 0.1%, within di$^+$ -aromatics range of 1-12%, it can be seen that NOx emission is increased by 1.2 g/kWh. In case when minimum di$^+$ -aromatics content is 1% and minimum tri$^+$ -aromatics content is 0%, as well as when maximum di$^+$ -aromatics content is 12%, and tri$^+$ -aromatics content is 2% the growth of NOx emission is approximately the same. Therefore it might be concluded that the increase of tri$^+$ -aromatics content from 0% to 2% shows the same effect to the emission as does the di$^+$ -aromatics content increase from 1 to 12%.

4. Conclusions

The following conclusion may be drowning as a result of the present study:

1. Contribution of aromatics to diesel exhaust emission is evident.
2. Simultaneous addition of mono, di$^+$ and tri$^+$-aromatics into low sulfur diesel fuel has different effect on engine emission. Reduction of aromatics content in diesel fuel contributes to decrease of the PM, HC and NOx emissions.
3. The intensity of aromatics effect on emission is as follows: tri$^+$ > di$^+$ >mono.
4. With simultaneous adding mono, di$^+$ and tri$^+$-aromatics into EI fuel, the effect of mono aromatics to engine emission obvious only when did$^+$ and tri$^+$-aromatics content is lower.
5. The effect of mono aromatics to PM emission is more visible than to HC and NOx emission.
6. The increase of mono aromatics from 14 to 25% and di$^+$ -aromatics content from 1% to 12% in EI fuel has approximately the same effect on NOx emission as has be increase of tri$^+$-aromatics content from 0.2 %.
7. Total contribution to HC emission of mono- and di$^+$ -aromatics content depend on their ratio. With the constant did$^+$ -aromatics content, the growth of HC emission in function of mono-aromatics, is moved between 0.022 g/kWh (for low di$^+$ -aromatics content) to 0.06 g/kWh (for high di$^+$ -aromatics content).
   The influence of mono-aromatics on PM emission is noticeable up to approximately 7% of di$^+$ - aromatics. When the content of mono-aromatics reaches 14-22% the growth of PM emission amounts to approx. 0.08 g/kWh. When di$^+$ -aromatics content exceeds 7% the effect of mono-aromatics is less visible.
8. In the case the effect of mono and tri$^+$-aromatics on HC emission it can be seen that the effect mono-aromatics is noticeable only when the content of tri$^+$ -aromatics is the lowest (0 - 0.2%), and the highest (approx. 1%). In the rest area the effect mono-aromatics in coupling

with tri$^+$ -aromatics is the minor. Strong growth of HC emission is noticeable when tri$^+$ -aromatics content is increased over 0.8 %.

9. The growth of HC and PM emission depends on the increasing di$^+$ and tri$^+$ -aromatics content. With low concentration of di$^+$ - (< 10%) and tri$^+$ -aromatics (> 0.6%), the growth of HC emission is uniform in the area from 0.075 g/kWh, whereas at the higher concentration, HC emission is increased strongly by 0.09 g/kWh. In the case of PM emission approximately the same effect to the growth of PM emission has the content of di$^+$ -aromatics, about 11%, and tri$^+$ -aromatics, 1%.

Acknowledgments

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