2018-01-1759 Published 10 Sep 2018

The Choice of a Rational Type of Fuel for Technological Vehicles

Victor Zaharchuk Lutsk National Technical University

Igor V. Gritsuk Kharkov National Auto and Highway University

Oleg Zaharchuk Lutsk National Technical University

Andrii Golovan Odessa Naitonal Maritime University

Sergey Korobka Lviv National Agrarian University

Larisa Pylypiuk Lutsk National Technical University

Nickolay Rudnichenko Odessa Naitonal Maritime University

Citation: Zaharchuk, V., Gritsuk, I.V., Zaharchuk, O., Golovan, A. et al., "The Choice of a Rational Type of Fuel for Technological Vehicles," SAE Technical Paper 2018-01-1759, 2018, doi:10.4271/2018-01-1759.

Abstract

The article deals with the results of experimental and theoretical studies of the technological vehicle during its work on various types of fuel.

The purpose of the work is to choose a rational type of fuel or an energy source for vehicles according to one general criterion.

The feature of the proposed methodology is that the indicators of fuel and engine are estimated by the criterion of adaptability of technique to a particular type of fuel. A new approach to environmental safety assessment of technological vehicles while working on different fuels by environmental criterion taking into account the amount of emissions of harmful substances, their maximum permissible concentrations and hazard class.

The economic efficiency in the operation of vehicles on alternative fuels is estimated by the criterion of economic efficiency.

Fuel consumption and emissions of harmful substances of the engine 4FS 11.0/12.5 at various speed and loading modes when working on different fuels were determined in the experimental method. The obtained characteristics of the engine for their use in the mathematical model of motion of the vehicle were described by polynomial dependencies.

Quantitative values of fuel consumption and emissions of harmful substances in the process of moving a technological vehicle for a ride cycle using various types of fuels were obtained by method of mathematical modeling.

The analysis helps to define the efficient type of the fuel in accordance with the above mention criteria. Natural gas has the greatest value for choosing the appropriate fuel type. Less criterion is used for biodiesel fuel, the lowest value criterion is appropriate for petroleum diesel fuel.

Introduction

A large fleet of wheeled vehicles and mobile agricultural machinery with engines working on diesel fuel of petroleum origin is in the world today. But the cost of diesel fuel is increasing and the environmental situation in the world is deteriorating. The adaptation of diesel engines to work on alternative fuels is one of the main ways out of this situation [1, 2, 3].

The possibility of using a certain type of alternative motor fuel (AMF) is determined by its regional resources, the price ratio between alternative and traditional fuels, costs of adaptation engines to work on the AMF, for the delivery, storage and refueling of equipment.

A significant part of universal wheeled tractors, in particular class 1.4, is used as a technological transport in agricultural production, utilities and industry for their getting into closed buildings and long-term work in these buildings. Maximum permissible concentrations of harmful emissions in the exhaust gases of the engine exceed the norm after several minutes of their operation in closed building [4]. Alternate motor fuels can be used to reduce this negative phenomenon.

Analysis of Literary Data

The priority for alternative motor fuels belongs to biofuels based on vegetable oils and gas fuels [5, 6] for vehicles. The economic efficiency of using natural gas and biodiesel fuels in agricultural machinery is proved in the monograph [5]. The ecological efficiency of gas fuels when used in trucks with engines transmitted from gasoline to gas, is confirmed in the monograph [6]. A significant number of works to research of indicators of vehicles at their work on alternative motor fuels was completed in Ukraine. In particular, at the National Transport University, at the Kharkiv National Automobile and Road University, at the Kharkiv Polytechnic Institute [7, 8, 9]. Information on improving the environmental indexes of diesel engines when working on natural gas and biodiesel is presented in the monographs [7, 8]. The possibility of increasing the ecological safety of automobiles due to structural changes in engines, as well as through the use of gas fuels, is considered in work [9]. However, complex researches of energy, ecological and economic indicators of vehicles at their work on different types of fuel are absent currently.

The Aim of the Study

The purpose of the work is to choose a rational type of fuel for technological vehicles.

Materials and Methods of Researches

Application of system principles allowed to carry out research of the process of exploitation of auto tractor machinery on the alternative motor fuels on the model of the operating system "fuel-engine-vehicle" [8]. A certain type of fuel is fed to the system's entrance. This fuel is characterized by its elemental composition, lower heat of combustion, price and other indicators. The general criterion of choice of fuel is the output of the system. System analysis has shown that the methodology for selecting alternative fuels should be based on the estimation by different criteria [7]. Researchers agree that the most important criteria are: adaptation criterion, ecological safety of the vehicle and the economic efficiency of operation [5, 6, 7], which includes the general criterion of choice of fuel.

The task of selecting a fuel for vehicle leads to optimization of the parameters of the operating system in the general case "fuel- engine-vehicle". It is necessary to find such values $x_1,\ldots,x_m$, $y_1,\ldots y_n$, $z_1,\ldots, z_k$, in which the condition is fulfilled:

$$F\left(x_1,\ldots,x_m,y_1,\ldots,y_n,z_1,\ldots,z_k\right)\rightarrow \max \qquad (1)$$

Where,

$x_i \in X$ = set of fuel parameters;

$y_i \in Y$ = set of engine parameters;

$z_i \in Z$ = set of vehicle parameters, or prove that such values on the set as $X \in Y \in Z$ (definition area of system parameters "fuel-engine-vehicle") do not exist.

System objects of the system "fuel-engine-vehicle" are characterized by a large number of parameters. All these parameters are very difficult to take into account during the study. Therefore, the method of the priori ranging determined the most important of them, in particular, for the subsystem "engine" is power and fuel consumption.

The general methodology of the choice of motor fuels for technological vehicles was developed for the first time by one criterion in the work. This criterion includes the criterion of adaptability of K_a of system to alternative motor fuels, the criterion of ecological safety of K_e of vehicle and the criterion of economic efficiency of operation of K_{ee}. Structural scheme of the method of choice of motor fuels was shown in Figure 1.

The adaptation criterion is used to evaluate the energy indicators and fuel consumption by engine on different types of fuel. This criterion is determined on the basis of the method of analysis of hierarchies (MAH) T. Saati.

This method can solve the problem of multicriteria optimization with a sufficiently large number of optimality criteria [10]. The objects of researches are estimated by pairwise comparison with the help of the developed mathematical matrix model with application of a set of criteria. These criteria are chosen depending on the tasks and problem areas and have different levels of detailing (Figure 2).

The relative value of each criterion is compared with the relative importance of any other criterion (element) using the hierarchy analysis method. This element is implemented by mathematical matrix model. The comparison is carried out by calculating its own vector by lines, calculating and normalizing of the priority vector. The index of consistency and the relation of consistency are used to evaluate consistency in the method of analysis of hierarchies. The final stage of the method of analysis of hierarchies

FIGURE 1 Structural scheme of the method of choice of motor fuels

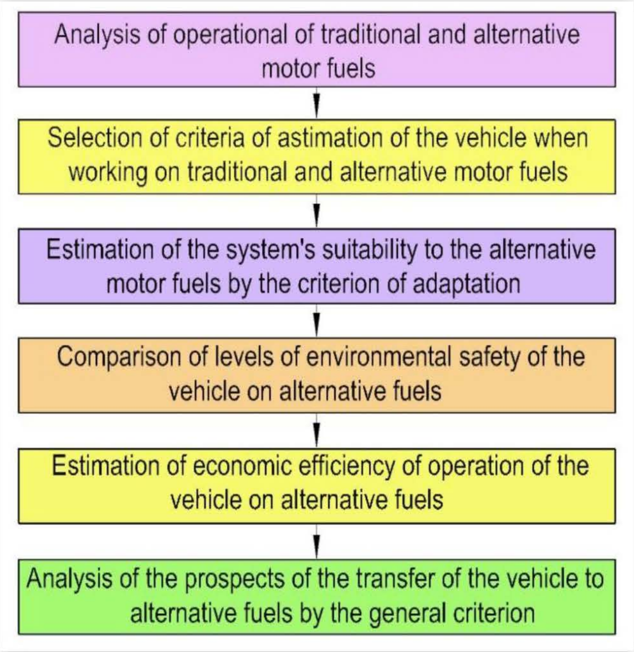
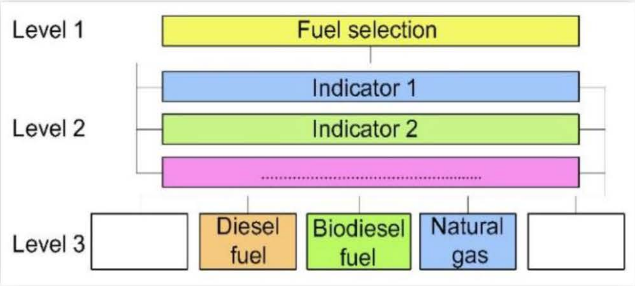


FIGURE 2 The structure of the subsystem hierarchy "fuel" and "engine"



is the calculation of the criterion of adaptability of technique to different fuels:

$$K_a = \sum_{i=1}^{i=n} x_i \cdot \varphi_i, \tag{2}$$

Where,

x_i = the vector of the priority of a certain evaluation criterion obtained by paired comparison of the relative importance of the criteria on the second level in relation to the general purpose on the first level;

φ_i = the vector of the priority of a certain object of researches obtained by paired comparison of the relative importance of the research objects on the third level (double comparison of research objects) in relation to the criteria of the second level.

The connection between the useful work (power) of the engine and the amount of heat spent for its obtaining was used to calculate the engine power. The fuel efficiency of the engine is estimated by the specific effective fuel consumption in the energy units.

Evaluation of environmental properties of technological vehicles working on alternative and basic types of fuel is carried out taking into account sanitary norms [11]. It is carried out by criterion of environmental adaptability of the engine to alternative fuels in the first stage [11]:

$$EA = \frac{1}{n} \sum_{i=1}^{n} (K_i)^{\alpha_i} = \frac{HCV}{HCV_b}, \tag{3}$$

Where,

HCV = is a hazard category of the vehicle that operates on alternative fuel, m^3/s;

HCV_b = is a hazard category of the vehicle that operates on base fuel, m^3/s

$$HCV = \sum_{i=1}^{n} HCS_i = \sum_{i=1}^{n} \left(\frac{M_i}{MPC_i} \right)^{\alpha_i}, \tag{4}$$

Where,

HCS = is category of danger of a certain substance, m^3/s;

M_i = amount of emissions of a certain substance, g/s, the values of which are obtained on the basis of the data on road emissions, g/km, obtained by calculations using mathematical models of motion of the vehicle by driving cycle;

MPC = average daily maximum permissible concentration of a certain substance, g/m^3;

α_i = dimensionless constant, which makes it possible to compare the hazard classes of a certain substance and sulfur dioxide (the third class of danger);

n = amount of harmful substances in exhaust gases.

In fact, HCV shows what volumes of air should be fed into the premises per unit time so that harmful substances present in the atmosphere can be diluted to safe concentrations. The value of the daily average maximum permissible concentration (MPC) in air and the hazard class of the main harmful substances are given in the Table 1.

The indicator of environmental hazard of the vehicle, working on an alternative fuel is determined at the second stage.

$$K_{eh} = EA \cdot K_b, \tag{5}$$

Where,

K_b = indicator of environmental hazard of the vehicle, working on base fuel.

Environmental safety criterion

$$K_e = \frac{1}{K_{eh}}. \tag{6}$$

The economic efficiency of the use of alternative motor fuel is estimated by the criterion of economic efficiency

$$K_{ee} = \frac{E_{sc}}{C}, \tag{7}$$

Where,

C = capital costs for conversion of the vehicle to use alternative motor fuel;

E_{sc} = operating cost saving when using alternative motor fuel.

Basically, the operating cost saving is due to low cost of fuels or less its consumption.

The combination of individual criteria in the general criterion of the optimal fuel type is as follows:

$$K = \varphi_1 K_a + \varphi_2 K_e + \varphi_3 K_{ee}, \tag{8}$$

Where,

φ_1, φ_2, φ_3 = weight coefficients of the criteria of adaptability of technique to alternative motor fuel, ecological safety and economic efficiency of operation of vehicles on different fuels ($\sum \varphi_i = 1$).

The results of expert assessments were used to evaluate the importance of individual criteria [9]. The greatest importance is taken for the environmental safety criterion (0,38…0,42), somewhat lower values (0,28…0,32) have: criterion of adaptability and criterion of economic efficiency of operation. The condition must be fulfilled in order to determine the fuel with the best indicators and evaluate its properties: $K \rightarrow max$.

TABLE 1 The value of the permissible concentration in the atmosphere and the hazard class of the main harmful substances

Substance	Hazard class	Daily average MPC, ml/m^3
Carbon oxide CO	IV	3,0
Hydrocarbons CH	IV	1,5
Nitrogen oxides NO_x	II	0,04
Smoke S	II	0,05

Research Results

The effective engine power and heat rate per unit of effective power at the 4FS 11,0/12,5 engine at nominal mode for various fuels were determined by calculation to assess the adaptability of the vehicle to a certain type of motor fuel (Table 2).

Complex estimation of operational indicators of alternative motor fuels and indicators of engine for the purpose of determining the adaptability criterion was performed by using the method of analysis of hierarchies and mathematical matrix model. Evaluation indicators of motor fuels were shown in Table 3.

Fuel indicators and engine indicators are estimated indicators of fuel and energy properties. These indicators were given in Table 4: A1 - sufficiency of resources and the possibility of mass production of fuel; A2 - energy indicators of the engine when working on this fuel; A3 - detonation resistance of fuels and the tendency to self-ignition; A4 - fuel price; A5 - specific effective fuel consumption by the engine in energy units; A6 - energy consumption of fuel production; A7 - safety in use.

TABLE 2 Energy and fuel-economic indicators of the engine 4FS 11,0/12,5 during the work on different fuels

Fuel	Effective engine power N_e, kWt	Specific effective fuel consumption g_e, MJ/kWt hour
Diesel fuel	56	8
Biodiesel	54	9
Natural gas	57,2	10,2

TABLE 3 Evaluation indicators of motor fuels

Indicator	Fuel		
	DF	BDF	CNG
The sufficiency of resources and the possibility of mass production	–	+/–	+/–
Lower heat of combustion MJ/kg (MJ/m^3)	42,5	38,3	38
Detonation stability (octane number) or propensity for self-ignition (cetane number)	45	49	110-125
Price, UAH / l (UAH/m^3) at the beginning 2018	27,2	25,7	16,8
Environmental qualities (environmental impact)	–	+	+/–
Energy costs of production	–	+	+
Safety in use	+/–	+	+/–

Note: « + » = presence of advantages in comparison with diesel oil fuel;
«-» = absence of advantages in comparison with diesel oil fuel;
«+/–» = combination of advantages and disadvantages.
DF = diesel fuel, BDF = biodiesel fuel, CNG = compressed natural gas.

The highest value of the criterion is natural gas according to the results of calculations of the criterion of adaptability of the technique to different fuels (Table 5).

Road fuel consumption and road emissions of the harmful substances of the technological vehicle (tractor MTZ-80) during the work on different fuels were determined by mathematical modeling. Comparison of fuel and economic and ecological indicators of engines during the work on different fuels was carried out according to experimental load and speed characteristics, described by polynomial models (Figure 3).

The researches were conducted on the basic diesel 4FS 11,0/12,5 during its work on petroleum diesel and biodiesel fuel - isopropyl ether of rape oil and also on the gas engine converted from diesel 4FS 11,0/12,5 with spark ignition during its work on natural gas. The gas engine with spark ignition converted from diesel 4FS 11,0/12,5 was shown in the Figure 4 as an example.

Hourly fuel consumption, air and content of harmful substances in the exhaust gases of all types of engines while operating in self-idling mode are satisfactorily described by polynomials of the second degree, depending on the idle speed engine n_e. The indicators are determined during the engine operation with spark ignition on gas fuel in the loading modes in function of two variables: frequency of rotation of the crankshaft of the engine n_e and rarefaction in the intake manifold Δp_m. Diesel indicators in the loading modes are described by polynomials depending on n_e and torque of the engine M_e.

For example, indicators of diesel while working on biodiesel fuel and its mixes with petroleum fuel (air consumption G_{air}, fuel consumption G_f, concentration of harmful substances in exhaust gases: carbon oxide CO, hydrocarbons CH, nitrogen oxides NO_x and smoke *S*) are described by polynomials of the third order:

$$\begin{aligned} G_f, G_{air}, CO, CH, NO_x = A_0 - A_1 n_e M_e^2 - A_2 C_{bdf} M_e^2 - \\ - A_3 M_e^3 + A_4 M_e^2 - A_5 n_e C_{bdf} M_e + A_6 C_{bdf}^2 - \\ - A_7 C_{bdf} M_e + A_8 M_e - A_9 n_e M_e + A_{10} n_e^2 M_e + \\ + A_{11} n_e C_{bdf}^2 + A_{12} C_{bdf}^3 + A_{13} C_{bdf}^2 - A_{14} C_{bdf} - \\ - A_{15} n_e^2 C_{bdf} + A_{16} n_e^2 C_{bdf} - A_{17} n_e + A_{18} n_e^2 - A_{19} n_e^3, \end{aligned} \tag{9}$$

TABLE 4 Paired comparison of estimated indicators of motor fuels

Criteria of evaluation	A1	A2	A3	A4	A5	A6	A7	The vector of priority *(x_i)*
A1	1	1/5	6	4	1/7	1/6	1/6	0.14
A2	5	1	1/3	6	1/2	1/4	1/5	0.14
A3	1/6	3	1	3	5	1/4	1/3	0.14
A4	1/4	1/6	1/3	1	1/6	1/3	1/4	0.11
A5	7	2	5	6	1	5	1/2	0.16
A6	6	4	4	3	1/5	1	1/5	0.15
A7	6	5	3	4	2	5	1	0.16
ΣC_i	25,42	15,37	19,66	27	9,01	12	2,65	$\sum_n \approx 1.0$

TABLE 5 Calculated values of the criterion of adaptability of the technique to different types of fuel

	Criteria of evaluation							Criterion of adaptability K_a
Fuel	A1	A2	A3	A4	A5	A6	A7	
Σ(xi)	0,14	0,14	0,14	0,11	0,16	0,15	0,16	
Diesel fuel	0,26	0,4	0,24	0,27	0,25	0,27	0,36	0,30
Biodiesel	0,43	0,34	0,34	0,27	0,32	0,33	0,36	0,34
Natural gas	0,31	0,25	0,42	0,46	0,43	0,38	0,28	0,36

FIGURE 3 Load characteristics with measurement of toxicity of exhaust gases of the engine 4FS 11,0/12,5 when working on different fuels at the frequency of rotation of the crankshaft 1400 min^{-1}

Note:

N_e = effective engine power;
g_e = specific effective fuel consumption in Mega Joule of energy at kWt hour

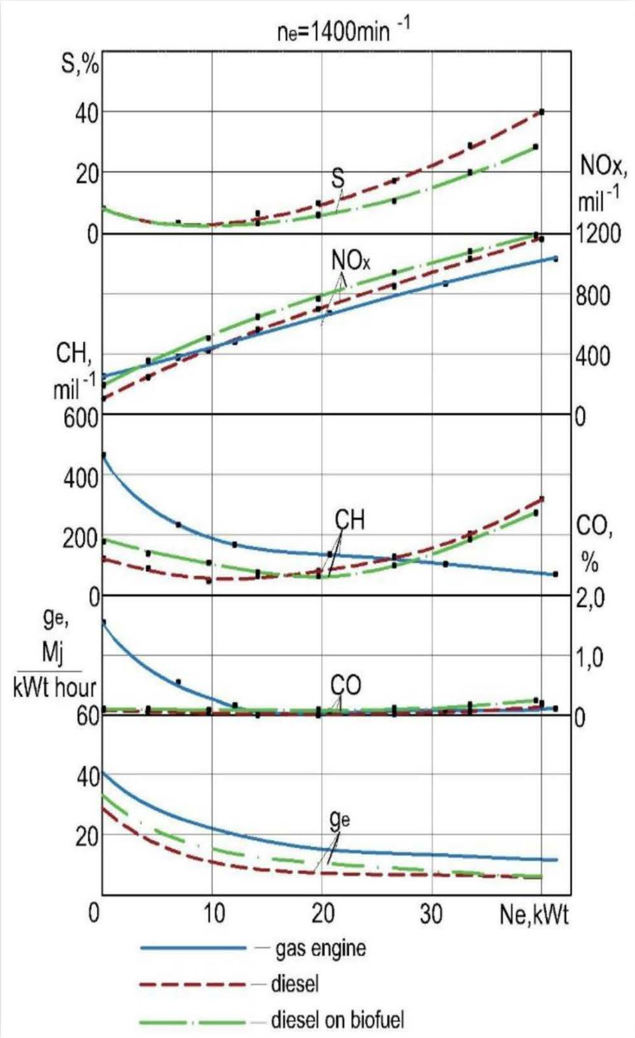


FIGURE 4 Gas engine with spark ignition, converted from diesel 4 FS 11,0/12,5

Where,

C_{bdf} = the content of biodiesel fuel in mixtures with petroleum fuel;

A_1A_{19}= coefficients of a polynomial

The test for adequacy of polynomial models of the third degree according to Fisher's criterion has shown that it allows us to determine the necessary indicators with sufficient accuracy. The procedure for determining Fisher's criterion is standard and described in many sources [8, 9]. Mass emissions of harmful substances were determined by fuel and air consumption and concentrations of these substances in exhaust gases.

The mathematical models of the movement of technological vehicles by taking into account the work of the technological means with trailer and the design features of the engine and transmission have been developed. Mathematical models of the movement of vehicles in driving cycle are systems of differential and algebraic equations that describe the modes of the movement of vehicles and their corresponding modes of operation of engines. Input parameters in mathematical models are curb weight of the vehicle, size and speed of movement controls fuel supply, selected gear, and gear shift time, speed of movement, transmission losses, road conditions and loadings of the vehicle. Output parameters are fuel consumption, air consumption and emissions of harmful substances with exhaust gases of the engines of the technological vehicle.

The value of the effective torque of the engines was accepted as the main value for the calculation of all modes. It is calculated by the polynomial dependence of the second degree from the rotational speed of the crankshaft and position of the fuel control lever (in diesels) or rarefaction in the intake manifold (in engines with spark ignition). During the movement of the vehicle, the force of traction on the driving wheels is spent to overcome the resistance forces of the movement which are created by the road, as well as the forces of resistance to the accelerated motion. The force of air resistance due to low speeds of the vehicle is not taken into account. The equation of the conversion of the rotational motion of the wheels into the forward motion of the vehicle has the form:

$$\frac{1}{r_d} \cdot M_e \cdot U_t \cdot \eta_t = G_v \cdot \psi \pm M_v \cdot \delta \cdot \frac{dV}{dt} \tag{10}$$

Were,

r_d = dynamic radius of driving wheels;
M_e = effective torque of the engine;
U_t = transmission number of gears;
η_t= transmission efficiency;
G_v, M_v= weight and mass of the vehicle respectively;
ψ = coefficient of road resistance;
δ = coefficient of account of rotating masses;
V = the speed of the vehicle

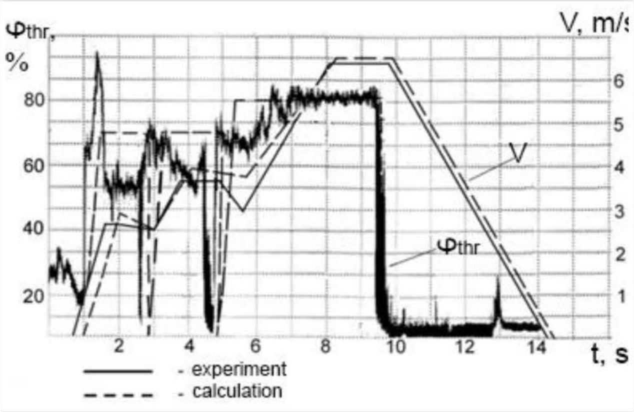
The process of overclocking the vehicle with blocked clutch, delay with disconnected and attached engine are described by differential equations which ae solved by the Runge-Kutta method. The mode of operation of a vehicle is described by solving systems of differential equations. The average values of the parameters are determined on each section of the ride cycle and determine the mode of operation of the engines. Mathematical models allow us to calculate the specific fuel consumption and the specific mass emissions of harmful substances of technological vehicle for concentrations of these substances and the costs of different types of fuel and air.

The device is based on the Hall sensor for rotation frequency registration of the traction wheel and the throttle position sensor for a gas-air mixer is installed on the wheeled tractor. The E-14-140 analogue-digital converter board of the L-Card firm is used to receive signals from these sensors and transfer the received data to a laptop. The standard program LGraph2 for processing sensor signals and own program for final data processing were used [8].

The change in the speed of the vehicle V technology during operation on the gas and the position of the throttle φ_{thr} of the gas-air mixer in the first part of the accepted driving cycle, depending on the time of movement was shown in Figure 5. The indicators obtained by experiment and calculation different to 6%. Verification of adequacy of the mathematical model of the motion of the technological vehicle with a diesel engine while driving in driving cycle was performed in a similar way.

The test for adequacy of the mathematical models of the subsystems of the system "fuel-engine-vehicle" in comparison with the results of experimental researches showed that the mathematical models describe the main processes of the system satisfactorily and can be used to estimate the feasibility of using alternative fuels in the technological vehicle.

FIGURE 5 Diagrams of change in the speed of the technological vehicle and the position of the throttle flaps of the gas-air mixer in the process of working on gas by time of performance of the driving cycle



© SAE International

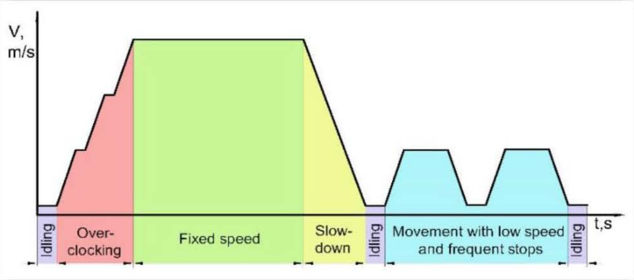
Usually, the motion simulation of vehicles is carried out according to the regimes of standard riding cycles simulating the movement of vehicles. Since there are no standard driving cycles for technological transport, then the driving cycle was formed to evaluate the indicators of such technique which includes the main modes of its movement. The driving cycle consists of two parts: the first part - acceleration, movement with relatively high speed and deceleration. The cycle is characteristic for the delivery of goods for production. The second part is the movement with low speed and frequent stops (Figure 6). The cycle is characteristic for delivery of cargo.

Cargo delivery to the enterprise is a very common operation performed by technological transport. In particular, the delivery of feed to the farm and distribution to their animals is characteristic of agricultural production. If the tractor can move at a speed close to the maximum (within 35 km / h) when delivering fodder to the farm, then the speed of movement does not exceed 10 km / h. The movement of technological transport is similar in the case of other types of work (maintenance of greenhouses, warehouses).

The general scheme of the method for assessing the performance of vehicles during driving on a ride cycle is shown in the Figure 7.

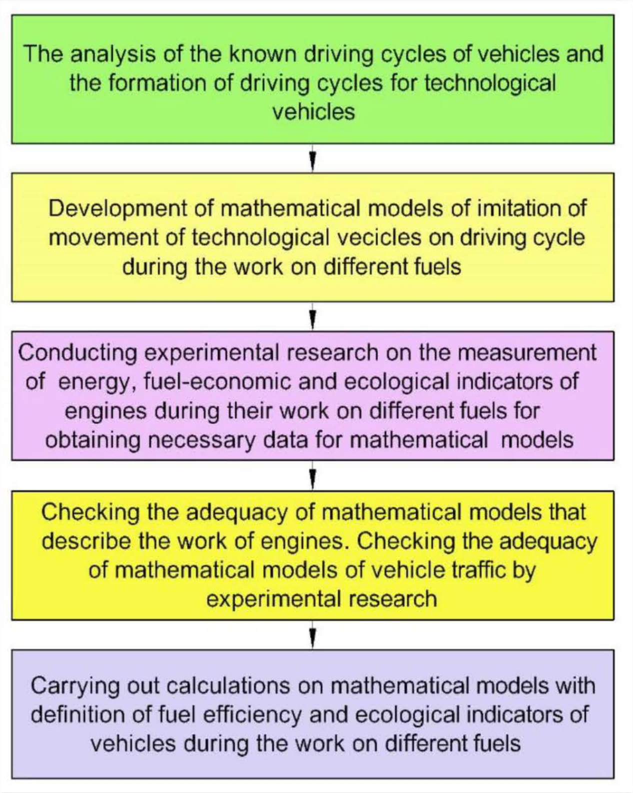
Specific emission (g/km) of harmful substances and specific fuel consumption g_f was determined by mathematical modeling depending on the mass of the loaded cargo M_c the vehicle (Figure 8).

FIGURE 6 Riding cycle of means of technological transport



© SAE International

FIGURE 7 General scheme of the method of estimation of fuel-economic and ecological indicators of the vehicle during movement for driving cycle



The analysis of the known driving cycles of vehicles and the formation of driving cycles for technological vehicles

Development of mathematical models of imitation of movement of technological vecicles on driving cycle during the work on different fuels

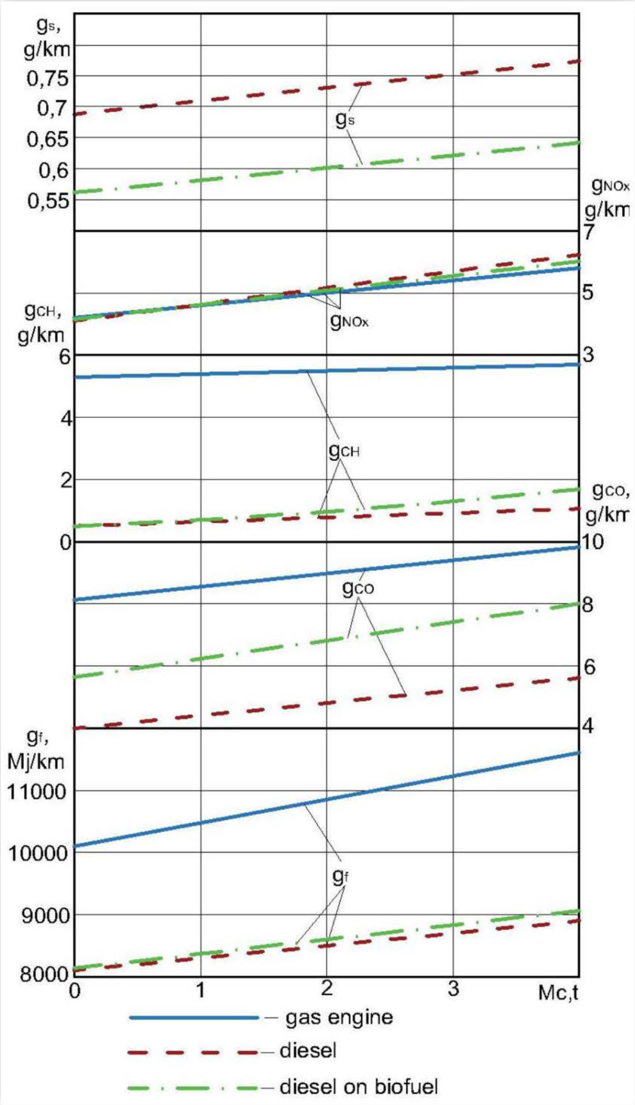
Conducting experimental research on the measurement of energy, fuel-economic and ecological indicators of engines during their work on different fuels for obtaining necessary data for mathematical models

Checking the adequacy of mathematical models that describe the work of engines. Checking the adequacy of mathematical models of vehicle traffic by experimental research

Carrying out calculations on mathematical models with definition of fuel efficiency and ecological indicators of vehicles during the work on different fuels

© SAE International

FIGURE 8 Dependencies of fuel consumption and emissions of harmful substances from the mass of the cargo of the technological vehicle when the engine is running on different types of fuel



© SAE International

Calculations have shown that the technological vehicle with diesel at driving on the adopted driving cycle consumes less fuel (correspondingly on average) by 22% (Figure 8), emissions CO at the tractor with the diesel engine are lower by 47%, CH - is less by 90% than in the technological vehicle with a gas engine. This is due to the fact that the gas engine in all modes works on richer fuel-air mixtures. Technological vehicle with diesel emits oxides of nitrogen NOx by 4% more. Unlike technological vehicle with a gas engine, technological vehicle with diesel also emits soot. Comparing the total specific emissions of harmful substances (HS), brought to the carbon oxide ΣCO taking into account the relative aggressiveness, it is evident that the more toxic (36%) is the technological vehicle with a diesel engine. The total toxicity of a tractor engine operating on biodiesel is lower than on oil fuel. The use of other types of fuels is the reason for the differences in the parameters of the wheeled tractor. The engine was regulated appropriately when working on alternative fuels to get the best indexes. The optimum angle of ignition advance was set when working on gas [8]. Figure 8 is modeled according to the data of driving cycle. But the amount of emissions of harmful substances in the exhaust gases does not allow an analysis of the environmental safety of the technological vehicle.

The results of the complex assessment of the ecological hazard of the exhaust gases of the technological vehicle on the basis of the category of vehicle hazard at maximum allowable concentrations and the hazard class of harmful substances were given in Table 6.

The hazard category of the technological vehicle, working on biodiesel, is 1,11 times smaller and on natural gas in 1,26 times less than on diesel fuel. Moreover, the ecological danger of exhaust gases for all types of fuel is determined by the danger of oxides of nitrogen NO_x on average by 90%, the content of which in the exhaust gases by weight is not very significant.

Determination of the ecological hazard indicator and level of environmental safety of the technological vehicle working on different types of fuel by criterion K_e (Table 7) was the next stage. The best value of the criterion of environmental safety corresponds to the vehicle working on natural gas. The results of calculating the indicators of economic efficiency were summarized in Table 8.

TABLE 6 Category of hazard of exhaust gases of the technological vehicle at work of its engine on different fuels

Type of fuel	Category of hazard of harmful substances of exhaust gases				Category of hazard of exhaust gases of the technological vechicle (HCV), M^3/C
	NO_x, M^3/C	CO, M^3/C	CH, M^3/C	Soot, M^3/C	
Diesel fuel	2789,1	9,1	1,9	377,5	3177,6
Natural gas	2599,8	15,1	17,4	-	2632,9
Biodiesel	2694,1	12,8	4,5	288,2	2999,6

TABLE 7 Estimation of ecological safety of the technological vehicle at work on different fuels

Type of fuel	Indicator of environmental hazard K_{eH}	Environmental safety criterion K_e
Diesel fuel	2,98	0,33
Natural gas	2,38	0,42
Biodiesel	2,7	0,37

TABLE 8 Economic efficiency of operation of the technological vehicle on alternative fuels

No	Indicator	Unit of measurement	Type of fuel	
			Natural gas	Biodiesel
1.	Capital costs on conversion of the tractor to work on alternative motor fuel	UAH	10892	3266
2.	Operating cost savings	UAH	7712,1	662,3
3.	Payback period	years	1,41	4,9
4.	Annual economic effect of using alternative fuels	UAH	6078,3	177,3
5.	Criterion of economic efficiency	-	0,71	0,2

The operation of the technological vehicle on gas fuel in comparison with diesel fuel provides an annual economic effect of 6078.3 UAH. The payback period for the cost of refurbishment for gas operation is 1.41 years. The annual economic effect will be 177.3 UAH when operating on biodiesel fuel. The payback period for the cost of refurbishment will be 4,9 years.

The highest value of the general criterion for choosing the appropriate fuel type has natural gas in the case of its use in the redesigned diesel engine for gas. The least value of criterion has oil diesel. These values were set as a result of researches. The results of calculating were summarized in Table 9.

TABLE 9 The value of the general criterion for choosing the appropriate fuel type

Fuel	General criterion K choose the appropriate fuel type
Diesel fuel	0,240
Natural gas	0,484
Biodisel	0,295

Conclusions

Model representations of functioning of the automotive engineering (motor-and-tractor equipment) working on different fuels allowed to reduce the problem of the choice of fuel to optimize the parameters of the operational system "fuel-engine-vehicle" by the criterion of adaptability, criteria of ecological safety and economic efficiency of operation. The proposed methodology allows to evaluate the indicators of automotive engineering (motor-and-tractor equipment) at its work on different fuels according to one general criterion. This methodology greatly simplifies the choice of rational type of fuel. It is established that the highest value of the general criterion for choosing a rational type of fuel is natural gas for the case of its use in a gas engine converted from diesel. The results obtained will be reliable for all diesels of technological transport, performed according to this design scheme.

References

1. Markov, V., Efanov, A., and Devyanin, S., "Alternative Fuels and the Methods for Assessing their Ecological Qualities," *Truck*. 6:27-34, 2007.
2. Patrahaltsev, N., "Increase of Economic and Ecological Qualities of Internal Combustion Engines Based on the Basis of Use of Alternative Fuels," 248, 2008.
3. Goryachkin, V., "Use of Alternative Fuels in Self-Propelled Machinery", presented at *Scientific and Information Material*, 2010, 95.
4. Maksymenko, O., "Technology of Improving the State of the Air in Rooms of Limited Volume When Internal Combustion Engines with Liquid Neutralizers Operate in Them," Ph.D. thesis, Mechanical Engineering Department, Ryazan, Russia, 2006.
5. Gavrysh, V., "*Ensuring Efficient Use of Fuel and Energy Resources in the Agrarian Sector of Economy*," Monograph, (Mykolaiv, Ukraine, 2007).
6. Bazarov, B., "The Work of Reciprocating Engines on Alternative Fuels," 238, 2001.
7. Parsadanov, I., "Improving the Quality and Competitiveness of Diesel Engines on the Basis of Complex Fuel-Ecological Criterion," 244, 2003.
8. Zaharchuk, V., "The Use of Alternative Motor Fuels in the Means of Technological Transport," 233, 2015.
9. Mateychyk, V., "*Methods of Evaluation and Methods of Increasing Environmental Safety of Road Vehicles*," Monograph, Kyiv, Ukraine, 2006.

10. Saati, T., "Decision Making. Method of Analysis of Hierarchies," *Radio and Communications*, 1993.
11. Tsytsura, A., Dvornikov, G., and Bondarenko, Y., "Evaluation of the Impact of Road Transport on the Quality of the Air Environment of the Orenburg Region," 1:47-49, 2000.
12. Gritsuk, I., Volkov, V., Mateichyk, V., Gutarevych, Y. et al., "The Evaluation of Vehicle Fuel Consumption and Harmful Emission Using the Heating System in a Driving Cycle," *SAE Int. J. Fuels Lubr.* 10(1):236-248, 2017, doi:10.4271/2017-26-0364.
13. Gritsuk, I., Mateichyk, V., Tsiuman, M., Gutarevych, Y. et al., "Reducing Harmful Emissions of the Vehicular Engine by Rapid After-Start Heating of the Catalytic Converter Using Thermal Accumulator," SAE Technical Paper 2018-01-0784, 2018, doi:10.4271/2018-01-0784.

Contact information

Prof. Victor Zaharchuk,
Zaharchukov205@gmail.com

Prof. Igor Gritsuk,
gritsuk_iv@ukr.net

Assoc. Prof. Oleg Zaharchuk,
Zaharchukov205@gmail.com

Dr. Andrii Golovan
andrew.golovan@gmail.com

Assoc. Prof. Sergiy Korobka
korobkasv@ukr.net

Assoc. Prof. Larisa Pylypiuk,
lorena_18@ukr.net

Assoc. Prof. Nickolay Rudnichenko
nickolay.rud@gmail.com

ISSN 0148-7191