The Effect of Alternative Fuel on the On-Board Diagnostics System at Compression-Ignition (Diesel) Combustion Engines

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Abstract

The aim of our study was to monitor the alterations of the on-board diagnostics (OBD) system of compression-ignition combustion engines, when alternative fuels were used as a source of energy. We described a theory of emissions formation, diagnostics of standards defects of diesel engines and the formation of opacity. We also focused on processing and evaluation of readiness code, which is used to control various functions of the engine. Diesel fuel and alternative fuel were used for realized measurements in accordance with selected methodology. By means of measurements, we detected conditions of readinesscode and the coefficient values of light absorption factors of exhaust gases. Compared to the reference fuel, we detected no alterations in readinesscode, when we monitored the impact of fuel on the on-board diagnostics system. The components controlled by on-board diagnostics system (complex components, fuel system, exhaust gas recirculation) operate with the alternative fuel without detected defects of conditions.

Keywords: alternative fuel, exhaust gas emission, on-board diagnostics OBD, readiness code.

1. Introduction

In recent years, the requirements on automotive performance, emissions and safety have become stringent. In spite of advanced concepts entering the industry, achieving fuel economy, emission and cost targets simultaneously still remain an arduous task. Homogeneous charge compression ignition (HCCI) engines shifted the spotlight from traditional spark ignited (SI) and compression ignited (CI) engines owing to its ability to reduce emissions and fuel consumption significantly [1-3]. The fuel lean mixtures allow HCCI to operate with a larger compression ratio similar to diesel engines resulting in high thermal efficiency. In addition, absence of throttle improves volumetric efficiency. The fuel and oxidizer are premixed which results in clean combustion and hence reduced emissions [4]. A characteristic feature of HCCI combustion is that the peak in-cylinder temperatures are low resulting in low nitrogen oxides (NO_X) emissions [5]. The homogeneous mixtures result in reduced soot emissions [4]. In spite of its known advantages, HCCI combustion poses several challenges for implementation. These include the absence of a direct trigger for combustion, narrow operating range and high sensitivity to ambient conditions amongst others. Control of HCCI combustion is a challenging problem and control decisions are often made using a predictive model of the engine [6-8]. The quality of the predictive model in terms of its accuracy of prediction and computational requirement for on-line application are some of the important criteria that directly affect the control performance for HCCI engines. HCCI combustion is characterized by complex nonlinear chemical kinetics and thermal Dynamics and high-fidelity behaviour can be assessed using numerical simulations [9-12]. Such models demand a large

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computational time and effort and are not directly suitable for control. Control-oriented reduced order models [8, 13] can be developed by using simplifying assumptions but require significant development time and associated costs. To accelerate HCCI implementation on automotive applications, a key requirement is to develop predictive dynamic models quickly that can capture the required dynamics for control purposes and has the potential to be implemented on-board having limited computation and memory resources. On-board diagnostics (OBD) system was developed at the beginning of eighties in the US for the purpose of petrol engines emissions monitoring. Since then, the system has been modernized, and newly developed system OBD2 (US)/EOBD (EU) is used, without exception, in all vehicles with petrol engine of M1, N1 category produced after 2002. The situation with diesel engine vehicles was quite different. Diesel engine was fully mechanical machine and its emissions depended on its mechanical condition, i.e. especially on engine mechanical condition, injection system deterioration or on supercharging device deterioration. Increasing requirements for exhaust gases composition as well as tendency of fuel consumption reduction forced vehicle producers to integrate electronic components into fully mechanical diesel engine, ensuring constant monitoring of emission relevant components of diesel engine as well as its operational conditions. Such conditions are enabled by partial electronization and replacement of fully mechanical components with electric ones, which are capable for operational control (direct or indirect) by OBD system [14].

Characterization of On-board diagnostics (OBD)

On-board diagnostics of control unit is one of standard electronic systems of engine control unit. Input and output signals as well as communication between individual control units are monitored along with control unit Readiness Check. A control of individual systems is realized by means of comparison of actual information with fixed defined values. Electronic scanners are controlled based on their output electric signal, which is compared to electric signal from toleration zone defined by manufacturer. The operation of fully mechanical components (e.g. turbocharger) is monitored indirectly by means of output signals of additional scanners, which enable to evaluate component operational conditions. Data about engine or individual component, which does not reach toleration zone, is logged into memory as a fault code, while malfunction indicator lamp (MIL) light is activated.

Readinesscode

On-board diagnostics OBD system is realizing its Readiness Check. Control unit is checking systems condition, which is checked continuously and non-continuously. The checklist of monitored systems and test results is provided by means of Readinesscode. Each monitored system is corresponding to Bit (number), and their order is counted from zero, beginning from right hand side, i.e. Bit “0” is on the right hand side and Bit “7” is on the left hand side. Value of „1“ of each Bit at monitored system code means, that test of that system is supported in given vehicle. Value of „0“ means, that test of the system is not supported. Same rule applies in tests evaluation, value of “1” of Bit at monitored system condition code means, that test was not realized, or system does not pass in case, when test has been realized. Value of „0“ of Bit at monitored system condition code means, that monitored system pass the test [15]. The aim of our study was to monitor the alterations of the on-board diagnostics (OBD) system of selected vehicles with compression-ignition combustion engines, when alternative fuels were used. We verified a condition of combustion engine according to measurement of coefficient values of light absorption factors of exhaust gases.

2. Materials and methods

The study focused on alterations caused by alternative fuel, expressed by unequal results of tests evaluation codes of components with a relevancy to emissions, which were realized by means of on-board diagnostics after vehicle engine was started. Technical condition of diesel engine was tested based on opacity values alteration and on comparison to legislative regulations. We verified technical condition of diesel combustion engine according to alterations of opacity values. We selected diesel engine vehicles with on-board diagnostics (OBD) system. Selected vehicles (M1 and N1 category) have their first-time vehicle registration after the 1st of January 2008.

Table 1. Selected vehicles

Brand and model of vehicle	Engine type
Hyundai Accent	D3EA
Citroen Berlingo	9HY
Fiat Croma	939A2.000

Main parameters of selected compounds of diesel fuel and compared fuel MERO were used as a baseline for our study. Selected sample of MERO was in accordance with requirements of the European Standard for Biodiesel EN 14214. Measurement devices, used in our study, were in accordance with measurement requirements: opacimeter (in accordance to Council Directive 70/220/EEC), thermometer, speedometer MAHA RPM VC 2, communication device, connector (OBD according to SAE J 1962, ISO DIS 15031-3). The process and measurement realization are consistent with valid methodology of emissions control testing. A testing process of selected vehicles with on-board diagnostics OBD system was as follows: Vehicle identification, definition of controlled parameter values, visualization of admission, fuel and electric systems, vehicle start, providing of communication with OBD system and visual control (e.g. function of OBD system MI indicator, detection of OBD status, exhaust system, engine condition detection), engine conditioning, measurement (engine temperature, idle rpm, maximal engine rpm, opacity by engine idle method, control of OBD system MI indicator – MI indicator light should be off after engine start, memory status check, data logging.

3. Results and discussion

The effect of alternative fuel on on-board diagnostics OBD system was monitored on three vehicles with diesel combustion engine. The vehicles were provided by two injection systems, i.e. hydraulic cylinder injection, which is provided by integrated fuel injection unit system (Pumpe – Düse) and hydraulic accumulator injection (Common Rail). Readinesscode of petrol engines with on-board diagnostics OBD system is monitored in seven steps, readinesscode of diesel engines is monitored in three steps: complex components, fuel system and exhaust gas recirculation. Informally, diagnosis can be defined as the task of explaining why a given physical system does not exhibit its nominal behaviour. Every diagnostic problem is characterized by a set of observations to account for. Due to its generality, to its dramatic importance in many application domains, and to its intrinsic complexity, automated diagnosis has received constant and considerable attention in research. The classical theory of model-based diagnosis [16, 17] addresses the limited range of static systems whose nominal behaviour can be specified as a time invariant mapping from input to output variables. The need for model-based diagnosis of dynamic (as opposed to "static") systems was recognized very early and several relevant contributions can be found in the literature [18-27].

Measurement of Hyundai Accent vehicle

Main parameters of vehicle: engine type/output: D3EA/60kW/4000/min, cylinders/arrangement: 3-straight, valve control: OHC, capacity: 1493 ccm, injection device: BOSCH – Common Rail. Alternative fuel did not create an undesirable readinesscode alternation of monitored parameters (Table 2). Technical condition of vehicle was verified by opacity measurement by engine idle method, the evaluation is presented in graphical form in Figure 1. Based on results of emissions condition control of Hyundai Accent vehicle with diesel fuel we detected, that opacity value was 0.97 m^{-1}, which is by 35.33% lower, than defined value within regulation. We detected an opacity value of 0.77 m^{-1}, which is value by 48.67% lower than defined regulation value, when we used alternative fuel as energy source. We can allege, that fuel system, as well as components, which are essential for correct operation of combustion engine are at suitable condition.

Table 2. Measurement – HYUNDAI ACCENT vehicle

Brand and model of vehicle			HYUNDAI ACCENT			
Type of OBD		EOBD				
Engine type		D3EA				
Engine maximal output		60/4000				
Fuel			DIESEL		MERO	
MIL indicator before engine start			ON		ON	
MIL indicator after engine start			OFF		OFF	
Errors, type of P-0- ; logged in memory			NONE		NONE	
			Monitored systems	System condition	Monitored systems	System condition
Readiness-code	Monitored continuously (Data byte B)	Complex components	1	0	1	0
		Fuel system	1	0	1	0
		Combustion misfire	0	0	0	0
	Monitored non-continuously (Data byte C/ Data byte D)	Exhaust gas recirculation	1	0	1	0
		EGO sensor heating	0	0	0	0
		EGO sensor	0	0	0	0
		Air condition	0	0	0	0
		Secondary air	0	0	0	0
		Tank ventilation	0	0	0	0
		Catalytic converter heating	0	0	0	0
		Catalytic converter (efficiency)	0	0	0	0

Deviation in memory at fuel change	Not detected	
Deviation in systems condition at fuel change	Not detected	
Value of opacity measured by engine idle method	0.97 m^{-1}	0.77 m^{-1}

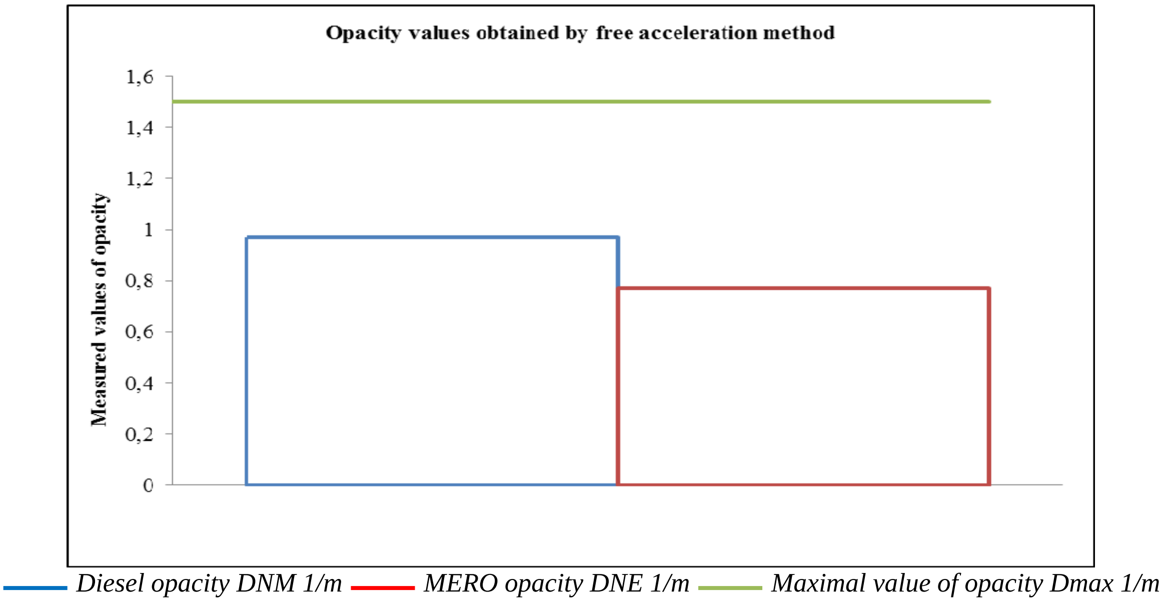

Figure 1. Opacity values measured on Hyundai Accent vehicle

Measurement of Citroen Berlingo vehicle

Main parameters of vehicle: engine type/output: 9HY/55kW/4000/min, cylinders/arrangement: 4-straight, valve control: DOHC, capacity: 1560 ccm, injection device: BOSCH – Common Rail. Alternative fuel did not create an undesirable readinesscode alternation of monitored parameters

(Table 3). Technical condition of vehicle was verified by opacity measurement by engine idle method, the evaluation is presented in graphical form in Figure 2. Based on results of emissions condition control of Citroen Berlingo vehicle with diesel fuel we detected, that opacity value was 0.57 m^{-1}, which is by 62% lower, than defined value within regulation. We detected an opacity value of 0.31 m^{-1}, which is value by 79.33% lower than defined regulation value, when we used alternative fuel as energy source. We can allege, that fuel system, as well as components, which are essential for correct operation of combustion engine are at suitable condition.

Table 3. Measurement – CITROEN BERLINGO vehicle

Brand and model of vehicle			CITROEN BERLINGO			
Type of OBD Engine type	EOBD 9HY					
Engine maximal output	55/4000					
Fuel MIL indicator before engine start MIL indicator after engine start Errors, type of P-0- ; logged in memory			DIESEL ON OFF NONE		MERO ON OFF NONE	
			Monitored systems	System condition	Monitored systems	System condition
Readiness-code	Monitored continuously (Data byte B)	Complex components	1	0	1	0
		Fuel system	1	0	1	0
		Combustion misfire	0	0	0	0
	Monitored non-continuously (Data byte C/ Data byte D)	Exhaust gas recirculation	1	0	1	0
		EGO sensor heating	0	0	0	0
		EGO sensor	0	0	0	0
		Air condition	0	0	0	0
		Secondary air	0	0	0	0
		Tank ventilation	0	0	0	0
		Catalytic converter heating	0	0	0	0
		Catalytic converter (efficiency)	0	0	0	0

Deviation in memory at fuel change Deviation in systems condition at fuel change	Not detected Not detected	
Value of opacity measured by engine idle method	0.57 m^{-1}	0.31 m^{-1}

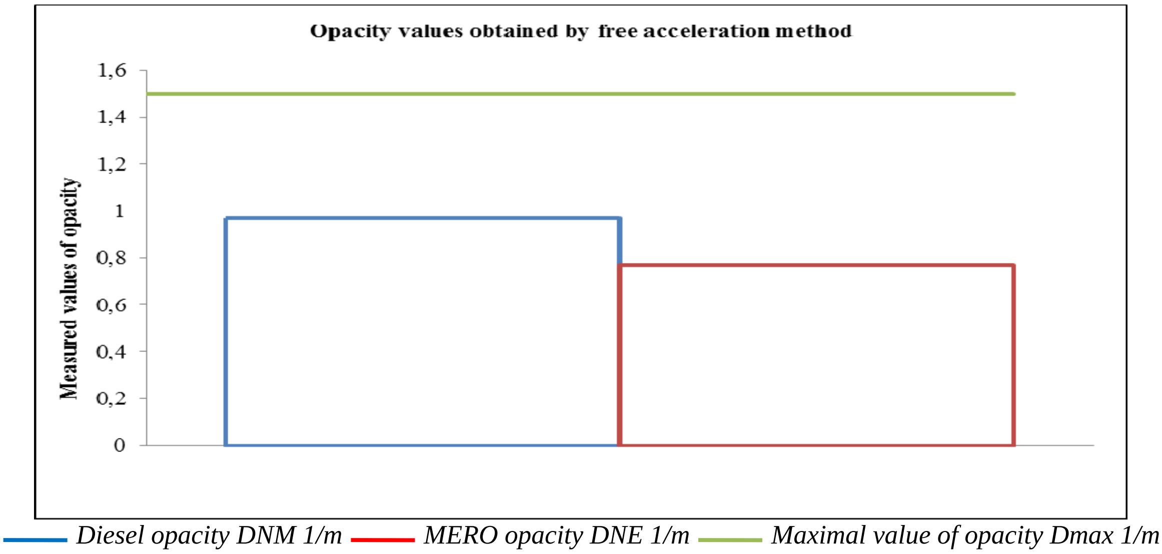

Figure 2. Opacity values measured on Citroen Berlingo vehicle

Measurement of Fiat Croma vehicle

Main parameters of vehicle: engine type/output: 939A2.000/110kW/4000/min, cylinders/arrangement: 4-straight, valve control: DOHC, capacity: 1910 ccm, injection device: BOSCH – Common Rail. Alternative fuel did not create an undesirable readinesscode alternation of monitored parameters (Table 4). Technical condition of vehicle was verified by opacity measurement by engine idle method, the evaluation is presented in graphical form in Figure 3. Based on results of emissions condition control of Fiat Croma vehicle with diesel fuel we detected, that opacity value was 0.51 m^{-1}, which is by 66% lower, than defined value within regulation. We detected an opacity value of 0.42 m^{-1}, which is value by 72% lower than defined regulation value, when we used alternative fuel as energy source. We can allege, that fuel system, as well as components, which are essential for correct operation of combustion engine are at suitable condition.

Table 4. Measurement – FIAT CROMA vehicle

Brand and model of vehicle			FIAT CROMA			
Type of OBD		EOBD				
Engine type		939A2.000				
Engine maximal output		110/4000				
Fuel			DIESEL		MERO	
MIL indicator before engine start			ON		ON	
MIL indicator after engine start			OFF		OFF	
Errors, type of P-0- ; logged in memory			NONE		NONE	
			Monitored systems	System condition	Monitored systems	System condition
Readiness-code	Monitored continuously (Data byte B)	Complex components	1	0	1	0
		Fuel system	1	0	1	0
		Combustion misfire	0	0	0	0
	Monitored non-continuously (Data byte C/ Data byte D)	Exhaust gas recirculation	1	0	1	0
		EGO sensor heating	0	0	0	0
		EGO sensor	0	0	0	0
		Air condition	0	0	0	0
		Secondary air	0	0	0	0
		Tank ventilation	0	0	0	0
		Catalytic converter heating	0	0	0	0
		Catalytic converter (efficiency)	0	0	0	0
Deviation in memory at fuel change			Not detected			
Deviation in systems condition at fuel change			Not detected			
Value of opacity measured by engine idle method			0.51 m^{-1}		0.42 m^{-1}	

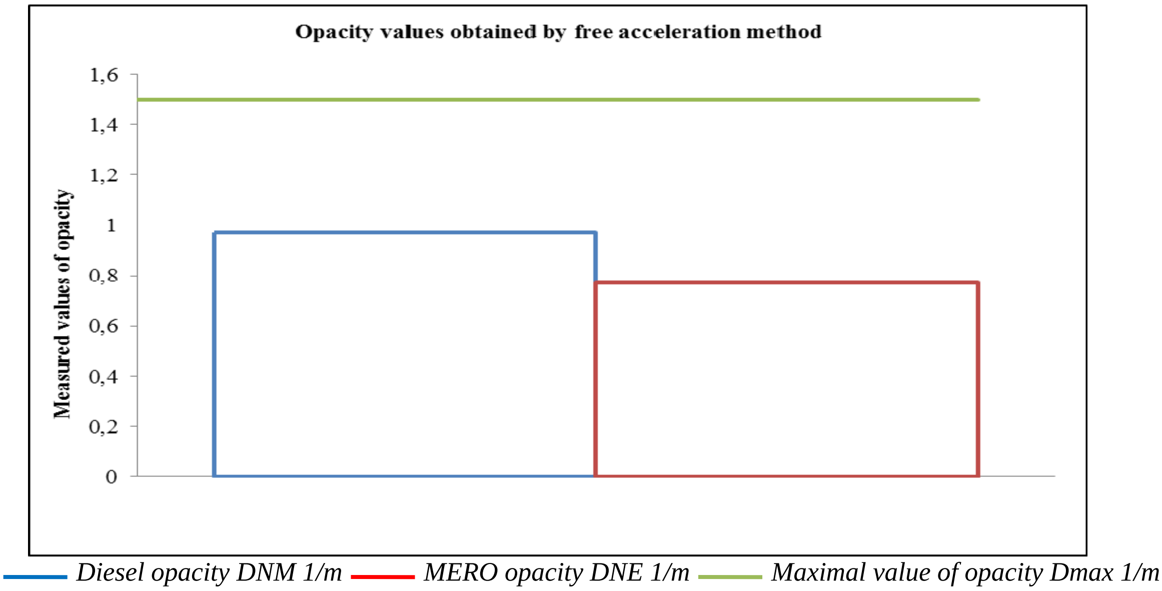

Figure 3. Opacity values measured on Fiat Croma vehicle

4. Conclusions

No alterations of readinesscode were detected, while we investigate an effect of alternative fuel on on-board diagnostics OBD system. Systems, which were tested by on-board diagnostics (complex components, fuel system and exhaust gas recirculation) operate with alternative fuel without recorded defects of condition. A control and diagnostics of diesel particulate filter, consisting of pressure control, belongs to monitored systems. An error, detected by pressure scanner would by logged into memory as a fault code. Diagnostics OBD system was used to detect combustion misfires. Combustion misfire causes a penetration of unburned fuel mixture into exhaust gases, which deteriorates exhaust gases composition. In case of no combustion in cylinder, crankshaft has not sufficient acceleration, and scanner signal is detected as an error, which is recorded into memory as a fault code. Fuel system check was another realized control. We monitored fuel pressure of fuel injectors, fuel injectors switching function (according to injection system) as well as fuel temperature of fuel return line. Exhaust gas recirculation system and EGO sensors belonged to monitored parameters. We did not detect any fault codes of monitored components. A measurement of opacity by engine idle method was realized to verify correct operation of fuel system as well as total technical condition of diesel engine. We can allege that all tested vehicles have suitable technical condition, and opacity values did not exceed defined regulation values.

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