Experimental description of the vehicle emissions and fuel consumption in real world operation

Jan Valášek, Ing. Vojtěch Klír PhD.

ČVUT v Praze, Fakulta strojní, Centrum vozidel udržitelné mobility, Přílepská 1920, 252 63 Roztoky, Česká republika

Abstrakt

Práce se věnuje měření vozidla v reálném provozu a rozboru vlivů působících při tomto typu testů. Posuzovanými parametry jsou především výfukové emise a spotřeba paliva. Nezbytnou součástí je zhodnocení současného stavu problematiky měření emisí za provozu, vymezení a definice provedených experimentů, včetně popisu použitého zařízení. Hlavní část práce je věnována především rozboru a hodnocení naměřených dat a z nich odvozených poznatků.

Paper or article deals with the measurement of the vehicle operation under the real traffic conditions and analysis of influences in this type of test. Parameters to be assessed are primarily exhaust emissions and fuel consumption. An essential part of the evaluation in the current state of problems measuring emissions during operation, the definition of experiments, including description of the equipment used. The main part is devoted to analysis and evaluation of the measured data and the derived knowledge.

Klíčová slova / Keywords: RDE; emise; spotřeba paliva; jízdní zkoušky

1. Introduction

On-road testing is currently very important topic in the different parts of the automotive industry. Current EURO 6 standards already counts with the dedication of this type of test during approval of new cars. Upheaval caused by the recent scandal and issue of long-term consumer complaints on fuel consumption based on the NEDC cycle, calling for its quick replacement. Most of experts also agree that emissions on the road under different conditions are the main parameter that should be monitored. Measurements under real operating conditions also bring some problems and risks. The first and major one is the question of repeatability. However this parameter is crucial for all laboratory measurements. That is the reason why currently under discussion on how the results of such tests and how to access further interpreted. Another drawback is difficult to precise definition of such a cycle, including the subsequent execution of this definition, due to external influences.

The question of external influences entering measurements during operation, are discussed in this article. The aim of the article is not to find answers to the problems associated with on-road tests, but to demonstrate it by the practical measurements carried out in CVUM. Influences which need to be in this kind of tests to count with are substantially reflected in the results.

2. Experimental

Description and characteristics of individual instruments and measuring devices used in the test are listed in this chapter, including the important settings that could affect the final results, which means especially the emission equipment

2.1. Measuring equipment

The test vehicle was equipped with devices for collecting data that can be distinguished into two groups:

- Vehicle data (Fuel consumption, GPS, OBD data)
- Emission devices

To capture vehicle data, equipment from National Instruments was used. It was a plug-in modules in the chassis cDAQ 9174, specifically NI 8473 (acquiring OBD values), NI 9402 (digital data from fuel-flow meter), NI 9234 (analogue data from fuel-flow meter). Recording was done by in-house software created in LabVIEW. Software enables continuous recording of selected variables with sampling frequency of 1 Hz. Data file also contains date and time information to be subsequently possible to synchronize with data from other measuring devices.

Fuel consumption measurements were performed using Fuel-Flow meter Kistler DFL 3x. It is a volumetric type of measurement of fuel with temperature correction. Fuel-flow meter was mounted in vehicle fuel system using PTFE hoses and couplings.

* Kontakt na autora: Jan.Valasek@fs.cvut.cz

Data recording about the route parameters was conducted using a GPS Garmin Edge 500, which is equipped with independent measurement of ambient pressure to calculate altitude changes.

During the measurement, the video was recorded with help of cameras GoPro HERO 4 Silver placed on the windscreen of the vehicle to provide a view very similar to the view of a driver.

Used emission equipment and its wiring diagram is shown in Figure 1. The entire system is powered by a pair of 12V 90Ah battery Winston. Inverter Steca XPC 1400-12 changes 12V DC voltage to a standard AC 230 V 50 Hz, which is normally used by whole

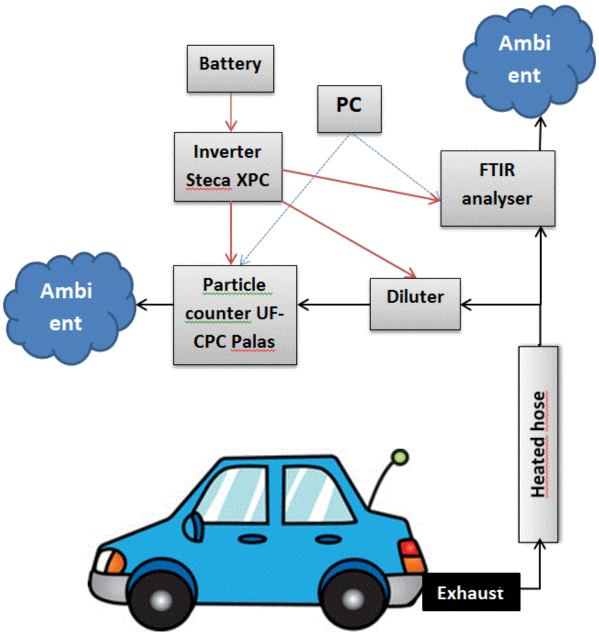

Figure 1 – Emission equipment scheme

emission equipment installed in the vehicle. When connected to a network, then the inverter allows battery charging. The basis of the emission equipment was FTIR analyser MIDAC with the chamber able to form a 6 meter length reflective preheated to 121 ° C equipped with a ZnSe window and a nitrogen-cooled detector measuring with a resolution of 0.5 cm^{-1}, enabling the measurement of the gaseous emissions (CO, CO2, NOx, and THC). Measurement of non-volatile particles ensures condensation particle counter UF-CPC Palas. Particle counter is preceded by a two-stage adjustable sample diluter (1:5, 1:10-60). To bring the sample in the emission analysers is used heated hose.

All measured data (GPS, OBD, fuel-flow meter, emission devices) were subsequently evaluated in time.

2.2. Vehicle

A typical European family car, 2013 Skoda Octavia (3rd generation) station wagon, with four-cylinder 1.4 litre turbocharged gasoline direct injection TSI engine (parameters of the engine are given in Figure 2), 6-speed manual transmission, tire size 225/45 R17, 1272 kg curb weight, has been rented from a car rental agency and brought to testing facility in CVUM Roztoky. The vehicle was certified to Euro 5 standards, with rated fuel consumption of 6,6/4,3/5,1 l/100 km, rated CO_2 emissions 119 g/km, designed to run on 95 octane (RON) gasoline (EN228).

1,4 TSI engine parameters	
Engine type:	SIDI turbocharged
Cylinders / Valves:	4 / 4
Displacement (cm^3):	1395
Power (kW / min^{-1}):	103 / 4500
Torque (Nm / min^{-1}):	250 / 1500 - 3500

Figure 2 – Engine parameters

Gasoline with a nominal research octane number of 95, meeting ČSN EN228 specifications, has been obtained at the local fuelling station and used as the baseline.

2.3. On-road tests

For test was selected 26 kilometres long track leading from Kostelec nad Černými lesy to Prague. The route includes both urban and sub-urban parts. No part of the route is guided along the highway. The approximate shape of the route is shown in Fig. 3 and it´s elevation

Figure 3 - Shape of the route

profile and typical speeds are given in Fig. 4. Speed in urban parts is limited to 50 km/h, in suburban to 90 km/h. It can be therefore said, that this is a typical route that passes many drivers every morning on their way to work.

The whole route was passed twice, each time by another driver, in order to compare the different driving styles. Demand on driver was only compliance of speed limits.

The aim was not to determine driver´s style. There was not defined neither economic nor aggressive driving.

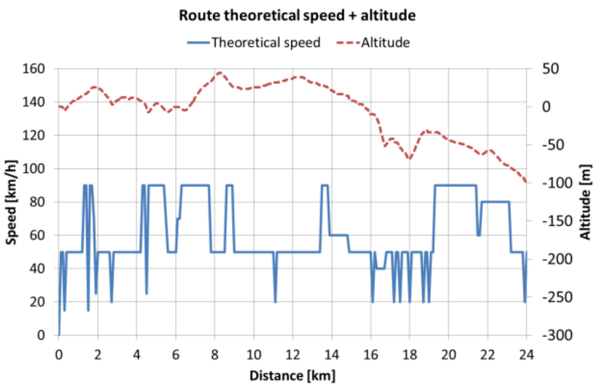

Figure 4 - Route theoretical speed + altitude

Influence of traffic, which in each session introduces an element of unpredictability, will be discussed in more detail in the next chapter, which will be evaluated by various factors.

Measurement was supplied by video from the passenger point of view, which was subsequently completed with basic data (date, time, vehicle speed, engine speed and load, GPS position including points along the route, distance and elevation). Both of these tracks were synchronized together in time, Fig. 5.

Figure 5 - Example of video

The advantage of this type of record, completed with basic measurement data is the possibility of explanation of the driver´s behaviour or specific traffic situations and manoeuvres.

3. Results

From the 26 km route length for the evaluation and comparison, was finally necessary to use only part in the length of 24 km. In the second run occurred discharge of the batteries to power emission devices and thus to end the measurement. Despite this problem can be 24 km part of route considered as sufficient.

On Fig. 6, there is a comparison of velocity versus time where can be seen, that the second run was approximately 20% shorter than the first one. Another factor evident from this graph is the greater number of stops and lower speed achieved in some parts due to heavy traffic in the first run.

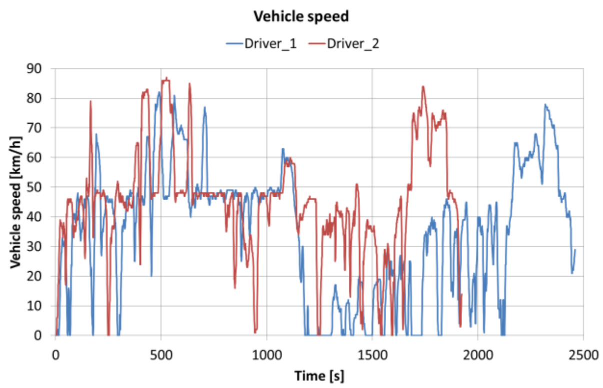

Figure 6 – Vehicle speed depend on time

Better can be seen the reduction of speed in some sections due to heavy traffic in Fig. 7, where the vehicle speed is plotted depend on the travelled distance. The graph also shows strict compliance with the speed limits.

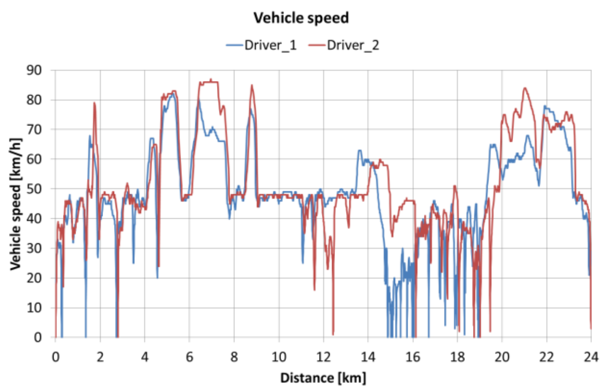

Figure 7 – Vehicle speed depend on distance

Comparison of the two driver´s driving styles is presented in Fig. 8, which shows engine speed and Fig. 9, where is plotted manifold absolute pressure. Absolute manifold pressure can be considered as an indication of the engine load. Looking at the engine speed record, can be said, that both drivers used approximately similar engine speed range. Interesting are only two engine speed peaks in the second run.

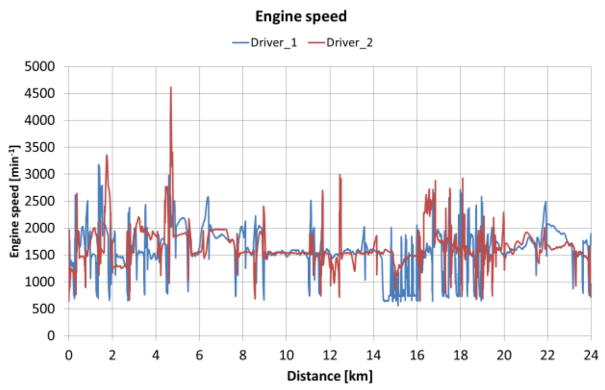

Figure 8 – Engine speed

The difference in the engine load is more obvious and detects, that the second driver used, in accelerations, the higher engine load, which means accelerated with wider open throttle.

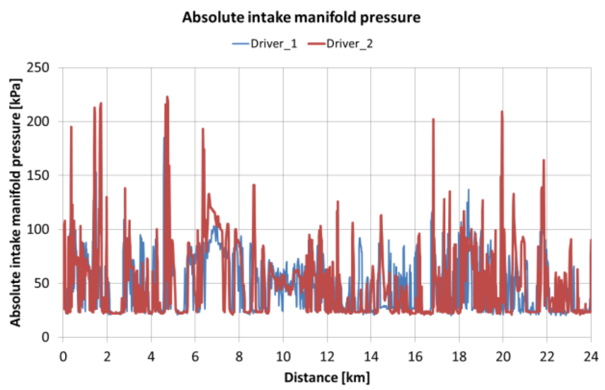

Figure 9 – Absolute intake manifold pressure

Influence of driving style and traffic is particularly evident on the charts of the fuel consumption. These are shown in Fig. 10 and Fig. 11. In the first case are evident peaks of the fuel consumption in the second run, which can be explained by using a higher engine load during accelerations.

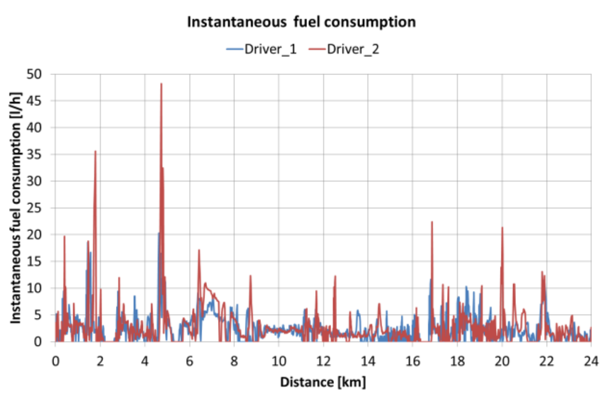

Figure 10 – Instantaneous fuel consumption

When looking at a chart showing average fuel consumption, there can be seen, that difference between the two drivers is relatively small. Difference is mainly caused due to heavy traffic, which affected run of the first driver. This phenomenon is visible in the travelled distance about 15 km. There was a significant increase in average consumption. In favour of the second drivers fuel consumption is using of higher engine load during accelerations, which is usually area with higher engine efficiency.

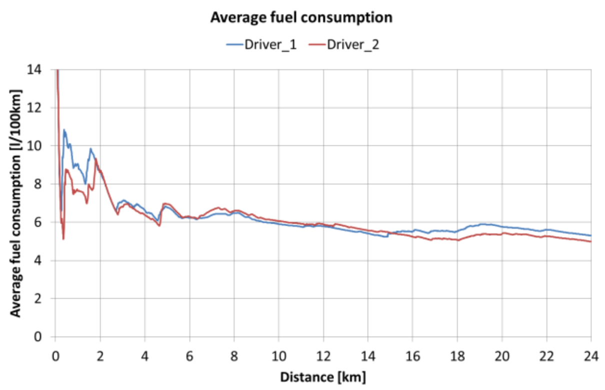

Figure 11 – Average fuel consumption

The greatest differences are then apparent in the measurement of gaseous emissions, mainly in case of carbon monoxide, illustrated in Fig. 12. During the ride of both drivers production of CO is practically very close to zero. The only exceptions are two peaks in the second run, where was has the production of CO increased significantly. In both cases there are two hard accelerations. For the first time it was overtaking of slower vehicle and for the second times it was entering of the main road. The explanation of this phenomenon is the enrichment of the mixture (reducing the Lambda value) and thereby paralyzing the function of three-way catalyst, which influenced it´s standard operation conditions. The reason for this enrichment is mainly three way catalyst and the turbocharger protection from overheating and possible damage at high engine loads and therefore high temperatures and high flow rates of burned gas.

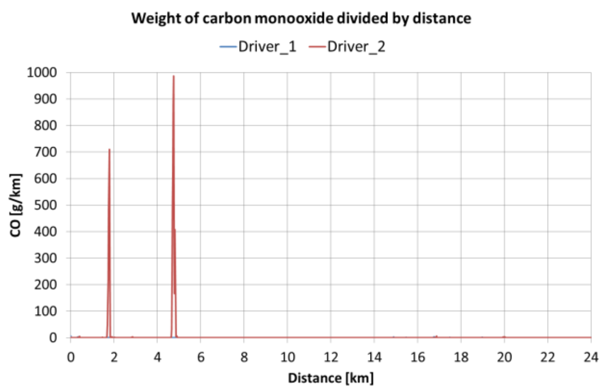

Figure 12 – Weight of carbon monoxide

A similar trend can be observed, with a lower percentage increase, also in the emissions of unburned hydrocarbons, shown in Fig. 13. Low THC values can be also seen in areas where, due to the increased traffic, lot of idle operations and subsequent vehicle starts were executed. But it´s absolute value is very low.

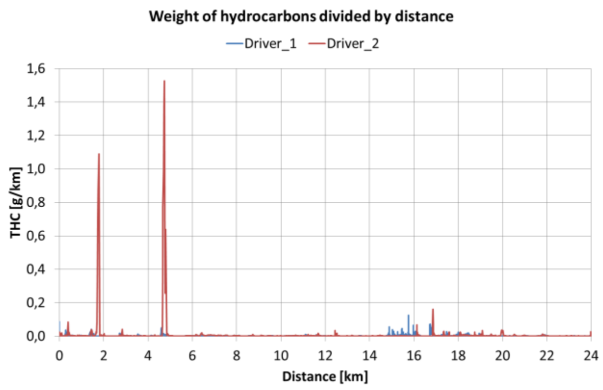

Figure 13 – Weight of hydrocarbons

A similar situation as in previous cases of CO and THC is also observable in case of nitrogen oxides. It´s production is primarily associated with high temperatures of combustion, in the areas of higher engine loads. In case of the highest two peaks, they can be again influence by paralysis of the three-way catalyst as was written before.

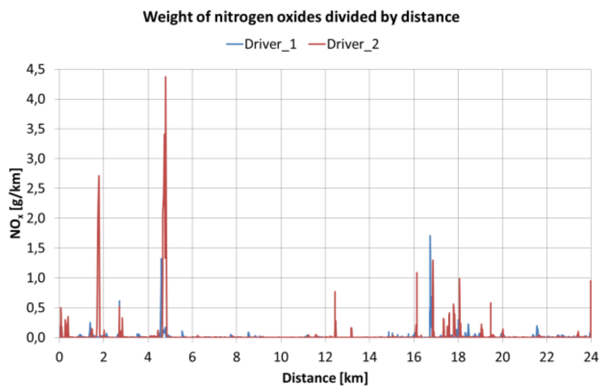

Figure 14 – Weight of nitrogen oxides

Graph of the carbon dioxide is, from the obvious reasons, very similar to the curve of instantaneous fuel consumption. The difference is that in the graph of CO_2 a sharp peak can be observed, but the graph of consumption is smoother. It can be probably explained by faster response and different characteristics of the emission analyser compared to fuel-flow meter.

Due to CO_2 is a product of ideal combustion, the only way to reduce it is the increase in the efficiency of the vehicle powertrain, or reduction in the resistances of the vehicle. CO_2 production and thus the fuel consumption is in the on-road tests mainly influenced by the driving style of the driver and the traffic situation. Thus it is very hard to compare it with different measurements, because every single on-road test is the unique situation.

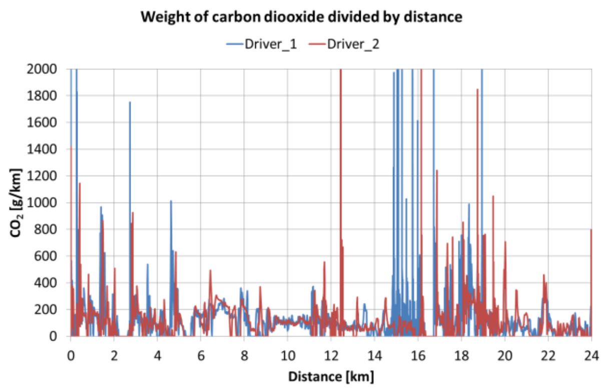

Figure 15 – Weight of carbon dioxide

Production of particulate emissions, Fig. 16, is for both runs very close. Interesting point is again increased production of PN when driving in a traffic jam, which is often discussed issues concerning pollution of cities with heavy traffic.

When the direct injection for gasoline engines was introduced, the question of particulate emissions has become also crucial. Current EURO 6 emission standard limits the number of particles emitted per kilometre for gasoline engines to $6 \cdot 10^{12}$ 1/km, and from 2017, it is planned lowering of this value to $6 \cdot 10^{11}$ 1/km. Of course, this value is relates to the emission test on the chassis dynamometer.

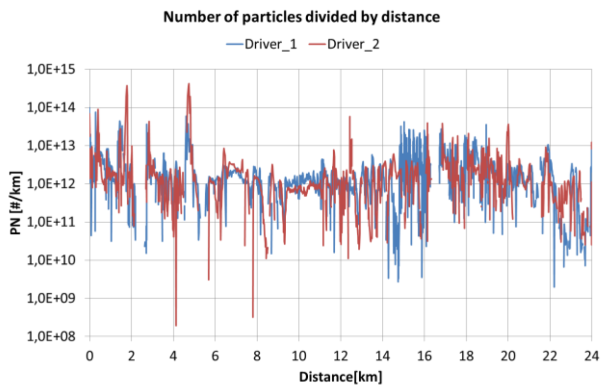

Figure 16 – Number of particles

The graph in Fig. 17 summarizes the comparison of all mentioned parameters between the two drivers. For better comparison, the first driver is set as the standard 100%. First noticeable thing is the huge drop in emissions of CO, NO_X and THC, which was explained by short enrichment of the combustion mixture. Other values in the same study correspond to the driving style of drivers and traffic.

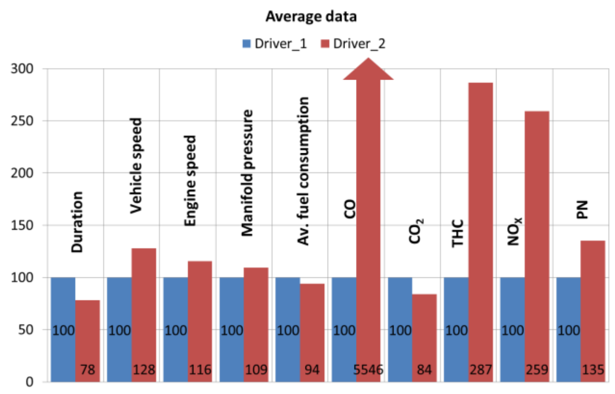

Figure 17 – Average data

Fig. 18 shows the final table comparing the average values of the individual variables for both drivers.

Average value	Driver 1	Driver 2
Duration (s)	2459	1922
Vehicle speed (km/h)	35,14	44,96
Engine speed (min^{-1})	1363,27	1578,78
Intake manifold pressure (kPa)	43,24	47,31
Fuel consumption (l/100km)	5,31	4,99
CO (g/km)	0,07	3,62
CO_2 (g/km)	150,46	126,39
THC (g/km)	0,003	0,007
NO_X (g/km)	0,01	0,03
PN (1/km)	2,74E+12	3,70E+12

Figure 18 - Average data table

4. Summary / Conclusion

The article describes the design and evaluation of on-road test of typical family car with a modern turbocharged gasoline engine on the urban and suburban track. This route can be considered as a common example of the way to work.

The paper does not attempt to evaluate or analyse whole test in detail. It´s goal is a practical demonstration of performance and evaluation of on-road test.

Results show that the evaluation of these tests should be approached differently. It brings impossibility to evaluation and comparison of the results to other measurements and, in most cases, specific numbers are not relevant. The sense of these tests can be seen especially in observing trends and abnormalities in various data for vehicle operation. It is exactly mode where the vehicle should behave as ecological as possible and where this behaviour is most important. Behaviour of the driver and traffic are thus only inputs that make it more difficult.

According to these rules is evaluated and executed also this test. Driver behaviour is taken as an input and only limitation were speed limits during the test. All results are within the expected values. In the case of an evaluation of measured emission values, they are usually below the limits required for the fulfilment of the vehicle approval. The only exception is two peaks where the mixture was enriched. So it can be said, that it probable, that this regime, which can be easily identified in the on-road tests, will be restricted by future standards.

Acknowledgement

At this point I would like to thank especially to CVUM in Roztoky, which enables making of this test. Furthermore, my thanks go to all my colleagues who were involved in the preparation and execution of the test, especially to Vojtěch Klir for his assistance with preparation of this paper.

List of symbols

RDE	Real driving emissions
CVUM	Vehicle centre of sustainable mobility
NEDC	New European Driving Cycle
GPS	Global position system
OBD	On-board diagnostic
PTFE	Polytetrafluoroethylene
DC	Direct current
AC	Alternating current
FTIR	Fourier Transformation infrared
CO	Carbon monoxide
CO_2	Carbon dioxide
NO_X	Nitrogen oxides
THC	Total hydrocarbons
RON	Research octane number
PN	Particle number

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