Influence of Ambient Temperature on the CO₂ Emitted With Exhaust Gases of Gasoline Vehicles

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Abstract. This article focuses on the regulation of CO₂ emitted in the exhaust gases of gasoline vehicles. Based on comparing the world practices of restrictive measures on greenhouse gas emissions with Russian legislation, we conclude that there is a need to adjust the limits of CO₂ emission taking into account the negative impact of ambient temperature on CO₂ emission. The climatic conditions of many countries stipulate the use of vehicles in temperatures below zero. At the same time, the existing regulations fully take into account the temperature features of the various countries, which casts doubt on the existence of uniform emission standards for all countries. Here, we conduct an experiment on one of the most popular cars in Russia: the Mitsubishi Lancer 9. We establish that lower temperatures are correlated with larger concentrations of CO₂ in the exhaust gases. We draw a conclusion about the need to account for the actual operating conditions when establishing limit values on CO₂ emissions of vehicles.

1. Introduction

Significant attention worldwide is paid to environmental issues such as the negative impact of emissions from anthropogenic stationary and mobile sources; these emissions have a negative impact on the Earth's climate. As the 20th century began, active international activity aimed to fight climate change. The most well-known conference on the subject took place in December 1997 in Kyoto (Japan), and there has been a considerable extension of the United Nations Framework Convention on Climate Change (UN FCCC) in 1994. The UNFCCC defined legal obligations for emission reductions. The Kyoto Protocol outlined the basic rules, but it did not provide details about how such rules would be applied. The Kyoto Protocol also required a separate formal process of signature and ratification before taking effect. The obligatory purposes and terms of reducing greenhouse gas (GHG) emissions in the majority of the countries have been modelled on the Kyoto Protocol.

The mandate involved maintaining GHG emissions at a level of 8–10% compared with 1990 levels. The Kyoto Protocol was the first global agreement about environmental protection. The primary GHG include water vapour (H₂O), carbon dioxide (CO₂), methane (CH₄) and ozone (O₃).

Of all of these gases, we focus on CO₂. The sources of CO₂ in the atmosphere of Earth include volcanic activity and the activity of living organisms.
Anthropogenic sources of CO₂ include the burning of fossil fuels in both stationary and mobile sources. A number of countries have reduced the negative impact on the nature from the operation of motorised transportation; exhaust gases (EG) consist of a significant amount of CO₂.

The European Union (EU) imposes some of the strictest restrictions on CO₂ emissions in the world. By 2020, new cars in Europe will be required to emit only 95 g/km of CO₂ [1]. In the United States and Japan, there are similar programs to decrease GHG emissions [2]. This standard is the same for countries with different climatic conditions (i.e., the EU, United States, Japan and others). CO₂ emissions are monitored along with carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOₓ) and soot; but in Russia, an assessment of the component structure of EG the CO₂ emissions is not considered at all [3,4].

Moreover, according to a letter of the Ministry of Natural Resources and Environmental Protection of the Russian Federation from October 3, 2015 (number 12-47/5413) entitled "About a payment for negative impact from mobile sources," the following is reported:

Enacted since January 1, 2015 of the Federal Law (FL) of July 21, 2014 (number 219-FL) "On Amendments to the Federal Law On Environmental Protection and separate acts of the Russian Federation" the 28th article of the FL of May 4, 1999 (number 96-FL) "On air protection" is presented in a new version, according to which legal entities and individual entrepreneurs will be charged for emissions of harmful (polluting) substances (HS) into the atmosphere from stationary sources.

Therefore, since January 1, 2015 the charge for emissions of HS into the atmosphere from mobile sources from legal entities and individual entrepreneurs is not provided by the legislation of the Russian Federation.

The Ministry of Natural Resources and Environmental Protection of the Russian Federation is currently preparing regulations specifying the rules for calculating, collecting and adjusting charges for negative impacts on the environment.

However, in 2014 the Russian Federation became one of the top five emitters of CO₂ emissions [5]. Annually, the country emits 1,766,000kt of CO₂ due to human activities. At the same time, a substantial fraction of these emissions derives from motor transport.

Considering the absence of Russian CO₂ emissions restrictions and the total annual level of emissions, there is a need for CO₂ emission reduction programs that applied to mobile sources. At the same time, it is necessary to take into account the peculiarities of the conditions in which Russian motor transport is operated. Therefore, according to Köppen V.P. climate classification [6], more than 70% of country consists of areas with average annual ambient temperatures below 0°C (figure 1).

Figure 1. Köppen V.P. map of climates
Gray colour corresponds to Tundra climate, Green colour corresponds to Subarctic climate, Blue colour corresponds to Humid continental climate.

Research about the influence of low ambient temperatures on the emissions of HS in the EG of vehicles has been conducted [7-9]. However, research about the influence of sub-zero ambient temperatures (SZAT) on the CO₂ emissions has not yet been undertaken. At the same time as the
The introduction of a program dedicated to decreasing and controlling CO₂ emissions in Russia, other countries with similar climatic conditions may also enact such programs. Therefore, the establishment of the level of SZAT influence on CO₂ emissions from the EG of vehicles is an urgent task.

The aim of this research is to investigate changes in CO₂ emissions in the EG of vehicles under the influence of SZAT.

2. Methodology
Experimental studies were carried out in Tyumen city on a gasoline-powered car (Mitsubishi Lancer 9). This car is one of the most popular models of foreign cars in Russia. There are currently approximately 4,000 such cars in Russia. The Mitsubishi Lancer 9 is equipped with a catalytic converter. The technical characteristics of this vehicle are presented in table 1.

| Index                | Value       |
|----------------------|-------------|
| Volume of engine     | 1584 cm³    |
| Fuel System          | Multi-point injection |
| Position of cylinders| Inline      |
| Number of cylinders  | 4           |
| Number of Gears (automatic transmission) | 4 |
| Max. weight          | 1750 kg     |
| Engine power, kW (h.p.) | (98)       |

The car was technically sound. Prior to carrying out the experiment, we ensured that the vehicle passed a routine maintenance test.

We used an AVG-4 gas analyser (Garo Company) to measure CO₂ emissions, engine speed and oil temperature.

An AVG-4 gas analyser was used to measure the volume fraction of carbon monoxide, hydrocarbons, CO₂ and oxygen in the EG of vehicles with gasoline engines. There are channels in the gas analyser for measuring the engine speed and the oil temperature. The maximum measurement error for CO₂ is ±0.5%. The operating principle of the CO₂ volume fraction sensor is optical absorption.

The instrument readings were recorded after steady-state values in the range of 15–30 seconds.

We measured ambient temperatures using a Checktemp1 (Hanna, Germany) thermometer with a measurement accuracy of ±0.5°C.

By choosing the engine operation mode, we can analyse and determine that vehicles operating in cities spend a considerable amount of time in a stationary condition when the engine of the vehicle is ticking over for various reasons, including:

1. Warming up the engine prior to driving. This warm-up time period depends on the ambient temperature.
2. Downtime in congestion. At the same time, the downtime depends on the total number of vehicles in the settlement, transport infrastructure and the time of day (downtime in anticipation of a traffic light signal, yielding to pedestrians, peak times, interpeak times, weekdays, weekends, holidays, etc.).
3. Frequent technological stops connected with downtime and the loading/unloading of passengers and (or) freight.

At the same time, the HS emitted with EG during the movement of the vehicle dissipate evenly as the car moves. However, in the case in which a car is in a steady state (e.g., congestion), HS concentrate in much larger quantity in one area (i.e., in the space of the congestion). Therefore, the
The real question pertains to rationing the amount of HS emitted with EG, in particular CO₂, while the engine of a vehicle is ticking over.

We focused on a vehicle in tick over mode with an engine speed of 800–850 rpm. The temperature of the engine (oil) was 75–80°C. The studied ambient temperatures ranged from 20–0°C. We used 92 octane gasoline.

3. Results and analysis

Figure 2 shows the results of the actual CO₂ emissions depending on the ambient temperature. Within each temperature interval, we carried out approximately 5 measurements.

![Figure 2. The influence of ambient temperature on CO₂ emissions in EG](image)

The measured regularity can be described by the model:

\[ X_{CO_2} = 15.4 - 0.03t_a, \]

where \( X_{CO_2} \) is the content of CO₂, \%; \( t_a \) is the ambient air temperature, °C.

The numeric values of the correlation coefficients is \( R=-0.97 \), and the determination coefficient is \( R^2=0.94 \).

We are able to draw the conclusion that a decrease in air temperature from 0 to -20°C results in a regular increase in CO₂ emissions. This finding can be explained by the fact that a decrease in temperature corresponds to a small increase in fuel consumption, which entails a certain increase in the harmful components in EG, including CO₂.

4 Conclusions

On the basis of the obtained data, it is possible to note that within the considerable country of Russia vehicles are operated in SZAT conditions, which leads to an increase in CO₂ emissions with EG. The lower the temperature, the higher the emission.

The introduction of a program to decrease and control CO₂ emissions is necessary must take into account the climatic features of the place in which the vehicles are operated. The regular increase in
CO₂ emissions with decreasing ambient temperatures demonstrates the need for the introduction of correction coefficients to existing standards for vehicles that are operated in SZAT. Depending on the climatic region and the average daily temperature, it may be necessary to differentiate the level of payment for environmental pollution via CO₂ emission.

To reduce the negative impact of gasoline vehicles on the environment, one can use alternative motor fuels (e.g., natural gas). In some studies, it has been noted that the operation of transport on natural gas is comparable to gasoline and achieves better environmental performance by separate components of EG, including CO₂ [10-20]. One should also take into account that CO₂ emissions associated with gaseous fuels will increase at lower temperatures.

Therefore, expanding use of natural gas use to transport in various regions of Russia will reduce the negative environmental impact of EG on the environment.

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