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Choosing the best available techniques of using the alternative engine fuels in automotive engineering

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Abstract: Purpose**:** The aim of our research work was to choose the best available technology of using the alternative engine fuels in vehicle and tractor technique use. Methodology**:** The methodology of multicriterial optimization was adopted for the purpose of the research. Results**:** There are given the results of calculating researches related to the choice of the best available techniques of the alternative engine fuels in vehicle and tractor technique use by the method of complex evaluation of fuel and power indexes of alternative fuels and engine, ecological safety and economic feasibility of vehicle exploitation. Fuel and power indexes of the fuels and of the engine are estimated by the criterion of adaptation, which is calculated by the method of hierarchies, ecological safety is evaluated taking into consideration the number of pollutant emissions with exhaust gases, their maximum permissible concentrations and safety class, economic feasibility of technique exploitation is estimated by the economic feasibility criterion which is calculated taking into account the economy of exploitation charges while using alternative fuels and placement of funds for technique re-equipment. The highest value of general criterion of the choice of suitable technique of fuel use which integrates the listed criteria, belongs to the technique of natural gas using in the gas engine re-equipped from the diesel one, petrol diesel fuel has the lowest value. The theoretical contribution**:** is The research findings have contributed to the development of a common methodology of estimating the factors of vehicles functioning on alternative fuels on criteria of technical suitability, environmental safety and economic efficiency of operation. Practical implications: The proposed methodology allows to estimate the technique indexes while its functioning on different types of fuel by one general criterion, which simplifies a lot the choice of technique of rational type of fuel use.

Keywords: alternative engine fuels, vehicle and tractor technique, the best available techniques.

1. Raising the problem

A term «The Best Available Techniques» (BAT) appeared for the first time in Directive of the working group on air framework (Air Framework Directive – AFD) in 1984. The BAT are techniques of goods (commodities) production, implementation of works, granting of services, determined on the basis of modern achievements in science and techniques and the best combination of criteria for achievement of the environment protection aims at condition of availability of any economic feasibility and technical viability of its application. In the countries of post-soviet space, in particular Russian Federation, there were made some attempts to implement the researches concerning introduction of BAT in chemical industry [1].

As of today there is a large park of the wheeled transport vehicles and mobile agricultural technique in our country, the work of which is based on petroleum origin fuel. But the cost of fuel grows continuously; the ecological situation in the country is getting worse too. One of the basic exit ways

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from this situation is transfer of the equipment to the work which is based on the alternative engine fuels (AEF). Thus, separate technologies of AEF use may be considered as the BAT.

In the European Union there are 33 reference books of EU for BAT meant for different industries, taking into account all the technological features and hardware-controlled equipment of the processes with consideration for ecological influences and economic charges. However, the direct use of the European BAT reference books at home enterprises is hardly possible, having regard to present differences, including specifics of all the types of resources, features of raw materials, availability of different energy types, natural conditions, ecological descriptions of territories and technological culture of production.

In this connection the development of scientifically - reasonable methodical providing of transition for AEF is necessary, the first stage of which is a decision of the task: choice of techniques as BAT taking into account its technological possibility to be realized, ecological safety and financial viability.

Use of system approach and information technologies possibilities is the necessary condition of this problem solving, taking into account its complexity and multidimensionality.

2. Analysis of the recent researches and publication

A considerable contribution to the development of system analysis and theories of making decision was brought in by: V.N. Volkova, A.A. Denysov [2], A.V. Kostrov [3], O.I. Lerichev [4], S. Optner [5], F.I. Peregudov [6], V.V. Podinovskyi [7], D.A. Pospelov [8], T. Saati [9]. Among the best known researchers of the problems of alternative fuels in transport vehicles use are worth to be mentioned the scientists from Ukraine and post-soviet space countries Y. Gutarevych [11], F. Abramchuk [11], S. Gusakova [12], S. Devianina [13], V. Yerokhova [14], V. Lukanina and A. Khachiian [15], V. Markov and A. Gaivoronskyi [16], A. Ukhanov [17], G. Saveliev [18] and others. In particular, Gutarevych Y.F. [10] studied the influence of using the natural gas, biodiesel fuels, non-alcohol mixtures on the energetic and ecological indexes of engines and vehicles. Abramchuk F.I. [11] explored the influence of natural gas on the similar indexes of gas engine re-equipped from diesel one. S.Gusakov [12] and S. Devianin and S. Markov [13] examined the influence of biological fuels on the engine indexes. V.Yerokhov [14] has devised a methodology of making a specific complex program of using the alternative fuel types in the automobile transport.

These problems solving are covered in lots of works of western scientists, among them P. Hamling, 2002 [18], N. Nuland, 2002 [19], M. Karabektas, 2008 [20], A. Murugesan, 2009 [21]. The most widespread questions investigated in works of home and foreign scientists were indexes of engines and cars work while working at alternative fuels. However, the approaches expounded in-process do not give clear rules for determination of BAT in a concrete situation.

3. Aim and task of the article

The aim of our research work is to choose the best available technology of using the alternative engine fuels in the automotive engineering.

Research tasks:

- developing of the method of choosing the best available technology of using the alternative engine fuels in the automotive engineering;
- determination of the criteria of adaptedness, ecological compatibility, economical efficiency of using the alternative engine fuels and the general criterion of choosing the best available technology.

4. Materials and methods of researches

For determination of BAT it is necessary to choose such techniques (technical measures, management decisions), which are the most effective from the point of view of achievement the general high level of environment protection. In practice while realization of this principle, there could appear the situations in which it is not clear, which one of the techniques would provide the highest level of environment (E) protection and the highest economic effect (Figure 1). Therefore there is a necessity to conduct the preliminary estimate of technologies for identification of the exactly best technique.

The materials above characterize initial data for authentication of a technique as BAT as exceptionally compound because of system factors and measurable indexes heterogeneity, bound by heterogeneous criteria, as well as requirements and limitations, partitioned character of a control object - natural environment and elements of the technological system, different degree of studied current processes and necessity of participation in all the stages of techniques life cycle for different profile specialists (technologists, environmentalists, economists) for solving of the integrated task.

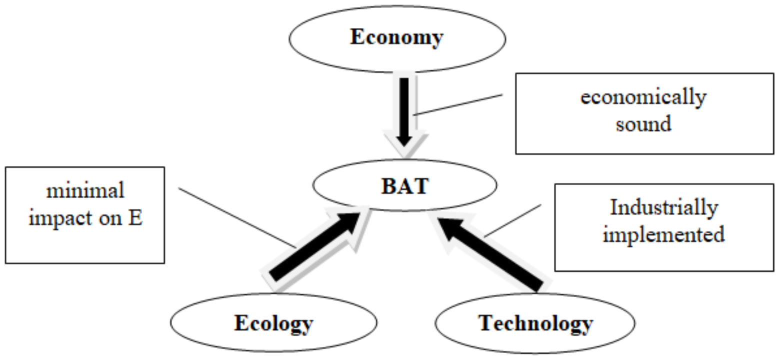

Figure 1. System factors of authentication of techniques as BAT.

Possibility of application of certain type of AEF is determined by many factors: its regional resources, correlation of prices between alternative and traditional fuels, charges on engines adaptation for working on AEF, on the delivery infrastructure, on storage and filling up of technique.

In such conditions, the effective methodological basis is a system approach. The system approach allows to lead the complex task (or difficult systems) of high dimension to more simple tasks (accordingly - subsystems or blocks) linked (united) by certain rules. Thus in each of subsystems can be arrived at not all, but only some aims (criteria), while others - in other subsystems; then a general result is reached on the basis of the results of partial tasks component decision.

In the process of making decision it is necessary to find a compromise between the most conflicting aims, taking into account plenty of criteria. For the efficiency increase of administrative decisions there were elaborated a lot of methods of multicriterion analysis and optimization.

Methodology of BAT choice of AEF use includes the determination of criterion of adaptation K_a of system «fuel-engine-vehicle» to the alternative engine fuels, criterion of ecological safety K_e of the vehicle (V) and criterion of economic efficiency of exploitation.

The adaptation criterion takes into account the technological possibilities of introduction. For determination of system adaptation criterion to different fuels (petroleum diesel fuel, natural gas, biodiesel fuel) there was worked out a methodology on the basis of hierarchies analysis method (HAM) of T. Saati [9]. By means of HAM it is possible to solve the task of multicriterion optimization with enough of optimality criteria. The next principles form the basis of HAM: decomposition (structuring of a problem into the hierarchic system of easier tasks); paired comparison (comparison of all possible combinations according to the results of determined priorities or weight coefficients); hierarchic composition (determination of a priority in each group on all the levels of hierarchy). The advantage of given method is a possibility of taking into consideration the non-numerical indexes.

During the estimation of ecological safety of the vehicle are taken into account the amount of pollutant (P) emissions with discharge gases (DG), their toxicity and danger class. The vehicle danger category which works on a traditional or alternative fuel

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

here *HCS* – is the hazard category of the i-th substance, m^3/s; M_i – is the amount of emissions of the i-th substance, g/m^3, values of which are obtained on the basis of records of the travel emissions of harmful substances (HS), g/km, obtained by calculations using mathematical models; *MPC* – is the daily average maximum permissible concentration of i-th substance, g/m^3; α_i – is the dimensionless constant, allowing us to relate classes of hazard of i-th substance and sulphur dioxide (III hazard class); *n* – is the amount of harmful substances in the exhaust.

It is advantageously to carry out an assessment of the environmental parameters of the vehicle, working on basic and alternative types of fuel, with the sanitary norms. Pollutant emissions with exhaust gases (g/s) during the engine work using different fuel types were determined by a mathematical modelling of a running cycle of the vehicle according to the methodology of prof. Y. Gutarevych [10]. In addition to that, the results of experimental researches of exhaust gases toxicity of a given engine on different speed and loading modes were taking into account.

In the first stage it is performed according to EA criterion that is the environmental adaptability of the ICE (internal combustion engine) to alternative fuels:

$$EA = \frac{1}{n}\sum_{i=1}^{n}(K_i)^{\alpha_i} = \frac{HCV}{HCV_b}, \quad (2)$$

here HCV – is the hazard category of the vehicle running on alternative fuel, m^3/s; HCV_b – is the hazard category of the vehicle running on a basic fuel, m^3/s.

On the second stage the index of environmental hazard of the vehicle running on alternative fuel is determined

$$K_{eh} = EA \cdot K_b, \quad (3)$$

here K_b – is the index of environmental hazard of the vehicle running on the primary fuel.

The criterion of environmental safety

$$K_e = \frac{1}{K_{eh}}. \quad (4)$$

The most effective decision from the economic point of view in relation to the choice of fuel will correspond to a minimum of the annual resulted charges:

$$B_{yi} = C_i - i \cdot K_i \to \min, \quad (5)$$

here C_i – is a cost price with the usage of i-type of fuel, UAH; i – is a permanent norm of discount.

Economic efficiency of the use of AEF is estimated by the criterion of economic efficiency:

$$K_{ee} = \frac{B_{yi}}{B_{p\max}}. \quad (6)$$

Natural gas has the highest value of economic efficiency criterion, biodiesel fuel has a little less value.

Thus, three criteria of choice of rational type of fuel are chosen for transport vehicles. A multicriterion task will be simplified to the onecriterion one by the method of rolling up. The integration of separate criteria in one general criterion of rational type of fuel is effectuated as follows:

$$K = \varphi_1 \cdot K_a + \varphi_2 \cdot K_e + \varphi_3 \cdot K_{ee}, \quad (7)$$

here φ_1, φ_2, φ_3 – are the significance coefficients of indexes of system adaptation to AEF, of ecological safety and economic efficiency of technological vehicles exploitation on different types of fuel ($\sum \varphi_i = 1$).

For the estimation of significance of separate criteria there were taken the results of expert estimations. The ecological safety criterion has the biggest meaning (0.4), the adaptation criterion and the criterion of economic efficiency of exploitation have some less values (0.3). To make a decision about the BAT choice of the AEF use there was formed an objective function.

5. Results

Using the method of hierarchies analysis (MHA) and mathematical matrix model it is carried out a comprehensive assessment of operating characteristics of the alternative motor fuels and of the performance of engine at each level of the system with a hierarchical structure. The estimates of motor fuels are given in a Table 1.

Table 1. Estimates of motor fuels.

Parameter	Fuel		
	Diesel	**Biodisel**	**Natural gas**
The adequacy of resources and the possibility of mass production	-	+/-	+/-
The lowest calorific value MJ/kg (MJ/m³)	42.5	38.3	38.0
Knock resistance (octane number) or propensity to self-ignition (cetane number)	45.0	49.0	110-125
Environmental quality (environmental impact)	-	+	+/-
Energy production	-	+	+
Security applications	+/-	+	+/-

Note: «+» – is the presence of advantages in comparison with petroleum diesel; «-» – is the lack of advantages in comparison with petroleum diesel; «+/-» – is the combination of advantages and disadvantages.

The performances of fuels and engine shown in a Table 2 are the assessment criteria of fuel and energy properties: A1 – is the adequacy of resources and the possibility of mass production of fuel; A2 – is the energy performances of the engine when operating on this fuel; A3 – is the knock resistance of fuels and the propensity for self-ignition; A4 – is the price of fuel; A5 – is the specific effective engine fuel consumption in power units; A6 – is the energy consumption of fuel production; A7 – is the safety of an application.

A track fuel consumption and travel emissions of a tractor, being operated on different fuels, are defined by mathematical modeling. The calculations showed that the tractor with a diesel engine, being driven on the adopted driving cycle, consumes (accordingly, on average) 22% less fuel, and its CO emissions are 47% less and CH emissions are 90% less than of the tractor with a gas engine.

This is due to the fact that the gas engine in all modes runs on richer fuel-air mixtures. A tractor with the diesel engine emits nitrogen oxides NO_x 4% more. It also emits soot unlike the tractor with the gas engine. Comparing the total specific emissions of harmful substances (HS), converted to carbon monoxide ΣCO, taking the relative aggressiveness, it is clear that the tractor with a diesel engine is (36%) more toxic. The total toxicity of a tractor engine running on biodiesel fuel is also lower than of an engine on oil fuel. But the number of emissions of harmful substances in the exhaust gases does not allow to analyze the environmental safety of the tractor.

Table 2. The pair comparison of the estimates 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	$\sum_n \approx 1.0$

The compressed natural gas has the maximum value of criterion according to the results of calculations of the fuel and energy criterion of different fuels (Table 3).

Table 3. Estimated values of the fuel and energy criterion for different fuels.

	A1	A2	A3	A4	A5	A6	A7	The energy criterion
$\Sigma(x_i)$	0.14	0.14	0.14	0.11	0.16	0.15	0.16	
Diesel	0.26	0.40	0.24	0.27	0.25	0.27	0.36	0.29
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

The results of comprehensive assessment of ecological danger of exhaust gases of an MTZ-80 tractor based on the hazard category HCV for the maximum permissible concentrations and hazard class of harmful substances are given in the Table 4.

The hazard category of a tractor running on biodiesel is 1.11 times less, and on natural gas is 1.26 times less than on diesel fuel. And on average 90% of environmental hazards of exhaust gases for all fuels consist of danger of nitrogen oxides NO_x, the contents which are in exhaust gases weight is not very significant.

Table 4. The hazard category of exhaust gases of a wheeled tractor with an engine running on different fuels.

Fuel	Hazard category of harmful substances of exhaust gases								Hazard category of a tractor (HCT)	
	NO_x		CO		CH		soot			
	m³/s	%	m³/s	%	m³/s	%	m³/s	%	m³/s	%
Diesel	2789.1	87.8	9.1	0.29	1.9	0.06	377.5	11.9	3177.6	100
Natural gas	2599.8	98.7	15.1	0.57	17.4	0.66	–	–	2632.9	100
Biodiesel	2694.1	89.8	12.8	0.42	4.5	0.15	288.2	9.6	2999.6	100

The determination of the index of environmental hazard and of the level of ecological safety of the MTZ-80 tractor running on different fuels according to the K_{eh} criterion (Table 5) was the next step. The Table 5 shows that the best value of the criterion of environmental safety is inherent to the tractor, running on natural gas. The results of calculation of indicators of economic efficiency are summarized in Table. 6.

Table 5. The assessment of environmental safety of the MTZ-80 tractor running on different fuels.

Fuel	The index of environmental hazard K_{eh}	The criterion of environmental safety K_e
Diesel	2.98	0.33
Natural gas	2.38	0.42
Biodiesel	2.7	0.37

The operation of the MTZ-80 tractor as a technological vehicle on gas fuel in comparison with that on diesel fuel provides an annual economic effect of EUR. 202.6; and the payback period of the cost of conversion to run on gas is 1.41 year. When it is operated on biodiesel the annual economic effect is EUR. 5.91; and the payback period of the cost of conversion is 4.9 years.

Table 6. The economic efficiency of tractor operating on alternative fuels.

№ i/s	Parameter	Unit of measure	Fuel	
			Natural gas	Biodiesel
1.	The capital cost of tractor conversion to run on AMF	EUR.	363	108.8
2.	The saving of operational costs	EUR.	257	22
3.	The payback period	years	1.41	4.9
4.	The annual economic effect from the use of alternative fuels	EUR.	202.6	5.91
5.	The criterion of economic efficiency	–	0.71	0.2

It is established as a result of researches that the natural gas in case of its use in gas engine converted from diesel one has the greatest value of the general criterion for the selection of the appropriate type of fuel; and the petroleum diesel fuel has the smallest value of this criterion. The results of the calculations are summarized in the Table 7.

Table 7. The value of the general criterion for the selection of the appropriate type of fuel for the MTZ-80 tractor.

Fuel	The general K criterion for selection of appropriate type of fuel
Diesel	0.221
Natural gas	0.479
Biodiesel	0.31

The general criterion of BAT choice of AEF use, for the tractor MT3-80 used as a technological transport vehicle, is determined, that means that a multicriterion task is simplified to the onecriterion. As a result of researches, there was set that natural gas has the greatest value (0.479) of general criterion of rational type of fuel choice in a case of its use in gas engine that was reconstructed from a diesel engine D-243, a petroleum diesel fuel has the least value (0.221), a biodiesel fuel – 0.31. As it is evident from the given results, while determining a general criterion of BAT choosing, its biggest value for natural gas is naturally determined. However the value of criterion of ecological safety and economical efficiency of machines operation is the biggest exactly for natural gas.

6. Conclusions

A method of many criteria choosing of the best available technology of using the alternative engine fuels in the automotive engineering was developed.

The model representations of operating of automotive and tractor vehicles, running on different fuels, allowed us to reduce the problem of the choice of fuel to the optimization of the parameters of the operating "fuel-engine-vehicle" system according to the fuel-energy criterion, to the criteria of environmental safety and of economic efficiency of operation. The proposed methods allow to evaluate the performance of automotive and tractor vehicles running on various fuels according to a single composite index (general criterion), which it greatly simplifies choosing of fuel.

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