Assessment of car emission masses at the change of kinetic energy of the "engine – transport vehicle" system

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Abstract. Negative anthropogenic impact on the environment can lead to global changes in the natural cycle of substances in the biosphere and the climate change in general. Assessment of the mobile sources emission is an important component of the diagnosis of the urbanized landscapes ecosystem state. The effective power of the car engine is accepted as the characteristic unambiguously reflecting the movement of the vehicle. The algorithm of determination of pollutants emission masses is stated in the article and unique calculation of relative effective power of the engine is presented. The current value of the engine effective power taking into account transformation of variable parameters to the coded sizes depending on kinematic and dynamic factors is calculated from the equation of the car movement at the change of kinetic energy of the "engine - transport vehicle" system in the form of Lagrange. Such dynamic characteristics as coefficient of the rotating masses and coefficient of mechanical efficiency of transmission are presented by functions of the engine relative effective power. Results of the research considerably simplify calculation of pollutants emission masses by traffic flow into the atmosphere and can be used for assessment of negative anthropogenic impact on the ecosystem.

1 Introduction

Reliable information about emission of pollutants by mobile sources is necessary for adoption of administrative decisions in the sphere of ecological management, assessment of efficiency of environmental protection actions, monitoring of ecological-and-economic damage to ecosystems of the urbanized landscapes. Assessment of emission masses by vehicles is a relevant and difficult task demanding improvement of methods of mathematical modeling of the car movement. Authors offer a method of calculation of mass of pollutant depending on the characteristic of transport work of the car, available to operating control, – the effective power of the engine.

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2 Methods

The techniques of assessment of motor transport emission accepted in the western countries and the Russian Federation [1] are approximately identical. Calculations of "the power of emissions" are based on very inexact empirical average values of consumption of fuel (the simplified approach) or on specific "pro-running" emissions of pollutants, far from reality, depending on characteristics of traffic flows.

Based on theoretical and pilot studies of regularities of car engines emission of pollutants [2], it is expedient to accept the following procedure of operations for finding mass of pollutant in emissions of cars:

1. Calculation of a volume consumption of the engine fulfilled gases, m^3/s , depending on the available and easily determined parameter characterizing transport work of the car.
2. Representation of concentration of pollutant in the fulfilled gases, g/m^3 , by the function of the parameter characterizing transport work of the car.
3. Determination of the car emissions mass, g/s , by multiplication of the volume consumption of the fulfilled engine gases by the concentration of pollutant in the fulfilled vehicle gases.
4. Calculation of cumulative issue of pollutant, g/s (kg/s or ton/year), (mass of emissions of the cars operated on the site of a street road network and in general in the city are summarized).

Performance of the presented algorithm is nowadays complicated by the fact that:

- for calculation of the volume consumption of the fulfilled gases indicators of the engine operation, difficult for expeditious definition, are used [3, 4];
- the "theoretical" data on the content of pollutants in emission products which are a little deserving attention are, as a rule, based on arrays of experimental information untied among themselves and depend on technical characteristics of the concrete engine, term and service conditions, brands of the engine, its state, etc.;
- concentration of pollutant in the fulfilled gases is expressed depending on parameters of operation of the engine, inconvenient for registration, for example, of the effective pressure of gases in the cylinder [3], specific effective fuel consumption [4], indicator efficiency of the engine [5], etc.;
- cumulative emission on the site of road transport network of vehicles, different in characteristics, is calculated approximately and depends on intensity of traffic and density of a stream of mobile sources, etc.

In order to avoid the above-mentioned methodological mistakes, it is necessary to employ the understanding of process of the atmospheric air pollution by vehicles. At the heart of determination of the parameter unambiguously characterizing work of a mobile source of emission of pollutants the following model is considered: operation of the car is followed by violation of balance between the effective power of the engine and power spent by the consumer (in this case, the road). Change of power setting and uneven fuel consumption is a consequence of lack of balance of the capacities mentioned. At the same time indistinct operation of the fuel equipment leads to creation of harmful chemical compounds in the products of emission and, as a result, to additional environmental pollution. Thus, the most convenient characteristic reflecting the movement of the vehicle and implementation of the scheme of calculation of emission of pollutants given above is the effective power of the car engine.

It is convenient to represent values of the changing factors in relative units. This form of transformation of full sizes to a numerical scale allows to display variables with easily interpreted functions and to reduce dispersion of characteristics of the cars of traffic flow.

The current value of the effective power of the engine depending on kinematic and dynamic factors considering transformation of variable parameters into the coded sizes is calculated with the equation of the movement of the car at change of kinetic energy of the "engine – transport vehicle" system in the form of Lagrange [2]

$$\bar{N} = \frac{\left[k_{\phi} \rho_b F_s v^2 + mg \cos \gamma (f \pm \operatorname{tg} \gamma) \pm \delta_{\text{ap}} a m \right] v}{\eta_{\text{tp}} (N_{\text{max}} - N_{\text{min}})} - \frac{N_{\text{min}}}{N_{\text{max}} - N_{\text{min}}}, \quad (1)$$

where $\bar{N}$, N_{max} and N_{min} – are relative, maximum, W, and minimum, W, engine capacities; k_{ϕ} – the stream-lining coefficient; ρ_b – density of air, kg/m³; F_s – area of the front surface of the car, m²; v – speed of the car, m/s; m – mass of the car, kg; g – acceleration of gravity, m/s²; γ – angle included between the surface of the road and the horizontal plane, degrees; f – coefficient of resistance to roll; δ_{ap} – coefficient of accounting of the rotating masses; a – acceleration of progressively moving masses of the car, m/s²; η_{tp} – mechanical efficiency of transmission.

The minus sign in (1) before $\operatorname{tg} \gamma$ and $\delta_{\text{ap}} a m$ is put at the downward movement and at negative value of acceleration of progress (the movement with deceleration) respectively. Parameters k_{ϕ} , F_s , m , g , γ , f , N_{max} , N_{min} are constant values (help data), a v , a , δ_{ap} , η_{tp} – variables.

Depending on the goal and opportunities of the researcher two versions of calculating $\bar{N}$ are offered.

3 Results

3.1 Acceleration of the car is unknown

This option of calculation of emission of pollutants by traffic flow can be used at any stage of implementing eco-protective actions as specification of the city vehicle fleet and individual characteristics of cars aren't required. Average speed of traffic flow is calculated by means of, for example, the Yandex.Traffic Jams Internet resource. On the basis of this preliminary statistical research the values of characteristics of a street road network and traffic flow of the concrete territory are detected. Dependences of concentration of pollutants in the emission products and also variables characterizing operation of engines from $\bar{N}$ on types of engines and the main consumer sign of cars have the general character and are established from available sources of information [4,5].

In this case it is convenient to consider not separately δ_{ap} but the result of multiplication of $\pm \delta_{\text{ap}} a$, which can be presented by the known formula

$$\pm \delta_{\text{ap}} a = g (D - \Psi), \quad (2)$$

where D is the dynamic factor of the car (its dependence on the speed of the movement is displayed graphically and is called dynamic characteristic of the car); Ψ is the coefficient of the specified road resistance. Values of the dynamic factor of some cars are given in reference books [4, 6].

Authors managed to solve the problem of definition $\pm\delta_{bp}a$ with accuracy, sufficient for practical calculations. For this purpose, dynamic characteristics have been carried out through the vicinity of the points corresponding to the sizes of dynamic factors of cars on each transfer. Analytical expressions of the approximated graphic functions (3 – 5) and the formula (6 – 8) for calculation of dependences are presented in the table 1 [7].

Table 1. Formulas for calculating the dynamic factor and $\pm\delta_{bp}a$

<i>D</i>	<i>R</i> ²	№ of formula	$\pm\delta_{bp}a$	№ of formula
Cars				
$2,023v^{-1,0678}$	0,9969	3	$g(2,023v^{-1,0678} - \Psi)$	6
Minibuses				
$1,6851v^{-1,3825}$	0,9804	4	$g(1,6851v^{-1,3825} - \Psi)$	7
Trucks and buses				
$0,5502v^{-1,11}$	0,9481	5	$g(0,5502v^{-1,11} - \Psi)$	8

*R*² – a square of the mixed correlation.

Detection of the mechanical efficiency of transmission is shown below.

3.2 Acceleration of the car is known

This option is applied at organized collection of information about emissions of pollutants from each car. *a*, *v* and γ , are estimated by means of the special sensors using the systems of navigation, for example, GLONASS or GPS. Dependences of change of characteristics of the engine operation and content of pollutants in the fulfilled gases from the $\bar{N}$ concrete car are established experimentally. Cumulative pollution of the street road network of the city is defined by the subsequent summation of emission of the motor transportation stream participants.

Taking into account the known formulas of mechanics and the current value of frequency of rotation of the engine shaft in relative units we will represent δ_{bp} in the following form [2]

$$\delta_{bp} = 1 + \frac{J_d \eta_{tp} \left(\frac{2\pi [\bar{n} (n_{max} - n_{min}) + n_{min}] r_k}{v} \right)^2 + \sum J_k}{mr_k^2}, \tag{10}$$

where J_d and $\sum J_k$ – are the moments of inertia of the rotating masses of the engine, transmission and wheels respectively (the moment of inertia of the transmission we neglect owing to the small importance of size), kg/m²; $\bar{n}$, n_{max} , и n_{min} – relative, maximum, s⁻¹, and minimum, s⁻¹, frequencies of rotation of the engine shaft; r_k – radius of swing of driving wheels considering sinking of the tire in the zone of contact with the road surface, m. Constant values J_d , $\sum J_k$, n_{max} , n_{min} , r_k are known for each car.

For simplification of determination δ_{bp} (with η_{tp} known), it is expedient to represent $\bar{n}$ by functions from $\bar{N}$. Such dependences can be received experimentally for each car or for types of car engines on the basis of the known experimental and calculated data [2].

3.3 The accepted assumptions and shortcomings of determination of coefficient of the rotating masses assuming approximate result [8]

1. Definition of a dynamic factor is based on the assumption that at engaging the clutch the fuel supply pedal is instantly squeezed out to the full (rated power of the engine is reached at once).

2. The moments of inertia of the rotating masses and pliability of shafts are determined experimentally (by swing of masses) and theoretically (by calculation). In both cases variations are possible.

3. For the assessment of δ_{bp} it is accepted that all rotating masses of the car fluctuate on shafts synchronously. It is acceptable if shafts are considered absolutely rigid.

3.4 Finding the mechanical efficiency of transmission

The completeness of energy transmission from the engine to driving wheels is caused by a set of factors. Losses depend on the value of transferred moments, the speed of details rotation, oil temperature in reducers, etc. [7]. Analytically η_{tp} is represented with the function of the efficiency factor of couples of cogwheels and the cardan hinges participating in torque transmission to driving wheels of the car and coefficient of the ratio of idling torque to nominal torque.

In this way estimating η_{tp} is quite difficult.

1. At least, estimating the number of couples of cogwheels and cardan hinges participating in torque transmission from the engine to driving wheels of the car directly in the movement is inconvenient.

2. Finding the value of the coefficient considering an idling torque share from nominal torque for the moving vehicle is difficult.

3. It is senseless to mention the nominal torque of the engine: the minimum value of effective torque corresponds to the nominal frequency of rotation of the engine; the maximum value of effective torque doesn't coincide with the idling mode.

The analysis of sources of information has revealed preferences of researchers [8 – 10] in establishing the correlation between η_{tp} and relative torque ($\bar{M}$) which in its turn is the function of $\bar{N}$. The authors' research [2] has allowed to interpret and approximate graphically dependences η_{tp} from $\bar{N}$.

4 Discussion

According to modern ideas of the process of vehicles pollution of atmosphere the most logical algorithm of finding the mass of pollutant in the cars emissions is offered. The effective power of the car engine is accepted as the characteristic which unambiguously reflects the movement of the vehicle and implementation of the submitted scheme of calculation of pollutants emission. The original interpretation of the formula for calculating the current value of effective power at change of kinetic energy of the "engine - transport vehicle" system in the form of Lagrange is offered. Transformation of variable parameters to the coded sizes and dependences of dynamic factors (coefficient of accounting of the rotating masses and mechanical efficiency of transmission) on the relative effective power of the engine leads expression (1) to the equation of the 4th degree the solution of which is

possible when using software, for example, Mathcad. Thus, determination of emission masses of pollutants is reduced to finding the relative engine capacity.

5 Conclusion

The experiments executed on models with the use of computer program and numerical values of pollutant masses released into the air basin by a motor transportation stream with an error, admissible for practical calculations, reflect the nature of anthropogenic impact on the city ecosystem and can serve as preliminary estimate of the environmental pollution state.

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