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COMPARATIVE ASSESSMENT OF CO_2 EMISSIONS AND FUEL CONSUMPTION IN A STATIONARY TEST OF THE PASSENGER CAR RUNNING ON VARIOUS FUELS

Introduction

The main goal of the development of the transport sector is to reduce the emission of pollutants to the environment, including CO_2, which is particularly important due to global warming. CO_2 emissions are directly related to fuel consumption. In addition, CO_2 emissions are also related to the type of fuel used in transport [1].

The hydrocarbon fuels used differ in many parameters related to CO_2 emission. The fuel consumption of a car engine is influenced by a very large group of factors [2], which include: fuel calorific value, efficiency of the engine and drive system, car weight, speed, acceleration, road gradient, transmission ratio, temperature, atmospheric pressure, humidity air, etc. These issues are the subject of many studies [3–9].

Analysis of the previous research

Efforts are being made to reduce CO_2 emissions and fuel consumption by improving the design of cars and engines to reduce energy consumption in road traffic, including by recovering some of the energy of lagging traffic in hybrid and electric drives. CO_2 reduction can also be achieved by using alternative fuels [10–13], hydrogen being the most preferred. Despite many years of research on the use of hydrogen to drive vehicles, this technology is very rarely used. The main problem limiting the use of hydrogen in cars is its production and distribution.

It should be expected that if there is an increase in hydrogen production and its distribution stations in the coming years, it will not be associated with the possibility of refueling the currently used cars equipped with internal combustion engines, which would be adapted to work by this kind of fuel. Hydrogen technology will be mainly associated with fuel cells. Therefore, to reduce CO_2 emissions from cars with internal combustion engines, the use of renewable and gaseous fuels such as LPG [3; 14] and natural gas should be developed.

Research methodology

The analysis was carried out for a passenger car, the basic technical data of which are presented in the Table 1. Based on the technical data of the car, road traffic energy consumption was calculated in the NEDC stationary test.

The value of energy consumption of traffic for individual sections of the test cycle was calculated on the basis of the equation:

$$ER_i = F_{oi}\, s_i \left[J\right] [\text{J}] \quad (1)$$

where ER_i — the energy demand of the car movement for the i-th test section [J]; F_{oi} — resistance force in the car motion for the i-th test section [N]; s_i — distance of the i-th test section [m].

Table 1

Basic technical data of the analyzed car

Data	Unit	Value
Vehicle weight	kg	1590 (for LPG – 1630, for CNG – 1670)
Vehicle reference area – A	m^2	2.17
Air drag coefficient – c_x	–	0.3
Rolling resistance coefficient – f_0	–	0.015
Rotational mass factor – δ	–	1.03
Efficiency of the transmission system η_{un}	–	0.9

The value of the resistance force to motion was calculated from the equation:

$$F_{oi} = F_{ti} + F_{bi} + F_{pi}\ [\text{J}] \quad (2)$$

where F_{ti} — car rolling resistance force for the i-th test section [N]; F_{pi} — car air resistance force for the i-th test section [N]; F_{bi} — car inertia force for the i-th test section [N].

The values of the individual resistance forces were calculated from the equations (3), (4) and (5):

$$F_{ti} = m\, g\, f_o \left(1 + 5 \cdot 10^{-5} v_i^2\right);\ [\text{N}] \quad (3)$$

$$F_{pi} = 0{,}047\, A\, c_x\, v_i^2;\ \ [\text{N}] \quad (4)$$

$$F_{bi} = m\, \delta\, a_i,\ \ [\text{N}] \quad (5)$$

where m — vehicle weight [kg]; f_0 — rolling resistance coefficient; g — gravitational acceleration [m/s^2]; v_i — average speed for the i-th test segment [km/h]; A — vehicle reference area [m^2]; c_x — air drag coefficient; δ — rotational mass factor; a_i — acceleration for the i-th test segment [m/s^2].

The values of the average total efficiency of the engine fueled with diesel fuel and gasoline were determined on the basis of the results of CO_2 emissions and fuel consumption of vehicle tests on a chassis dynamometer [3; 15]. The calculations were made on the basis of the equation:

$$\eta_{o,j} = \frac{ER_j}{G_{pal,j} W_{pal,k} \eta_{un}} \quad (6)$$

where $\eta_{o,j}$ — average overall engine efficiency in phase j (UDC, EUDC) and in the entire NEDC test, $G_{pal,j}$ — engine mass fuel consumption in phase j (UDC, EUDC) and the entire NEDC test [kg]; $W_{pal,k}$ — lower calorific value of k^{th} fuel [kJ/kg]; ER_j — total energy demand of car movement in phase j (UDC, EUDC) and for the entire NEDC test [kJ], η_{un} — average efficiency of the car transmission system.

Afterwards, estimated fuel consumption and CO_2 emissions were calculated for alternative fuels, for which a constant value of average engine efficiency, such as fueled by gasoline, was assumed. Basic data of the analyzed fuels accepted for the analysis are presented in the Table 2.

Table 2

Basic data of the analyzed fuels [16]

Data	**Fuel**						
	Petrol	**Diesel**	**Ethanol**	**Methanol**	**E85**	**CNG**	**LPG**
Density [kg/dm^3]	0.74	0.84	0.7893	0.792	0.783	0.75	0.55
Lower heating value [kJ/kg]	44000	43378	25510	17662	29430	48000	46000
Carbon mass share c_p	0.85	0.86	0.522	0.375	0.57	0.75	0.82
CO_2 emissions [Nm^3 CO_2/kg of fuel]	1.59	1.61	0.98	0.70	1.06	1.40	1.54

Results and discussion

Fig. 1 shows the cumulative energy consumption values during the NEDC test. The percentage values of energy consumption in motion for the tested car are shown in Fig. 2. The results of calculations of CO_2 emissions and fuel consumption are presented as well as Fig. 3 and Fig. 4 in Table 3.

Fig. 1, 2 show that the energy consumption of road traffic in the urban phase in the UDC test is significantly lower than in the extra-urban phase EUDC.

The absolute difference in energy consumption by road traffic in the NEDC test phases was approx 2.300 kJ.

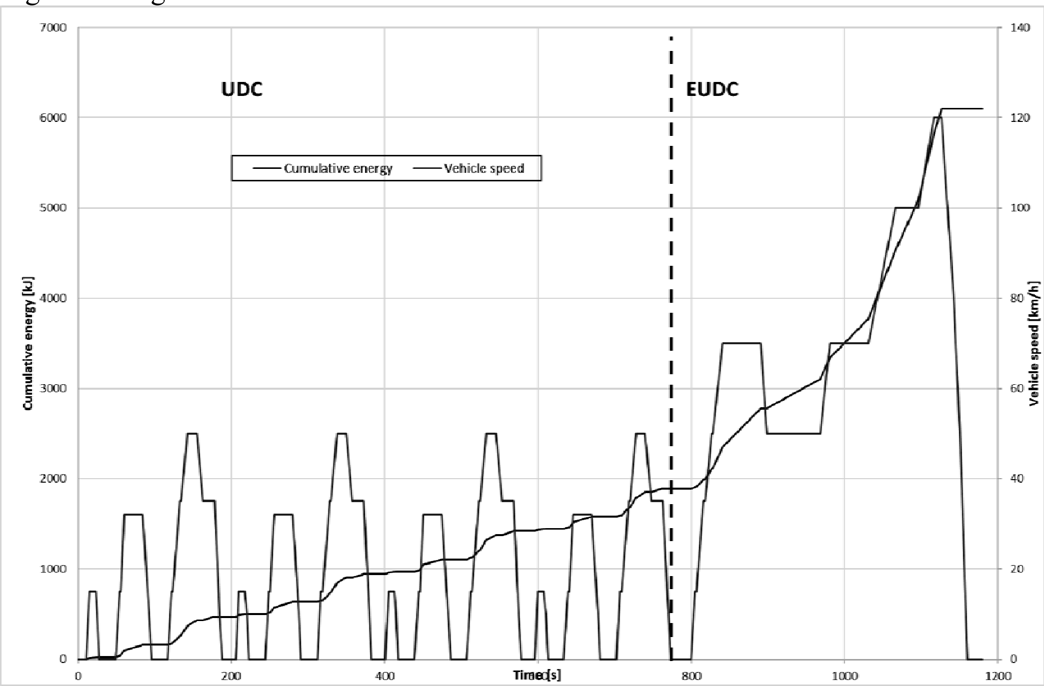

Fig. 1. Cumulative energy demand for vehicle in NEDC test

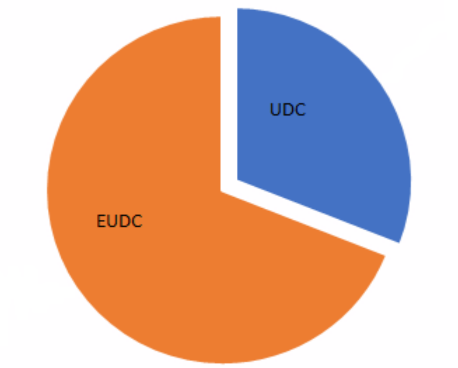

Fig. 2. The share of energy consumption in traffic of the urban phase (UDC) and the extra-urban phase (EUDC)

Table 3

CO_2 emission and fuel consumption values for a passenger car in the NEDC test using various fuels

Phase of test	Parameter	Fuel						
		Petrol	**Diesel**	**Ethanol**	**Methanol**	**E85**	**CNG**	**LPG**
UDC	CO_2 [g/km]	230.4	210.4	243.9	253.1	229.6	183.2	205.1
	Fuel consumption [dm^3/100km]	9.90	7.87	16.02	23.06	14.00	8.83 [Nm^3/100km]	12.28
	Fuel consumption [kg/100 km]	7.33	6.61	12.64	18.26	10.96	6.62	6.75
EUDC	CO_2 [g/km]	171.5	129.8	181.6	188.4	170.9	143.4	161.3
	Fuel consumption [dm^3/100km]	7.37	4.85	11.92	17.16	10.42	6.90 [Nm^3/100km]	9.66

The end Table 3

Phase of test	Parameter	Fuel						
		Petrol	Diesel	Ethanol	Methanol	E85	CNG	LPG
EUDC	Fuel consumption [kg/100 km]	5.46	4.08	9.41	13.59	8.16	5.18	5.31
NEDC	CO_2 [g/km]	190.9	161.0	202.1	209.6	190.2	160.1	179.8
	Fuel consumption [dm^3/100km]	8.20	6.02	13.27	19.10	11.59	7.71 [Nm^3/100km]	10.77
	Fuel consumption [kg/100 km]	6.07	5.06	10.47	15.13	9.08	5.78	5.92

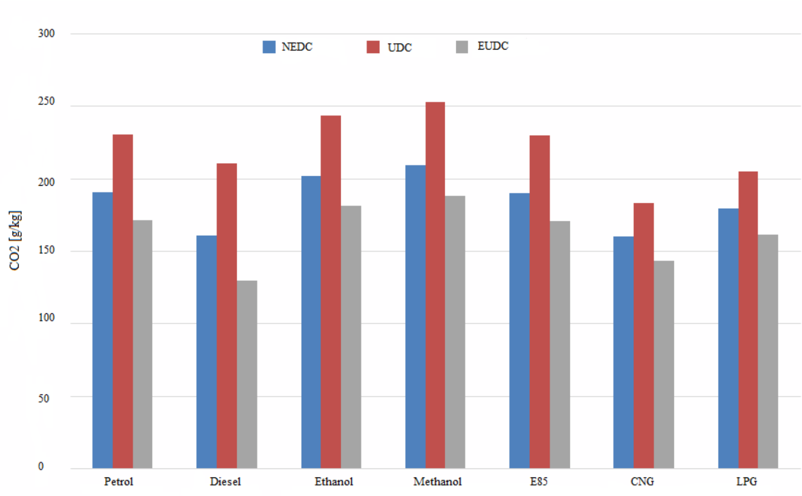

Fig. 3. CO_2 emissions for analyzed fuels by UDC, EUDC and NEDC test

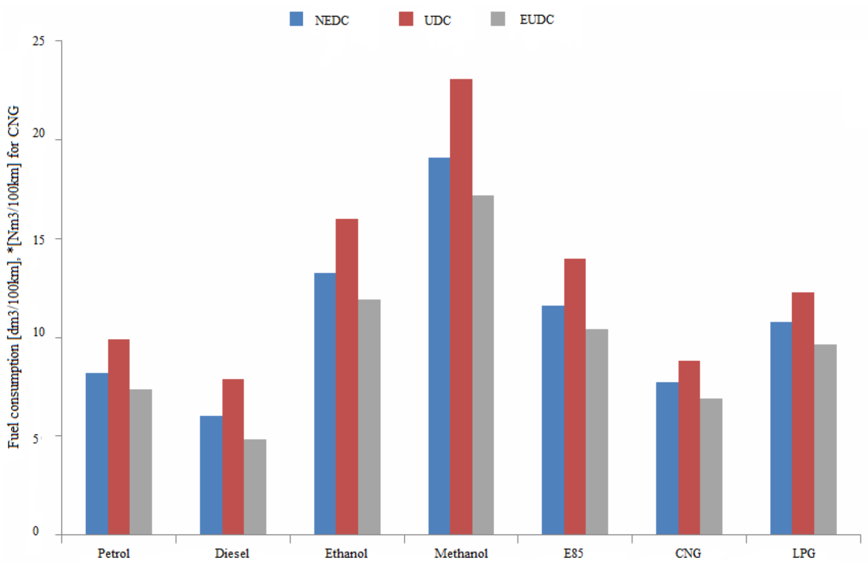

Fig. 4. Fuel consumption for analyzed fuels by UDC, EUDC and NEDC test

However, despite the lower energy consumption in road traffic, the fuel consumption and CO_2 emissions figures are higher for the UDC phase. This is mainly due to the operation of the engine in the area of lower efficiency, in the range of lower travel speeds and loads.

When analyzing the values of CO_2 emissions for the considered fuels, it can be concluded that the most advantageous fuel is CNG, for which CO_2 emissions were the lowest. For the entire test, CO_2 emissions with CNG fueling were very similar to those for diesel fuel. LPG is also a preferred fuel for spark ignition engines, for which the CO_2 emission factor for the entire test is approx. 180 g/km and is approx. 6 % lower than for gasoline. Feeding with renewable fuels: ethanol, methanol and E85 mixture is associated with higher CO_2 emission from the vehicle engine.

This is mainly due to the lower calorific value of these fuels in relation to gasoline. However, it should be borne in mind that the results for these fuels were obtained assuming the same engine efficiency value as for gasoline fueling. In practice, it is possible to obtain higher engine efficiency in relation to fueling with petrol. In addition, one should also take into account the absorption of CO_2 by plants that are a substrate for the production of renewable fuels, which reduces CO_2 emissions to the environment in the total balance.

Conclusions

Based on the research, the following conclusions can be made:

- CO_2 emission and fuel consumption in the stationary NEDC test are higher for the UDC phase, which is characterized by lower energy demand to motion in relation to the EUDC phase. It is related to the lower overall efficiency of the car engine in terms of city driving.
- The best hydrocarbon fuel for CO_2 reduction from the internal combustion engines is natural gas (CNG). CO_2 emission, assuming the same engine efficiency as when fueled with petrol, is lower in relation to fueling with petrol by approx. 16 % for the analyzed car.
- The use of ethanol and methanol is associated with higher fuel consumption and higher CO_2 emissions from the vehicle. In the case of producing these fuels from plant biomass, the total CO_2 emissions are lower due to the assimilation of CO_2 during their growth.
- The use of LPG is also a fuel more favorable from gasoline in terms of CO_2 emissions. In the case of fueling with this fuel, the estimated CO_2 emission was lower than in the case of fueling with petrol by approx 6 %.

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Яворський А., Бойченко С., Мадзіл М., Павлюх Л.

ПОРІВНЯЛЬНА ОЦІНКА ВИКИДІВ CO_2 І ВИТРАТИ ПАЛИВА ПРИ СТАЦІОНАРНОМУ ВИПРОБУВАННІ ЛЕГКОВОГО АВТОМОБІЛЯ ПРАЦЮЮЧОГО НА РІЗНИХ ПАЛИВАХ

Вступ. *Основною метою розвитку транспортного сектору є зменшення викидів забруднюючих речовин у навколишнє середовище, включаючи CO_2, що особливо важливо через глобальне потепління. Викиди CO_2 безпосередньо пов'язані зі споживанням палива. Крім того, викиди CO_2 також пов'язані з видом палива, що використовується транспортом.* ***Постановка проблеми.*** *Зусилля спрямовуються на зменшення викидів CO_2 та споживання пального шляхом вдосконалення конструкції автомобілів та двигунів для зменшення споживання енергії в дорожньому русі, в тому числі шляхом відновлення частини енергії відсталого руху на гібридних та електроприводних автомобілях. Зниження CO_2 також можна досягти, використовуючи альтернативні види палива, причому водень є найбільш перспективним.* ***Методологія дослідження.*** *Аналіз проводився для легкового автомобіля. На основі технічних даних автомобіля в стаціонарному тесті NEDC було розраховано споживання енергії в дорожньому русі.* ***Результати та обговорення.*** *У статті представлений порівняльний аналіз споживання палива та викидів CO_2 для легкового автомобіля з двигуном внутрішнього згоряння, що працює на традиційних та альтернативних видах палива. Аналіз розроблений за тестом NEDC. На основі розрахованого опору руху та енергоспоживання руху, а також для фактичних результатів випробувань, проведених на динамометрі шасі автомобіля, що працює на бензині та дизельному паливі, були визначені приблизні значення ККД двигуна. Потім були проведені розрахунки викидів CO_2 та споживання палива для наступного: СПГ, зріджений газ, етанол, метанол та E85.* ***Висновки.*** *Як випливає з результатів дослідження, проведеного для окремих фаз UDC та EUDC, споживання палива та викиди CO_2 не в кожному випадку прямо пропорційні енергоспоживанню руху автомобіля. Найкращим вуглеводневим паливом для зниження викидів CO_2 у двигунах внутрішнього згоряння є природний газ (СПГ). Викиди CO_2, при такому ж ККД двигуна, як і при заправці бензином, нижчі чим при заправці бензином приблизно на 16 % для аналізованого автомобіля.*

Ключові слова: легковий автомобіль; традиційні види палива; альтернативні палива; викиди CO_2.

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COMPARATIVE ASSESSMENT OF CO_2 EMISSIONS AND FUEL CONSUMPTION IN A STATIONARY TEST OF THE PASSENGER CAR RUNNING ON VARIOUS FUELS

Introduction. *The main goal of the development of the transport sector is to reduce the emission of pollutants to the environment, including CO_2, which is particularly important due to global warming. CO_2 emissions are directly related to fuel consumption. In addition, CO_2 emissions are also related to the type of fuel used in transport.* ***Problem statement.*** *Efforts are being made to reduce CO_2 emissions and fuel consumption by improving the design of cars and engines to reduce energy consumption in road traffic, including by recovering some of the energy of lagging traffic in hybrid and electric drives. CO_2 reduction can also be achieved by using alternative fuels, hydrogen being the most preferred.* ***Research methodology.*** *The analysis was carried out for a passenger car. Based on the technical data of the car, road traffic energy consumption was calculated in the NEDC stationary test.* ***Results and discussion.*** *The article presents a comparative analysis of fuel consumption and CO_2 emissions for the passenger car with an internal combustion engine powered by traditional and alternative fuels. The analysis was developed on the NEDC test. On the basis of the calculated resistance to motion and energy consumption of motion, as well as for the actual results of tests carried out on the chassis dynamometer of a car powered by gasoline and diesel fuel, approximate values of the engine efficiency were determined. Then, calculations of CO_2 emissions and fuel consumption were carried out for the following: CNG, LPG, ethanol, methanol and E85.* ***Conclusions.****As it results from the research carried out for individual UDC and EUDC phases, fuel consumption and CO_2 emission are not in each case directly proportional to the energy consumption of the car movement.The best hydrocarbon fuel for CO_2 reduction from the internal combustion engines is natural gas (CNG). CO_2 emission, assuming the same engine efficiency as when fueled with petrol, is lower in relation to fueling with petrol by approx. 16% for the analyzed car.*

Keywords: passenger car; traditional fuels; alternative fuels; CO_2 emissions.

Яворский А., Бойченко С., Мадзил М., Павлюх Л.

СРАВНИТЕЛЬНАЯ ОЦЕНКА ВЫБРОСОВ CO_2И РАСХОДА ТОПЛИВА ПРИ СТАЦИОНАРНОМ ИСПЫТАНИИ ЛЕГКОВОГО АВТОМОБИЛЯ РАБОТАЮЩЕГО НА РАЗЛИЧНОМ ТОПЛИВЕ

Введение. *Основная цель развития транспортного сектора - снизить выбросы загрязняющих веществ в окружающую среду, в том числе CO_2, что особенно важно в связи с глобальным потеплением. Выбросы CO_2 напрямую связаны с расходом топлива. Кроме того, выбросы CO_2 также связаны с типом топлива, используемого на транспорте.* ***Постановка задачи.*** *Предпринимаются усилия по сокращению выбросов CO_2 и расхода топлива за счет улучшения конструкции автомобилей и двигателей с целью снижения потребления энергии в дорожном движении, в том числе за счет рекуперации части энергии отстающего движения в гибридных и электрических приводах. Снижение выбросов CO_2 также может быть достигнуто за счет использования альтернативных видов топлива, наиболее предпочтительным из которых является водород.* ***Методология исследования.*** *Анализ проводился для легкового автомобиля. На основании технических данных автомобиля в стационарном тесте NEDC было рассчитано потребление энергии дорожным движением.* ***Результаты и обсуждение.*** *В статье представлен сравнительный анализ расхода топлива и выбросов CO_2 для легкового автомобиля с двигателем внутреннего сгорания на традиционном и альтернативном топливе. Анализ был разработан на основе теста NEDC. На основании расчетного сопротивления движению и энергозатратности движения, а также фактических результатов испытаний, проведенных на динамометрическом стенде автомобиля, работающего на бензине и дизельном топливе, были определены приблизительные значения КПД двигателя. Затем были проведены расчеты выбросов CO_2 и расхода топлива для следующих компонентов: КПГ, СНГ, этанол, метанол и E85.* ***Выводы.*** *Как следует из исследований, проведенных для отдельных фаз UDC и EUDC, расход топлива и выбросы CO_2 не в каждом случае прямо пропорциональны потреблению энергии при движении автомобиля. Лучшим углеводородным топливом для снижения выбросов CO_2 в двигателях внутреннего сгорания является природный газ (СПГ). Выбросы CO_2 при таком же КПД двигателя, как и при заправке бензином, ниже, чем при заправке бензином, прибл. на 16 % для анализируемого автомобиля.*

Ключевые слова: легковой автомобиль; традиционные виды топлива; альтернативные топлива; выбросы CO_2.

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