Opacity Analysis and Estimation of CO_2 Exhausted by a Diesel Engine Vehicle Running under Urban Traffic Conditions

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Abstract: - The study includes both the estimation of the total emission of CO2 exhausted by a vehicle equipped with spark ignition engine and the opacity control during testing on the chassis dynamometer in the Road Vehicles Lab of Politehnica University of Timişoara. The total CO2 estimations were accomplished by DEKRA software assuming that the vehicle is used 60% in urban traffic and 40% in the extra urban. Vehicle testing on the chassis dynamometer LPS 3000 has been achieved in different operating modes, in order to survey the gas opacity with AVL Dicom 4000 analyzer.
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Key-Words: - pollutant emissions, internal combustion engine, chassis dynamometer, traffic, gases analyzer

1 Introduction

Air pollution with particulate and gases leads to important changes in concentration, locally and worldwide. Climate changes due to the action of airborne pollutants can have very serious consequences. Most dangerous effects are produced by carbon dioxide of which increasing rate becomes more significant as time goes on. Engines polluting action manifests prominently in major urban centers which are characterized by a high vehicles density.

The smoke and gas smell are still outstanding issues for compression-ignition engines that keep many unknown data related to noxious origin due to the mixture formation processes complexity as well of combustion process [8].

Pollutant called visible smoke, which was regarded for years as a measure of the degree of pollution produced by compression engines proved to be a pollutant which not sufficiently characterize the combusted gases toxicity. In addition to soot particles that create an optical effect detectable by using opacimeters, exhaust gases containin ultrafine particles which cannot be detected only by collecting and weighing.

The most important factors which influence emissions level are:

- Operating mode (speed, load, engine temperature);
- Injection characteristics (injection advance, the injection law);
- Engine constructive features (turbulence in the combustion chamber, the waste gas quantity, heat transfer characteristic of the combustion chamber, supercharging, inlet intermediate cooling air, distribution phases, exhaust gas recirculation degree, variable air flow);
- Fuel characteristics (fuel physical and chemical properties);
- The engine technical condition (parts wear, the injection equipment status).

Diesel and petrol engines are constrained to very strict pollution standards. These engines pollutant emissions mainly consist of: nitrogen oxide (NO_x), carbon monoxide (CO), solid particles. During the combustion process carbon particles are generated in exhaust gases. Due to their presence in smoke opacity varies with their number: the opacity and implicitly the pollution increase as their number is higher. Smoke opacity is an indirect soot indicator in exhaust gases and can be correlated with the fuel tendency to form suspended powders during the engine operation (Fig. 1) [6].
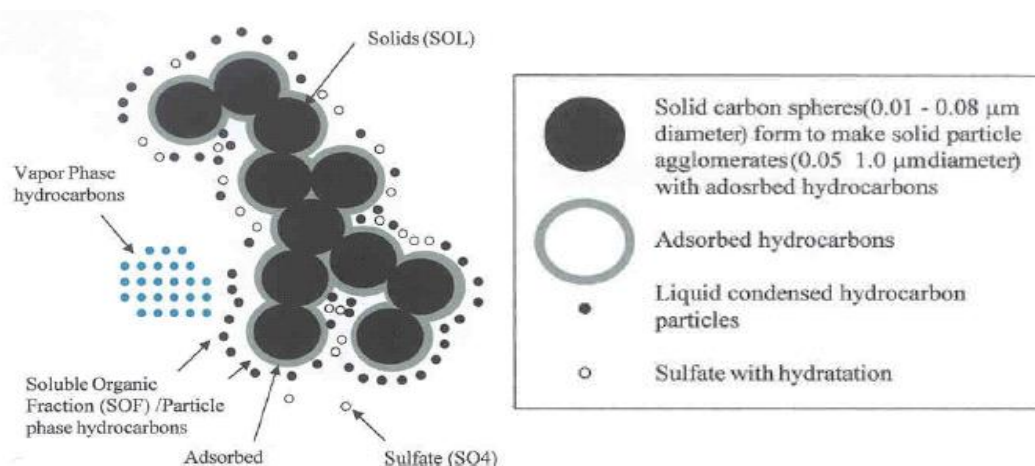
Fig. 1 Schematic of Diesel Particulates and vapor phase compounds

Opacity is a material related value defined by the relation: $N = 100\text{-}T$ where T is the environment global transmittance of which opacity is measured, calculated for a IEC Type A lighting and a receiver with the relative spectral responsiveness identical to the IEC standard observer one in %. The defined measured term value is the linear absorption coefficient (an independent value related to the measurement column length).

Recent studies show that CO_2 has a crucial role because on the one hand, it exists as a natural atmosphere component (around 0.04% volume) and on the other hand the rest, in large quantities, is the combustion processes result. A high rate of total CO_2 emissions is caused by road traffic. These emissions have been significant reduced as a result of restrictive measures despite the traffic significant increase in recent years [9].

Independent of the fuel type used, gasoline, diesel, natural gas, LPG or biofuel, in all cases, the air-fuel mixture is burned into the engine. Carbon is an essential component of all fuels, the carbon amount causing the CO_2 level resulted from combustion. Thus, by burning a liter of gasoline will result 2370 grams of CO_2 and by burning the same amount of diesel will result 2650 grams of CO_2. In conclusion, burning one liter of fuel will discharge into the atmosphere more than 2 kilograms of CO_2 [1].

There is a close relation between vehicle CO_2 emission and fuel consumption, which allows setting the consumption limits. European and world anti-pollution legislative measures have established EURO 1 - EURO 6 standards concerning light vehicles pollutant emissions.

In Fig. 2 are presented the upper limits allowed by EU rules: EU1-EU6 [4], [5].

Even that EURO 1 - EURO 4 regulations can also be achieved by vehicles without DPF, environmental legislations will no longer allow the sell of cars without DPF on the EU market.

Average exhaust emission			EU-1	EU-2	EU-3	EU-4	EU-5	EU-5+	EU-6
			1992	1996	2000	2005	2009	2011	2014
Compression Ignition Engines like Diesel	CO	mg/km	2720	1000	640	500	500	500	500
	HC + NOx	mg/km	970	700	560	300	230	230	170
	NOx	mg/km			500	250	180	180	80
	PM	mg/km	140	80	50	25	5	4,5	4,5
	PN	#/km						6E11	6E11

☐ Moderate Change (<30%)   ■ Large Change (>30%)

Fig. 2 EURO 1 - EURO 6 regulations concerning light vehicles emission limits.

2 The CO_2 Emissions Calculation with DEKRA Software

Emissions of CO_2 can be determined with the use of DEKRA software by taking into account the fuel consumption and number of kilometers traveled.

The EU objective is to limit CO_2 emissions for new vehicles to 120g/km in the medium term although the European Automobile Manufacturers Association established in 2008 a value of 140 g/km. Vehicle CO_2 emissions significantly depend on the vehicle using conditions, traffic conditions and driving style [1]. The software allows the fuel economy estimation by taking into account several conditions during the vehicle operation.

In Fig. 3 are presented the operating setting conditions for DEKRA software.

Determination of fuel consumption, CO_2 emissions and cost reduction potential depends on (Fig. 3):

- Transport type: urban and extra urban and highway;
- Vehicle load type;
- Traffic speed;
- Agglomeration type;
- Tire pressure (respecting the value imposed by the manufacturer);
- Consumers (electrical power consumption, air-conditioned unit);
- The driving mode.

The software displays the percentages of these estimations depending on the traffic type and driving conditions.

Input data are as follows (Fig. 4):
- The engine type (spark or compression ignition engine)
- Fuel consumption [l/100km];
- Number of kilometers.

Output data refers to (Fig. 5):
- Fuel economy [l/100 km];
- CO2 emission [kg/year];
- Cost[Euro/year] [3]

Ermittlung des möglichen Einsparpotentials				
Verkehrsbereich:	Stadt: 60%	Überland: 40%	Autobahn: 0%	
Maßnahme	**Einsparpotentiale**			
3 Fahrräder nicht auf dem Dach oder am Heck transportieren	5%	10%	20%	0.0 %
Leeren Dachträger oder Dachbox abnehmen	5%	7%	15%	0.0 %
☑ Verzicht auf Gewicht im Kofferraum (100 kg)	5%	4%	2%	4.6 %
☑ Motor aus bei Halt (Ampel Stop etc.)	3%	0%	0%	1.8 %
☑ Geschwindigkeit von 160 km/h auf 130 km/h absenken	0%	0%	10%	0.0 %
Reifendruck nicht um 0,5 bar unterschreiten	5%	5%	5%	0.0 %
☑ Reifenluftdruck nach Herstellerangaben ausnutzen	2%	2%	2%	2.0 %
☑ Sparsamer Umgang mit Klimaanlage und elektr. Verbrauchern	5%	4%	3%	4.6 %
angepasste Fahrweise (frühes Hochschalten, vorausschauend Fahren)	10%	7%	5%	0.0 %
gesamtes Einsparpotential bis zu:				13.0 %
Hier können Sie ihre persönlichen Daten eintragen:				
Welche Kraftstoffart hat ihr Fahrzeug?		○ Benzin ● Diesel		
Welche Jahreslaufleistung kalkulieren Sie?	3.15	in 1000 km		
Wie hoch ist Ihr Verbrauch (ohne die oben genannten Maßnahmen, in l/100km)?	6.0	l / 100km		
Kraftstoffpreis?	1.2	€ / l		
Das ermittelte Einsparpotential bedeutet:				
Kraftstoffersparnis nach Massnahmen bis zu:	0.8 l	/ 100km		
CO2-Einsparung bis zu:	64 kg	/ Jahr		
Kosteneinsparung bis zu:	29 €	/ Jahr		

Fig. 3 Operation conditions setting

Fig. 4 DEKRA software input file

Fig. 5 DEKRA software output file

For the tested diesel type vehicle, Skoda Roomster 1.4 TDI, the following records can be observed: 0.8 l/100 km fuel economy, 64 kg/year CO_2 emission reduction and up to 29 Euro/year cost reduction. These estimations were made under the conditions in which it was assumed that the vehicle is used 60% in urban traffic and 40% in extra urban traffic, moving at a speed lower than 130 km/h, loaded with 100 kg and respecting the tire pressure imposed by manufacturer.

3. Presentation of the Chassis Dynamometer for the Vehicle Testing

Experimental tests were performed on LPS 3000 chassis dynamometer, on which different operating modes were simulated (Fig. 6). The smoke opacity was measured using AVL DICOM 4000 gas analyzer which is an optical opacimeter. In order to analyze the internal combustion engines exhaust gases, the Automotive Laboratory of the University Polytechnica of Timisoara is equipped with an 4th generation AVL opacimeter, which measures the light reduction degree in the measurement chamber through which passes the gas sample [2]. The measured values are displayed as opacity, OPAC [%] or absorption value k $[m^{-1}]$.

Opacity is defined by the relation [7]:

$$N = 100 - T \qquad ()$$

Where:
T[%] - the global transmittance of environment whose opacity is measured, calculated for CIE illuminant type A and a receiver with the same relative spectral responsiveness of the CIE standard observer.

Linear absorption coefficient is a material size, defined by the relation [7]:

$$\tau = -\frac{\ln k}{L} \qquad ()$$

Where:
τ[-] - the measurand global transmittance (absolute), measured for CIE illuminant type A and a receiver with the same relative responsiveness of the CIE standard human observer
L[m] - the optical path length traveled through the medium whose linear attenuation coefficient is measured.

Due to the eddy current brake system, the stand can maintain rollers speed constant. LPS 3000 also has the latest software update making possible the power and torque variations control and recording and also permits recording of pressure, excess air coefficient, exhaust temperature, power to the wheel, inertia moment and speed. Dynamometer Cell is equipped with an excellent cooling system (MAHA Air 7 Cooling Fan) that incorporates a directional fan suitable for every vehicle type (regardless of the cooling system location). This is very important because the engine may be kept cold and at the same time is possible that they can be mapped or regulated. It is necessary for any vehicle to be adjusted in a controlled environment.

LPS 3000 uses a wide band Lambda Reader for excess air coefficient reading, and also SUN MGA 1200 Gas Bench in order to precisely establish the mixture for obtaining the indicated power values [3].

Fig. 6 Experimental stand

4. Experimental Results on opacity variation versus speed

Experimental simulation was performed in terms of the stand charged with F=200N and F=0N, for a variable speed mode and with air conditioned unit turned off.

The tested car Skoda Roomster 1.4 TDI -EURO IV presents the following characteristics:
- Engine   Diesel
- Cylinder capacity   1422 cm^3
- Cylinder number   3L
- Maximum power   51 kW
- Manufacturing year   2008
- Maximum weight   1750 kg
- Maximum torque   195 Nm
- Traveled km   3150
- ITP number   0
- Urban consumption   6.1 l/100km
- Extra urban consumption   4.5 l/100km
- Mixt consumption   5.1 l/100km

For the tested car, during the emission recordings the maximum values and environment ones are also displayed (Fig.7).

There were recorded in Road Load Simulation mode the following parameters: driving speed, power, engine speed and force, versus the recording time. The tests results are presented in Fig. 8.
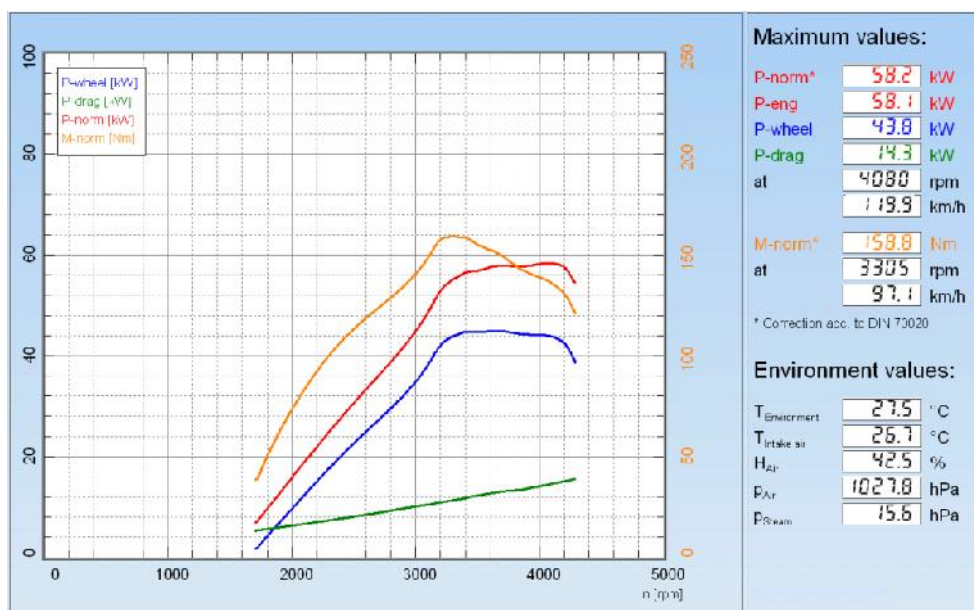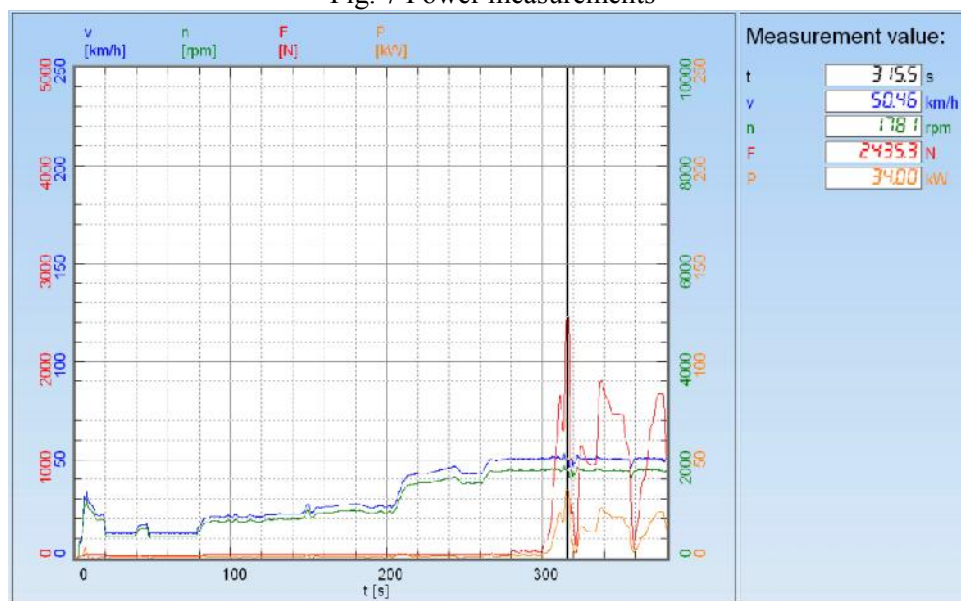

Fig. 7 Power measurements

Fig. 8 The parameters recording in Road-load Simulation

Due to the diesel engines operation in a wide range of loads and speeds modes, operation mode optimization is difficult. It is recommended to avoid prolonged operation under idle or sudden acceleration. To decrease the pollutant emission, their characteristics depending on load and speed are determined, which correlated with fuel consumption characteristics are important for the used power curves selection. These features are used for elaborating the automatic adjustment programs of operating modes, selecting the gear for localizating the areas where the engine operation is prohibited from environmental concerns point of view. If the engine is operating under load (accelerated, slopes climbing, run with the high speed, loaded), HC emissions are low while NOx emissions are high due to efficient combustion process.

In diesel engines, high HC emissions occur at cold start, idling or low loads, when deficient air - fuel mixing can lead to delayed or incomplete combustion.

AVL DICOM 4000 optical opacimeter display the smoke opacity value [%] and also maximum and current value of absorption coefficient, k [m^{-1}].

The opacity and linear absorbtion coefficient variation were controlled under transitory operating mode. Their values were plotted versus the engine speed (Fig. 9, Fig. 10, Fig. 11 and Fig. 12).
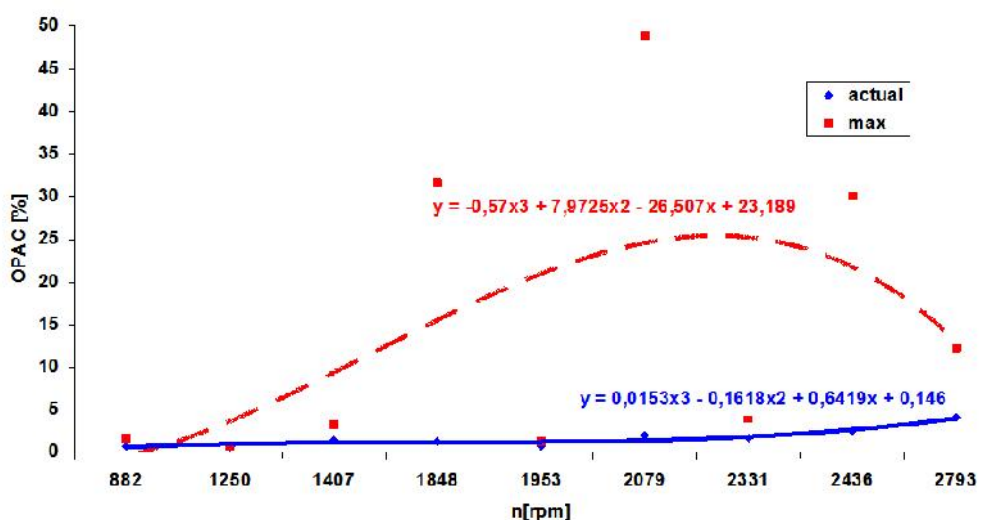

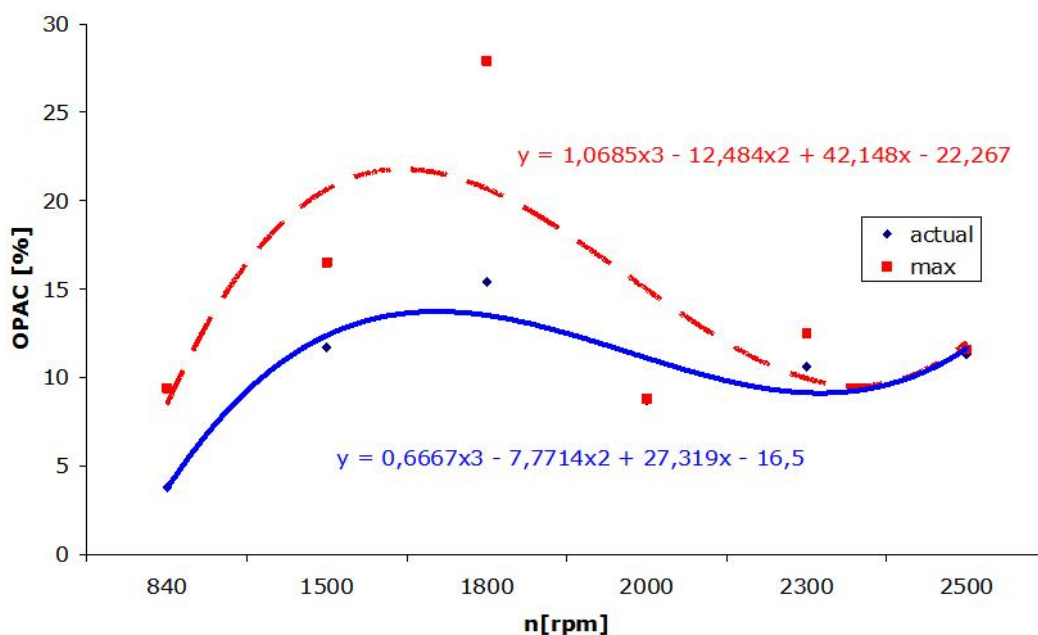Fig. 9 Opacity variation law versus speed at variable speed regime with F=0N load

Fig. 10 Opacity variation law versus speed at variable speed regime with F=200N load
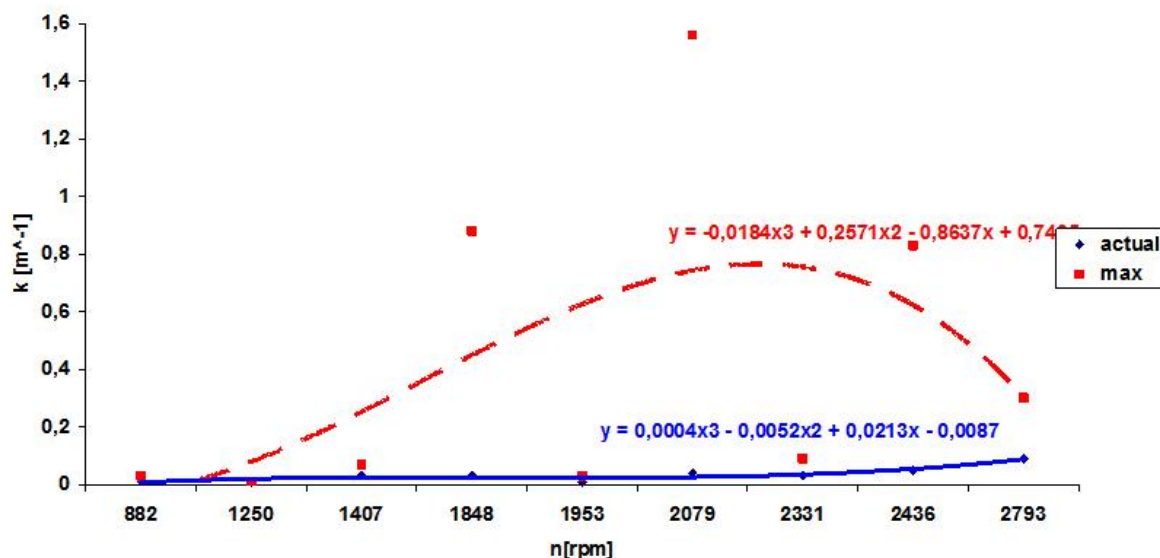
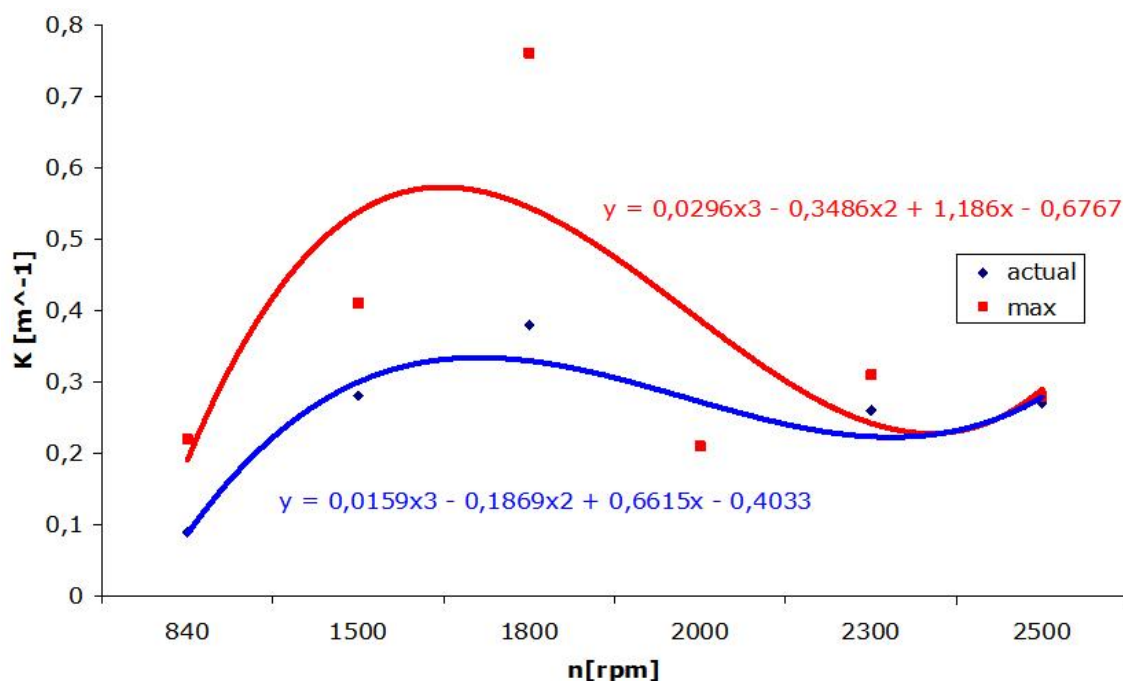Fig. 11 Linear absorbtion coefficient variation law versus speed under transitory operating mode, *F*=0N

Fig. 12 Linear absorbtion coefficient variation law versus speed under transitory operating mode, *F*=200N

The tests were achieved with the air-conditioning unit turned off both for the stand loaded with 0N and 200N.

For the transitory operating mode, when the stand was loaded with *F*=200N, the opacity records smaller values comparing to F=0N (Fig. 9 and Fig. 10) [4].

For the two analyzed cases, it can be observed that that the linear absorbtion coefficient maximum value obtained for F=0N is 0.8m^{-1} at around 2200rpm, while for F=200N the linear absorbtion coefficient maximum value is equal to 0.55 m^{-1} for an engine speed of 1600rpm. Comparing the linear absorbtion coefficient values at the same engine speed, it results that for F=200N this value is about four times smaller than for F=0N.

As a result of this analyze it is obvious that opacity and linear absorbtion coefficient values show an increasing trend up to the reach of the

thermal operating mode and afterwards their values decrease.

During measurement it was observed that if the air conditioning unit is turned on, for the same engine operating mode and F=0N, different opacity and linear absorbtion coefficient values are recorded (Fig.13 and Fig. 14).
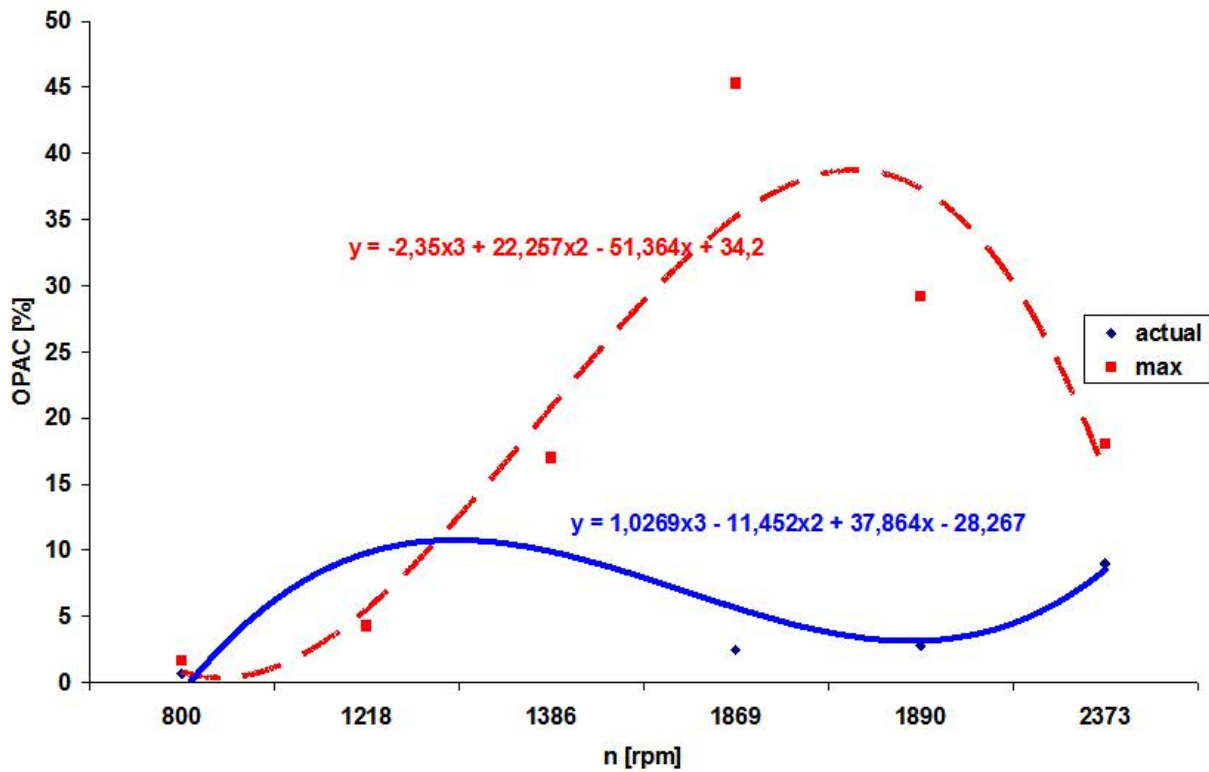

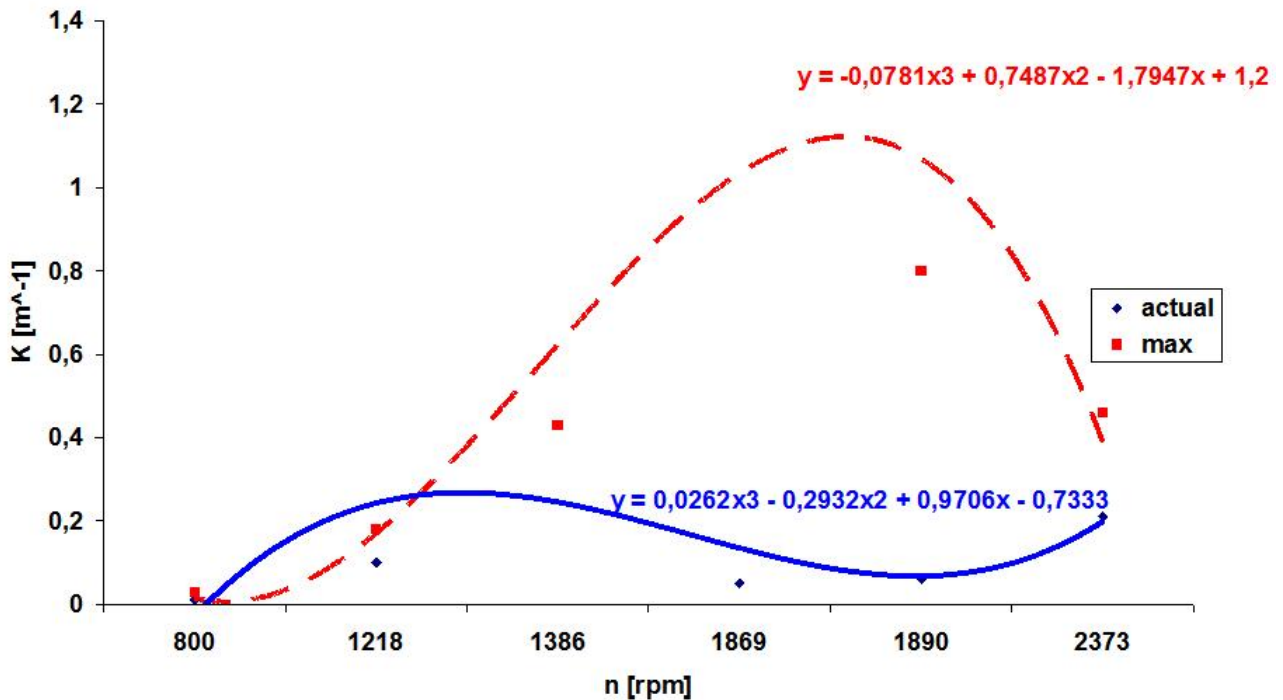Fig. 13 Opacity variation law versus speed at transitory speed mode, *F*=0N

Fig. 14 Linear absorbtion coefficient variation law versus speed under transitory operating mode, *F*=0N

By analysing Fig. 13 and Fig. 14, both opacity and linear absorbtion coefficient variation have an increasing trend up to about 1800rpm and than their values show an abrupt reduction.

The values of those two recorded parameters are higher when the air conditioning unit is turned on.
In summer the vehicles runn with this unit turned on most of the time, meaning a higher smoke quantity exhausted into the atmosphere. Therefor, in order to reduce this emissions, the nonconventional fuels are recommended for the vehicle operation.

5 Conclusion

Following the vehicle test on the chassis dynamometer under traffic conditions, passing through all operation modes, DEKRA software used to determine CO_2 exhausted into the atmosphere by the studied vehicle, allows the fuel economy estimation by taking into consideration certain conditions during vehicle operation.

Smoke opacity represents an indirect indicator of soot contained in exhaust gases and therefore can be correlated with the fuel tendency to form suspended powders during the engine operation.

Most studies agree that emission of suspended powders is due to a significant reduction in its concentration as insoluble fraction (mainly soot), as a consequence of oxygen presence and aromatic hydrocarbons absence when biodiesel fuels are used. The ester molecule oxygen content ensure, with the same amount of intake air, a more complete combustion, even in areas with rich mixture of the combustion chamber, and in addition helps to the already formed soot oxidation. When biodiesel is used, due to the lack of aromatic hydrocarbons, a reduction of the soot concentration in the combustion chamber will result.

Considerations concerning the emission reduction degree have imposed the development direction of the biofuels range. For this reason all European countries and the major fuel companies are making outstanding research efforts to develop new technologies for producing biofuels

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