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SELECTED PROBLEMS OF GREENHOUSE GAS EMISSIONS FROM VEHICLES

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Abstract

Emissions of greenhouse gases, such as carbon dioxide, methane, dinitrogene monoxide, water vapours and ozone was constant until the end of eighteenth century, and then began to increase. This increase was particularly steep after 1950 and continues until today. It is estimated, that changes in greenhouse gas concentrations in the air, which lasts for more than 200 years, stemmed largely from human activities, including the development of agriculture, transport and industry. The article discusses the problem of the greenhouse effect in terms of emissions of selected gases and components from the motor vehicles. It presents the results of pollutants emissions measurements, including greenhouse gas emissions from vehicles, in some research tests, curried out on the chassis dynamometer. There is assessed the impact on greenhouse gas emissions from different engine sources (exhaust system, fuel system, and crankcase) due to the following fuels: LPG, CNG, petrol, diesel oil and biodiesel. This article is a fragment of greater work devoted determination of emission indicators for greenhouse gases useful in calculation of total emissions by selected transport sectors. There are two interesting conclusion of this work: the first is that for diesel engine significant part of greenhouse gas emissions have PM emissions and the second that for older spark ignition engines equipped with open type fuel systems very important part of these emissions have hydrocarbon emissions from fuel system.

Keywords: *greenhouse effect, greenhouse gases, emissions, environmental protection*

1. Introduction

If the average amount of thermal energy that reaches the Earth were equal to the amount of energy, which is radiated into space, the planet would be in thermal equilibrium; the temperature would be fixed; and would not change in time. However, the observed increase in the surface temperature of the Earth's crust and atmosphere, melting glaciers and increased ocean temperatures commands to assume that the Earth receives more energy than it is radiating outside. Based on the rate of temperature increase it is estimated that this difference is equal to 0.85 W/m^2. In order to achieve the state of thermal equilibrium in the currently prevailing conditions, the temperature at the Earth's surface would have to increase by about 1°C.

As a result of natural processes occurring on Earth and as a result of human activity, to the atmosphere have been emitted substances, which are now present in the air, whose content is variable. The most important of these include:

- water steam, the content of which at the surface of the Earth's crust usually varies in the range from 0.00001% by volume in the polar zones to 4% by volume in the subtropics,
- carbon dioxide, methane, nitrous oxide, sulphur dioxide,
- ozone,
- atmospheric aerosols and particulate matter.

Basic components of atmospheric air, which are: diatomic oxygen (O_2), nitrogen (N_2) and argon (Ar), do not absorb IR radiation emitted from the surface of the Earth's crust. Reducing the permeability of the atmosphere for this type of radiation is caused by water vapour (H_2O), carbon dioxide (CO_2), ozone (O_3), methane (CH_4), nitrous oxide (N_2O), and other gases. The radiation photons' flux stimulates the located in the lower layers of the atmosphere molecules of these gases as a result of which these molecules increase their kinetic energy, causing heating of the air. The lower layers of the atmosphere emit radiation in all directions, including towards the upper layers. This way heated air is transferred gradually to higher and higher layers. These causes, so-called, the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), ozone (O_3), methane (CH_4), nitrous oxide (N_2O) and other gases are identified as "greenhouse gases".

According to [2], the share of the most important greenhouse gas in the creation of the greenhouse effect is as follows:

– water vapour, 36-70%,
– carbon dioxide 9-26%,
– methane 4-9%,
– ozone 3-7%.

Water vapour, carbon dioxide, methane, nitrous oxide, ozone and chlorofluorocarbons are greenhouse gases that exert a direct influence on the temperature of the Earth. The atmosphere contains also gases that affect this temperature indirectly. These include carbon monoxide, hydrocarbons, nitrogen oxides and sulphur oxides. They are ozone precursors, i.e. the substances participating in the formation of ozone in the atmosphere.

The natural greenhouse effect is a phenomenon beneficial to the conditions for the formation of life on Earth. It is estimated that it raises the temperature prevailing on Earth surface by about 20-34°C. The average temperature of the planet is 14-15°C. If the greenhouse effect did not exist, the average temperature of the Earth would be approx. –19°C.

The equivalent emissions of greenhouse gases are, so far, adopted as a criterion in terms of impact on global warming in only one EU provision – Directive 2009/30/EC amending Directive 98/70/EC. It does not apply directly to motor vehicles, but to the fuels used to power them: petrol, diesel oil, LPG, CNG, biofuels. One of its aims is to monitor greenhouse gas emissions. According to Directive 2009/30 /EC in determining, the equivalent emission one takes into account the emission of three greenhouse gasses from the exhaust system of vehicles' engines [1]:

– CO_2 (GWP = 1),
– CH_4 (GWP = 23),
– N_2O (GWP = 296).

Over many years, the only criterion for the evaluation of motor vehicles in terms of impact on global warming was carbon dioxide emission (CO_2) from the engine exhaust system. This compound is not the only substance emitted from motor vehicles that affects global warming. In order to make evaluations, taking into account the substances other than CO_2 there was introduced the concept of equivalent emission of the substances affecting global warming, expressed as carbon dioxide. It is determined by the formula (1).

$$E_e = E_{\mathrm{CO2}} \times \mathrm{GWP}_{\mathrm{CO2}} + \sum_{i=1}^{n} E_i \times \mathrm{GWP}_i \,, \tag{1}$$

$$k_i = E_i \times \mathrm{GWP}_i \,/\, E_{\mathrm{CO2}} \,, \tag{2}$$

where:

E_e – equivalent emissions,
E_{CO2} – carbon dioxide emissions,
$\mathrm{GWP}_{\mathrm{CO2}}$ – potential for creating global warming effect of carbon dioxide,
E_i – emissions of exhaust component "i" other than carbon dioxide,
GWP_i – potential for creating global warming effect of the component "i" other than carbon dioxide.

The equivalent emission is determined taking into account the potential of creating a global warming effect of each component. The equivalent emission, just like carbon dioxide emission is expressed as unit of mass per unit of activity, for example in g/km, g/MJ, g/kg of spent fuel, g/kWh.

In order to evaluate the effect of substances other than carbon dioxide there have been employed so far:
– method of equivalent emission of greenhouse gases,
– method of equivalent emission taking into account the particulate matter,
– method of equivalent emission taking into account greenhouse gases and particulate matter.

None of these methods includes all substances that affect global warming. Moreover, there is only one emissions source included in them – the engine exhaust system, and the emissions from other two sources are not taken into account, namely:
– engine crankcase,
– fuel supply system.

The emission from these two sources is important primarily for vehicles of older generation. The method developed envisages the criterion of evaluating vehicles in terms of the impact on the global warming to be the equivalent emissions of substances affecting global warming, expressed as carbon dioxide. It is calculated based on the emission of appropriate substance and its potential for creating global warming effect GWP according to general formula (1). It takes into account the components that affect the Earth's energy balance and, therefore, global warming. It was assumed that it takes into account the substances for which the relative potential for generating global warming effect k_i defined by the formula (2) is greater than about 0.002 (0.2%). Their main source is the exhaust system of the vehicle. All substances listed in Table 1.1. are emitted from it. The analysis conducted based on the past experience shows that in the comprehensive assessment of vehicles in the general case one should take into account not only exhaust emissions, but also the emission of:
– methane from the crankcase,
– non-methane hydrocarbons from the crankcase (converted to the non-methane volatile organic compounds),
– non-methane hydrocarbons from the fuel supply system (converted to the non-methane volatile organic compounds).

This article attempts a comprehensive assessment of greenhouse gases emissions from light-vehicles supplied with different fuel types and from different sources.

2. The bench studies of the emission of greenhouse substances from certain types of light vehicles

The objects of research were the following vehicles meeting the emission standards Euro 4 or 5:
1) car with spark-ignition engine powered by petrol,
2) car with spark-ignition engine powered by LPG,
3) car with a spark-ignition engine powered NG,
4) car with spark-ignition engine powered by E85,
5) car with a diesel engine powered by diesel oil,
6) car with diesel engine powered by biodiesel (100%).

The scope of the research included:
a) measurement of the exhaust system emission:
   – European cycle (UDC, EUDC, weighted),
   – measurements to determine the speed impact (0-140 km/h) and temperature (–10 to +25°C) on the emission,
   – pollutants measured: CO, THC, NMHC, CH_4, N_2O, NO_x and PM,
b) emission from the crankcase:
   – detaching the crankcase vent (emission into the atmosphere),
   – emission measurement from the crankcase in the European cycle (urban, extra-urban, total) – with the registration of the emissions and vehicle speed as a function of time.

c) emissions from the fuel supply system (type IV test according to Regulation No. 83 UN).

In all there were five cars tested. The following measurements of the pollutant emissions from the exhaust system were conducted:

- in D1 and D2 tests developed by ITS, the results of which were used to determine the baseline emission indicators from completely warmed up vehicle in urban-type traffic conditions and extra-urban one /expressway/ motorway,
- in the Type I test according to UN-ECE Regulations No. 83 after a cold start and a fully warmed-up engine, the results of which were used to determine the additional baseline emission o resulting from the start-up of the engine,
- at steady speeds and ambient temperatures of 25°C and –10°C, the results of which were used to determine the effect of ambient temperature on the emission.

For two vehicles: fuelled with petrol (the car "from before the introduction of Euro standards" and one powered by biofuel B100), measurements were made of the emission from the crankcase. For petrol-powered car, "from before the introduction of Euro standards" to an additional measurement was made of the pollutants emission from the fuel supply system.

3. Evaluation of the light motor vehicles in terms of the emission of greenhouse substances

As a criterion for the evaluation of vehicles in terms of the impact on global warming the equivalent emissions was adopted of substances affecting global warming, expressed in equivalent of carbon dioxide.

The developed method of evaluation includes components that affect the Earth's energy balance, and therefore the global warming effect. Their main source of emissions is the exhaust system of the vehicle. The analysis conducted based on the experiences gathered shows that the comprehensive assessment of motor vehicles in general one should take into the account not only emissions from vehicle exhaust systems, but also the emission of:

- methane from the crankcase of the engine,
- non-methane hydrocarbons from the crankcase (converted to non-methane volatile organic compounds),
- non-methane hydrocarbons from the fuel supply system (converted to non-methane volatile organic compounds).

The equivalent pollutant emissions calculated in each cycle were used to determine emission indicators for each of the car tested. These indicators are determined in accordance with the methodology developed in [5]. It involves:

- determining the emission indicator after the complete warm-up of the car,
- determining the baseline emission indicator, i.e.:
  - in a warmed up car,
  - at an ambient temperature of 20-25°C,
  - at road resistance corresponding to driving on a flat road,
  - at the mileages of 0 km,
- adjusting the baseline indicator by multiplying it by the correction factor depending on the ambient temperature and the vehicle mileage,
- adding to the designated indicator the additional emission value resulting from the cold start-up or partially warmed-up engine,
- determining the additional emission baseline indicator,
- adjusting the baseline indicator by multiplying it by the correction factors depending on the starting temperature, driving speed and distance travelled.

Baseline emission indicators after warming up the vehicle have been determined in this project based on the results of the equivalent emission measured in cycles D1 and D2. Calculating baseline emission indicator based on the results of testing in cycles for the given vehicle is performed according to the following methodology:

a) The results of emission tests in individual cycles are adjusted to the mileage of "0" according to the formulas given in the literature.
b) For each cycle, the average values of the emission are calculated with the mileage of "0".
c) The mean values of emissions are calculated for the following traffic type:
   – urban,
   – extra-urban, expressway and motorway.

The result are average baseline emission indicators for the urban type of traffic and extra-urban/expressway/motorway.

The next stage of determining the emission indicator in this methodology was to conduct correction of baseline indicators after complete warm-up with regard to:

– vehicles mileages,
– ambient temperature (correction coefficients for CO, THC, CH_4 and NO_x were adopted based on the literature, and for N_2O, PM and CO_2 have been determined based on the own tests).

Additional baseline emission resulting from the start-up was determined based on the results of tests in the UDC part of the NEDC cycle performed after the engine cold start and the warmed up engine. All tests were conducted at ambient conditions in the laboratory, i.e. at 20-25°C.

The developed methodology assumed that warming up of the car after the start-up occurs when driving in urban traffic type. The average speed in these conditions is 25 km/h, and so differs by 5 km/h from the one adopted when determining the additional baseline emission. To determine the correction coefficient with regards to the driving speed the relationships used between the additional emissions, and the driving speed quoted in the literature.

In order to determine the correction coefficient with respect to the start-up temperature there were used:

– for the start-up temperatures of up to 20°C the relationships established in the literature, but for the PM, own research results data was used,
– for the temperature range of 20-80°C own research results data [4].

Total baseline emission, which is the sum of the baseline emission indicator and additional baseline emission, is given in Tab. 1. For tested Mercedes Sprinter running on CNG the total baseline emission is equal to the baseline emission indicator, because a short time, for which the car was borrowed, did not allow to perform the tests on the pollutants emission from the exhaust system in the test I type of the UN-ECE Regulations No. 83 after starting the fully warmed up engine.

Tab. 1. Total baseline emissions [mg/km or in g/km for CO_2]

Car	Fuel type	CO	NO	CH_4	NMVOC	N_2O	CO_2	PM
Skoda Octavia	Petrol	453.7	12.8	22.9	5.8	16.0	172.3	5.5
Skoda Octavia	LPG	568.9	36.2	64.3	10.3	49.4	167.0	5.1
Renault Traffic	Diesel oil	184.8	200.7	12.7	5.3	7.4	272.4	59.7
Mercedes Sprinter	CNG	81.2	0.4	5.6	0.7	4.3	310.1	1.0
Mercedes Vito	B100	675.2	372.5	-2.3	16.3	0.4	250.4	71.9

Tables 2 and 3 show a partial equivalent emission of individual greenhouse substances from the exhaust system and their percentage share.

Tab. 2. Equivalent emissions of the individual greenhouse substances [g/km]

Car	CO	NO	CH_4	NMVOC	N_2O	CO_2	PM	Σ
Skoda Octavia	1.57	0.00	0.64	0.03	4.78	172.30	4.62	183.93
Skoda Octavia	1.97	0.00	1.78	0.06	14.72	167.04	4.29	189.87
Renault Traffic	0.64	0.00	0.35	0.03	2.22	272.38	50.11	325.73
Mercedes Sprinter	0.28	0.00	0.15	0.00	1.29	310.11	0.87	312.72
Mercedes Vito	2.34	0.00	0.00	0.09	0.76	251.59	60.39	315.18

Tab. 3. Percentage share of the individual greenhouse substances in the total equivalent emissions from the exhaust system

Car	CO	NO	CH_4	NMVOC	N_2O	CO_2	PM
Skoda Octavia	0.9%	0.0%	0.3%	0.0%	2.6%	93.7%	2.5%
Skoda Octavia	1.0%	0.0%	0.9%	0.0%	7.8%	88.0%	2.3%
Renault Traffic	0.2%	0.0%	0.1%	0.0%	0.7%	83.6%	15.4%
Mercedes Sprinter	0.1%	0.0%	0.0%	0.0%	0.4%	99.2%	0.3%
Mercedes Vito	0.7%	0.0%	0.0%	0.0%	0.2%	79.8%	19.2%

The largest share in the total equivalent emissions from the exhaust system has carbon dioxide. Its share is in the range of 80 to 99%. For the cars equipped with compression ignition engines, a high proportion has particulate matter emission. For the tested vehicles, the PM emission share ranged from 15.4 to 19.2%. For the vehicles equipped with spark ignition engine, running on petrol or LPG, further substances that affect the greenhouse effect having a clear part in the emissions are nitrous oxide (2.6-7.8%) and PM (approx. 2.5%). In addition, for a car powered by natural gas almost 100% of the equivalent greenhouse gases emission comes from carbon dioxide.

Running the engine on LPG reduces the equivalent carbon dioxide emission (from 93.7% to 88.0%), but does not change the overall equivalent emission from the exhaust system due to the increase in emissions of nitrous oxide (from 2.6% to 7.8 %) and methane (from 0.3% to 0.9%).

The component of the equivalent emission of hydrocarbons from the crankcase is calculated for CH_4 and NMVOC. In the course of the studies of the emission from the crankcase there were measured these emissions for the Mercedes Vito and PF 126p. Tab. 4 shows the results of calculation of equivalent emissions of CH_4 and NMVOC from the crankcase measured in the type I test of UN-ECE Regulations No. 83 following engine cold-start and a fully warmed-up engine.

Tab. 4. Equivalent emission from the crankcase [mg/km] for the Mercedes Vito and PF 126p cars

Cycle	Car			
	Mercedes Vito		PF 126p	
	CH_4	NMVOC	CH_4	NMVOC
UDC_{cold}	44.4	53.0	0.11	108.3
$EUDC_{cold}$	33.3	84.8	0.03	0.94
UDC_{hot}	2.8	19.0	0.08	1.37
$EUDC_{hot}$	0.0	5.6	0.03	0.83

Both cars tested had high mileage, 312 000 km for the Mercedes Vito and 224 000 km for PF 126p car. Due to the wear out of the engines in both vehicles, there were a clear difference between the emission after a cold start and fully warmed up engine. For the Mercedes Vito significant emissions of methane and NMVOC occur both in the urban test after a cold and fully warmed-up engine start. Only the results of the extra-urban emission test after starting completely warmed-up engine are close to zero. As for the PF 126p car, methane emissions can be omitted entirely, while significant NMVOC emissions occur only in the urban test after a cold engine start. In other conditions, this emission is negligible.

The component of the pollutants equivalent emission from the fuel supply system is calculated only for NMVOC expressing emissions of the fuel vapours. In the gas fuel systems (CNG, LPG), the problem of leaking fuel installations is practically non-existent. This component is important for older vehicles, particularly “before the Euro”, equipped with a fuel system without carbon fuel vapour absorber.

During tests, the emission from the fuel supply system of PF 126p car was measured. Total emission of NMVOC is 9.114 g/24 hours, which according to [2] indicates that the equivalent emission is 50.8 g/24 hours. The equivalent emission from the fuel supply system for this car is approx. 53.5% of the equivalent emission from the exhaust system.

4. Summary and conclusions

As a result of the work conducted the methodology was developed for determining the equivalent emissions of greenhouse substances from motor vehicles. The method developed can be used for evaluating not only light duty vehicles but any vehicles and engines, in terms of the emissions of substances causing global warming on Earth, where the emissions are measured according to any procedure, providing, it is expressed in a unit of weight per unit of activity, for example g/km, g/MJ, g/kg of fuel consumed, g/kWh. In addition, it can be used not only to assess individual motor vehicles, but also, for example, the entire road transport or vehicles, equipment and machinery used in other sectors of the economy.

For the emissions from the vehicle, exhaust system the largest share of the total emissions has carbon dioxide. Its share is in the range of 80 to 99%. For the cars equipped with compression ignition engines, a large part has also PM emissions. For the cars tested, it was from 15.4 to 19.2%. For the cars equipped with spark ignition engine, which are supplied with petrol or LPG, the further greenhouse substances having a clear part in the emission are nitrous oxide (2.6-7.8%) and PM (approx. 2.5%). While for a car powered by natural gas, almost 100% of greenhouse gases emission comes from carbon dioxide.

It was found that for the tested vehicles fuelled with LPG however equivalent carbon dioxide emissions (from 93.7% to 88.0%) were lower, but does not change the overall equivalent emission from the exhaust system due to the increase in the emissions of nitrous oxide (from 2.6% to 7.8%) and methane (from 0.3% to 0.9%).

The study has shown that, especially for the cars with high mileage, and therefore potentially significant engine wear, one should not ignore the crankcase emissions. Due to the wear of engines in both vehicles, it was possible to see a clear difference between the emissions after a cold engine start and fully warmed up. For the Mercedes Vito a significant emissions of methane and NMVOC occurs in both the urban test after a cold engine start and fully warmed-up engine. Only the results of the emissions in the extra-urban test after starting completely warmed-up engine are close to zero. And for the PF 126p car CH_4 emissions can be ignored entirely, while a significant NMVOC emissions occur only in the urban test after a cold engine start. In other conditions, the emission is negligible.

As part of the study, greenhouse gases emissions from the fuel supply system were measured. These studies were performed for PF 126p car, i.e. the car equipped with carburettor engine. This fuel supply system is characterized by high emission of hydrocarbons. This was confirmed by the tests. For the vehicle tested, the share of emissions from the fuel supply expressed as the equivalent emissions of CO_2 accounted for 53.4% of emissions from the exhaust system. Therefore, for cars equipped with carburettor engine, in estimating the emissions, one should not ignore the greenhouse gases, whose source is fuel supply.

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