Предметом дослідження є процес охолодження двигунів автомобілів різних марок і моделей. Розроблено показник пристосованості та методика його оцінки, яка враховує швидкість вітру, масу двигуна і його утеплення, щільність компонування підкапотного простору. Запропоновано трирівнева градація пристосованості автомобілів. Отримані результати дозволяють оцінювати тривалість охолодження непрацюючого двигуна автомобіля в заданих умовах експлуатації, а також меж умов експлуатації раціонального використання автомобілів в різному виконанні

Ключові слова: зимові умови експлуатації, охолодження двигуна автомобіля, темп охолодження, пристосованість автомобіля

Предметом исследования выступает процесс охлаждения двигателей автомобилей разных марок и моделей. Разработан показатель приспособленности и методика его оценки, которая учитывает скорость ветра, массу двигателя и его утепление, плотность компоновки подкапотного пространства. Предложена трехуровневая градация приспособленности автомобилей. Полученные результаты позволяют оценивать длительность остывания неработающего двигателя автомобиля в заданных условиях эксплуатации, а также границы условий эксплуатации рационального использования автомобилей в различном исполнении

Ключевые слова: зимние условия эксплуатации, охлаждение двигателя автомобиля, темп охлаждения, приспособленность автомобиля

UDC 629.3
DOI: 10.15587/1729-4061.2017.116317

ESTIMATION OF THE ADAPTABILITY OF AUTOMOBILES TO OPERATION UNDER WINTER CONDITIONS BASED ON THE ENGINE COOLING RATE

V. Tiulkin
PhD, Associate Professor*
E-mail: tulkin.v.a@bk.ru
I. Titla
PhD, Associate Professor*
*Department of Automotive and Technological Machines Service
Tyumen Industrial University
Volodarskogo str., 38, Tyumen, Russia, 625000

1. Introduction

A large part of the territory of the Russian Federation (over 60 %) belongs to areas with low-temperature climatic conditions with long winter period. Operation of automobiles under such severe climatic conditions is accompanied by a decrease in efficiency, resulting in great economic losses.

Harsh conditions exert significant negative impact on the temperature mode of automobile engines, due to the increased intensity of heat transfer from the motor into the environment. Thermal-technical analysis of cooling process reveals that the most informative characteristic of the process is the cooling rate. The possibility of its determining allows solving almost any thermal-technical problem on the thermal state of a vehicle engine, that is, estimation of intensity of heat transfer, determining the duration of cooling to the preset temperature, assessment of temperature change dynamics and others.

At the same time, it was noted that engines of automobiles of different makes and models under identical operating conditions differ in the intensity of heat transfer, that is, they are characterized by different cooling rate. This fact is explained by the different level of adaptability of automobiles to winter conditions. In order to improve efficiency of using vehicles under winter conditions, it is necessary to have an objective assessment of their adaptability by this indicator, which requires its development. Therefore, development and application of the estimation of adaptability of automobiles to winter conditions based on the engine cooling rate is an important task.

2. Literature review and problem statement

Much attention is paid to the problem of the estimation of thermal condition of a car engine and its aggregates during winter period. Authors of [1, 2] highlight a change in the force of cooling effect of wind and in the direction of airflow [3, 4] over automobile that impact thermal regime of the engine. In papers [5, 6], authors note the effect of engine position in an automobile and its heat insulation on heat transfer. The results of research, however, were limited to the comparative assessment of cooling intensity of an automobile engine under winter conditions [7–9]. The following factors were not taken into consideration. The automobile engine has a complex geometrical shape [10] and is placed in a confined under-hood space, which houses other structural units, assemblies and mechanisms of automobile [11]. Thermal field of the engine is not uniform by volume [12–14]. It is possible to take the indicated factors into consideration if we are to use cooling rate as a criterion for thermal mode [15].

The application of this criterion will make it possible to estimate heat transfer of the automobile engine with respect to the speed of wind that flows around it, the weight of engine and its heat insulation, its position in the under-hood space.

The studies undertaken earlier [16–18] failed to consider the impact of the specified factors on the cooling rate of automobile engine. The form of a mathematical model of change in the engine cooling rate under the influence of the noted factors was not established; the numerical values were not defined for the parameters of a given mathematical model.

The papers published earlier also noted different adaptability of automobile engines to operation under winter conditions [19, 20], though no indicator to estimate the adaptability was devised.

3. The aim and objectives of the study

The aim of present study is to develop a procedure for assessing the adaptability of automobiles to winter conditions based on the engine cooling rate, which takes into consideration the influence of wind, the weight of engine and its heat insulation, its position in the under-hood space, in order to establish the limits of operating conditions of the rational use of automobiles.

To achieve the aim, the following tasks have been set:

– to establish an indicator of the adaptability of automobiles to operation under winter conditions based on the engine cooling rate;

– to establish the form of a mathematical model for a change in the cooling rate of automobile engines;

– to determine numerical values for the parameters of mathematical model for a change in the cooling rate of automobile engines;

– to work out requirements to the assessment of the limits of operating conditions of the rational use of automobiles.

4. Procedure for studying cooling rate of automobile engine

At the first stage of analytical study we devised an indicator for the adaptability of automobiles to operation under winter conditions based on the cooling rate of engines. To obtain this indicator we applied the approach proposed in [7].

When assessing the adaptability of automobiles to operation under winter conditions based on the cooling rate of engines, we accepted as a basic magnitude the largest value, permissible by thermophysical properties, for the cooling rate m_∞. The cooling rate of engine m, implemented under given conditions of operation, differs from its basic value by the magnitude D:

$$m_\infty - m = D. \quad (1)$$

The ratio of correction D to the basic value of m_∞ is estimated by proportionality coefficient K:

$$K = \frac{m_\infty - m}{m_\infty} = 1 - \frac{m}{m_\infty}. \quad (2)$$

Proportionality coefficient K can serve as a quantitative estimate of the adaptability of automobiles to operation under winter conditions based on the cooling rate of engines. This coefficient assumed values from 0 to 1. The smallest value $K=0$ is assumed in the case when engine cools at the largest intensity, permitted by the thermophysical characteristics of the engine, $m \to m_\infty$. The largest value $K=1$ is acquired by the coefficient if engine cools at the lowest intensity or, in an extreme case, does not cool at all, $m \to 0$.

At the next stage of the study, we establish levels of the adaptability of automobiles for this indicator. In accordance with [6], it is proposed to characterize the adaptability of automobile to winter conditions based on the cooling rate of engines by three levels: high, medium, low. Because the adaptability factor assumes values from 0 to 1, then, at a three-level grading scale of adaptability, at each level, the range of interval of values for adaptability factor is 0.33 (Table 1).

Table 1

Characteristics of levels of the adaptability of automobiles to operation under winter conditions based on the cooling rate of engines

Adaptability level	Characteristic of the levels of adaptability	
	Interval of change in the values of adaptability factor	Mean value of adaptability factor
Low	[0; 0.33)	0.16
Medium	[0.33; 0.66]	0.49
High	(0.66; 1]	0.82

At the next stage of the study, we examined the process of change in the cooling rate. The engine cooling rate is predetermined by the thermophysical characteristics and conditions of the course of the cooling process on its surface [9, 13–15]:

$$m = \psi \frac{\alpha \cdot F}{c \cdot \rho \cdot V}, \quad (3)$$

where ψ is the coefficient of non-uniformity of temperature distribution in the engine; α is the coefficient of heat transfer; F is the surface area of the engine; c, ρ are heat capacity and density of the engine, respectively; V is the volume of the engine.

One of the difficulties in the study of the patterns of change in the cooling rate is to identify dependences of heat transfer coefficient, as, in a general case, it is a function of many factors. This issue can be resolved if one employs the similarity theory. Using similarity criteria and assuming that ratio V/F characterizes geometrical dimension l, the cooling rate is expressed:

$$m = \psi \frac{Bi \cdot a_{en}}{l^2}, \quad (4)$$

where Bi is the Biot criterion, which characterizes the ratio of internal and external thermal resistance of the engine; a_{en} is the thermal diffusivity of engine.

The Biot criterion is expressed through a dimensionless heat transfer criterion, the Nusselt criterion Nu:

$$Bi = Nu \frac{\lambda_a}{\lambda_{en}}, \quad (5)$$

where λ_a, λ_{en} is the coefficient of thermal conductivity of air and engine, respectively.

The Nusselt criterion Nu is derived from known criterial dependences of the form:

$$Nu = C \cdot \mathrm{Re}^n \cdot \mathrm{Pr}^m \quad (6)$$

or

$$Nu = C \cdot (\mathrm{Gr} \cdot \mathrm{Pr})^n, \quad (7)$$

where C, n, m are the parameters that depend on regime of the heat carrier motion; Re is the Reynolds criterion, which characterizes hydrodynamic regime of the heat carrier motion; Gr is the Grashof criterion, which characterizes kinematic similarity at natural convection; Pr is the Prandtl criterion, which characterizes properties of the heat carrier; which can be represented as a generalized similarity criterion Re″ proposed by V. Kast:

$$\mathrm{Re}'' = \sqrt{\mathrm{Re}^2 + c^2 \cdot \mathrm{Gr}}, \quad (8)$$

where c is the coefficient of equivalence.

Thus, by applying the theory of similarity, we determine patterns of change in the engine cooling rate. The following assumptions are made in this case.

1. The actual automobile engine is considered in the form of a body equivalent to it, a sphere whose thermophysical characteristics are determined based on the principle of additivity [10].

2. Heat transfer coefficient is determined from the criterial equations of similarity based on the theory by V. Kast [14]. Heat transfer of the body of an arbitrary geometrical shape, flowed over by the heat carrier and with flow in a channel is described in one form. To do this, an equivalent diameter and rational velocity of the heat carrier flow are used:

$$w_m = \frac{w_0}{\varphi}, \quad (9)$$

where w_0 is the speed of air motion in the free cross-section of channel in the under-hood space of automobile engine; φ is the arrangement density of the under-hood space of the engine.

3. Arrangement density of the under-hood space is defined as the ratio of the free volume of engine compartment to the full volume of the engine. Since objective assessment of the volume of engine compartment and of the engine with attached equipment is difficult, values of the arrangement density are assigned in a first approximation.

4. A decrease in the intensity of heat transfer of engines is achieved through heat insulation. One of the techniques of engine heat insulation is covering it with thermal insulation materials. Effect of heat insulation on the engine cooling process can be accounted for if we consider it as a constituent part of the engine. The consequence of this is a change in the thermophysical characteristics of the engine.

5. The process of heat transfer through convection and heat conduction is accompanied by simultaneous heat transfer by thermal radiation. Since the magnitude of this component of the process of heat transfer is small [9], its impact on the cooling rate is excluded from our consideration.

6. According to the theory of a regular mode [15], there are three stages in the cooling process of bodies of any form – non-regular, regular, and stationary regimes. The stages of non-regular regime when thermal field of the body is redistributed throughout the entire volume, as well as the stationary when thermal field reaches ambient temperature, are excluded from our consideration because a decrease in the excess temperature occurs at the stage of a regular mode.

7. In the absence of wind, the engine cooling process is determined by natural convection and its thermal conductivity, which is why the heat transfer intensity is low. But at the emergence of external cooling effect of wind the forced convection becomes decisive for the whole process of cooling. Intensive heat removal from the outer surface of the engine assigns the growth of excess temperature and increase in the speed of heat supply from its internal volume. But the increment of speed of the heat supply continues to a certain level, which is determined by the thermophysical characteristics of the material that the engine is made of. A further increase in the wind speed has no effect on the intensity of cooling process. The observed phenomenon allows us to argue that a dependence of the engine cooling rate on wind velocity is non-linear, and exponential in character.

8. In formula (4), coefficient of non-uniformity of temperature distribution in the engine depends on the cooling conditions on the surface of the body, in other words, on the Biot criterion. Given limited information about the interrelation between the Biot criterion and non-uniformity of temperature, as well as the complexity of analytical determination, the character of dependence of the cooling rate on the Biot criterion $m = f(Bi)$ is determined based on experimental research. The mathematical model of change in the cooling rate of automobile engines (4) may be submitted in the final form only after the experimental study is completed.

At the next stage of the study, we work out a procedure for the estimation of adaptability of automobiles to operation under winter conditions by the cooling rate of engines, which is based on the application of adaptability factor (2). The enlarged block diagram of the algorithm for estimating the adaptability of an automobile to operation under winter conditions based on the cooling rate of engines is shown in Fig. 1.

Applying the proposed procedure will make it possible to estimate the adaptability of automobiles under assigned operational conditions by setting the characteristics of engine and its heat insulation, arrangement density of the under-hood space.

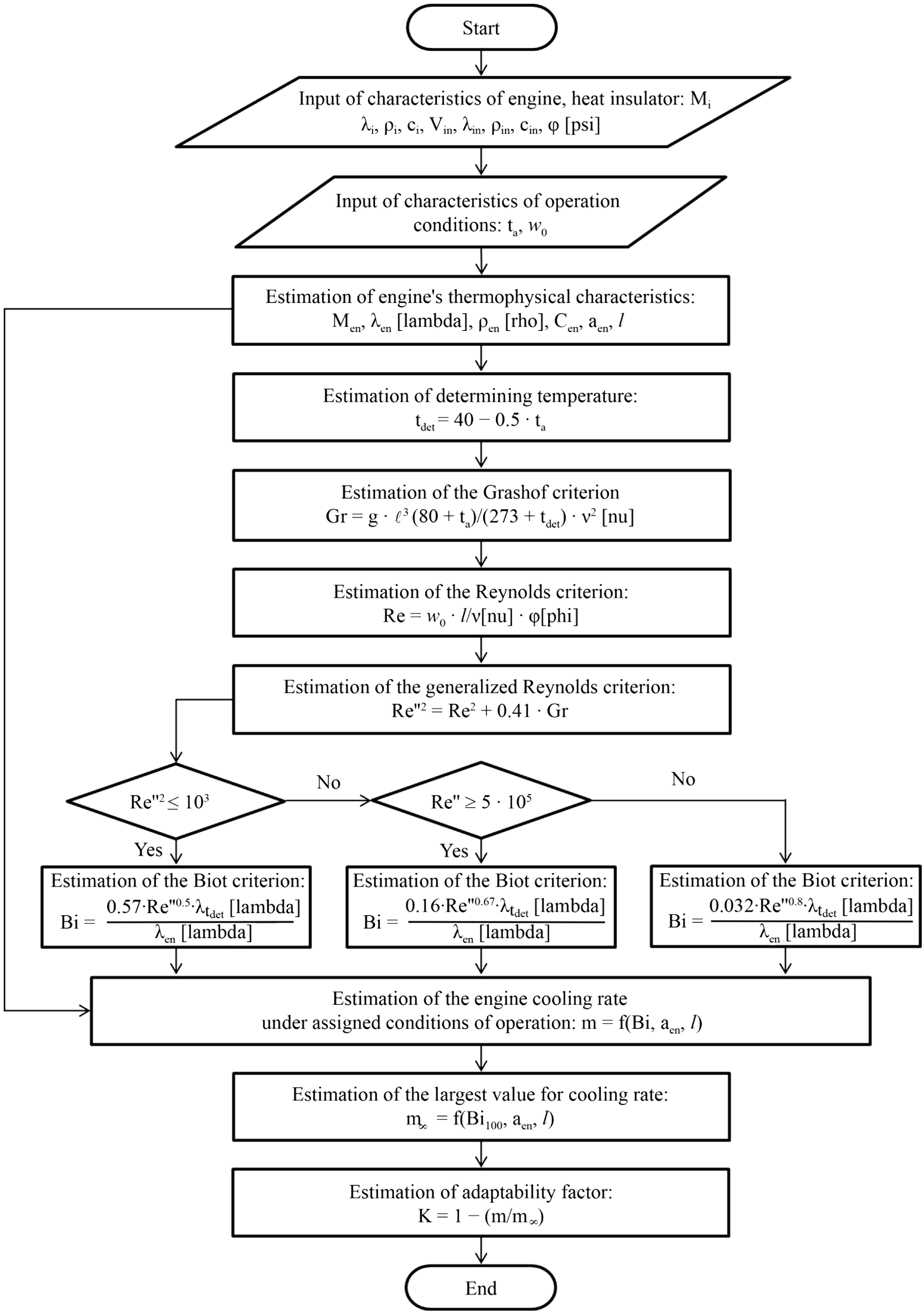

Fig. 1. Generalized algorithm for estimating the adaptability of automobiles to operation under winter conditions based on the engine cooling rate

5. Experimental study of the automobile engine cooling rate

In order to assess cooling rate of automobile engines under assigned operational conditions, we conducted an active experiment on estimating the duration of engine cooling τ from initial temperature t_i to the final temperature t_f at known air temperature t_a and wind force [21].

$$m=\frac{1}{\tau}\ln\frac{t_i-t_a}{t_f-t_a}. \qquad (10)$$

The methodological base of the experiment was the theory of a regular thermal mode [15], according to which at the stage of a regular cooling mode the excess temperature is the same at any point in the engine. We accepted, as the initial temperature, working temperature of the engine, which is reached during continuous operation of the vehicle. The latter guarantees the establishment of a steady thermal equilibrium of all engine parts. The engine was cooled to the temperature corresponding to the smallest value of scale for a coolant temperature indicator. A source of information about temperature of the engine was a coolant temperature gauge, mounted on the automobile dashboard. Air temperature was determined by the thermometer; cooling duration – by a wristwatch. Wind speed was determined by the anemometer.

Experiments were conducted on vehicles with thermally insulated and non-thermally insulated engine. In the case of a thermally insulated variant, automobile engine was covered with a heat insulation material.

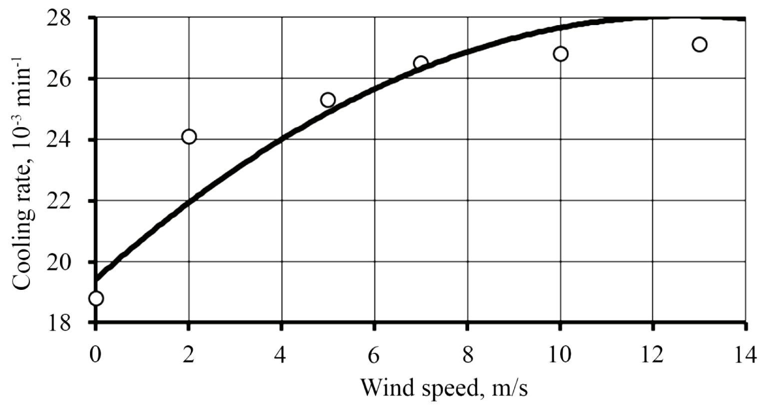

Fig. 2. Dependence of cooling rate of the non-thermally insulated engine of the automobileVAZ-2107 on wind speed

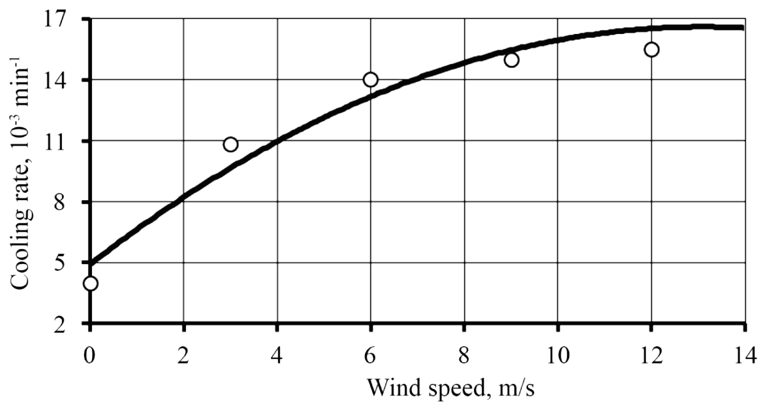

Fig. 3. Dependence of cooling rate of the thermally insulated engine of the automobile ZIL-130 on wind speed

Statistical analysis of experimental values for the rate of cooling of engines in the examined automobiles was performed by the software REGRESS 2.5 [22]. The analysis conducted using the Pearson criterion confirmed the normal distribution law. This allowed us to identify the required number of measurements to achieve 10 % relative error at confidence interval 0.9 [23, 24].

Fig. 2, 3 show results of experimental study. The charts reflect the influence of wind speed and heat insulation on the cooling rate of engines of the automobiles VAZ-2107 and ZiL-130.

After processing results of the experiments, we obtained values for the adaptability factor of an automobile to operation under winter conditions based on engine cooling rate. Using the obtained adaptability coefficients of the examined vehicles, we checked a significance of the difference between three previously proposed levels of adaptability for the devised adaptability factor. Testing the significance in the difference between adaptability levels is conducted using a statistical hypothesis on the equality of mathematical expectations [24].

An analysis of statistical characteristics revealed significant differences in mathematical expectations that allows us to argue about three different levels of vehicle adaptability for winter conditions based on the engine cooling rate.

At the next stage, the mathematical model of the cooling rate (4) that takes into consideration wind speed, the weight and heat insulation of the engine, and arrangement density of the under-hood space, is corrected. Correction is necessary to account for the irregularities of temperature distribution.

In order to identify the character of dependence $m=f(Bi)$, data on the conditions of experiments are employed to determine the Biot criterion Bi; numerical values for the rate of cooling – to determine dimensionless rate μ (mu)

$$\mu=m\cdot a_{en}/l^2. \qquad (11)$$

A certain error, assumed in this case due to the assumptions made, can be eliminated by correcting the parameters of the mathematical model, which is consistent with generally accepted practice.

As a result of processing experimental data and analytical estimations, we established a dependence of cooling rate on the Biot criterion Bi. Calculations have shown that the dependence of cooling rate on the Biot criterion Bi is determined from exponential dependence of the following form:

$$m=a\cdot\exp\left(-\frac{b}{Bi}\right)\cdot\frac{a_{en}}{l^2}, \qquad (12)$$

where a, b are the empirical coefficients.

Graphical form of dependence is shown in Fig. 4. Similar forms are demonstrated by dependences obtained for other examined automobiles, both with and without thermal insulation of the engine. Parameters of the obtained mathematical model (12) that reflects the influence of wind speed, arrangement density of the under-hood space, the weight of engine, presence of heat insulation, which finds its expression in the Biot criterion Bi, are given in Table 2.

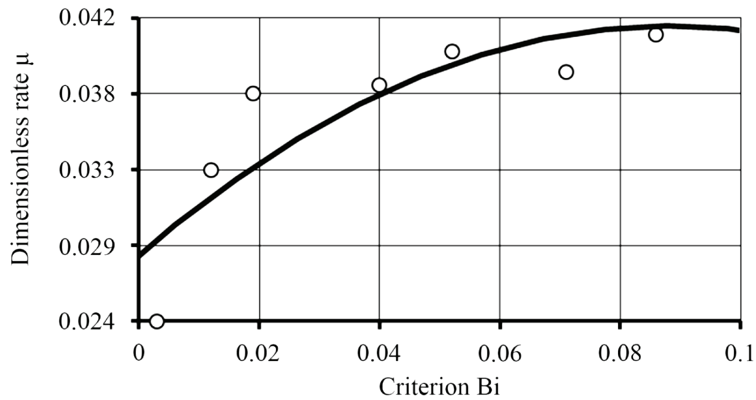

Fig. 4. Dependence of dimensionless cooling rate of engine of the automobile GAZ-31029 on the Biot criterion

Table 2

Parameters of the mathematical model of change in the engine cooling rate on the Biot criterion *Bi*

Make, model of automobile	Parameters of mathematical model			
	Non-thermally insulated engine		Thermally insulated engine	
	$a, \times 10^{-2}$	$b, \times 10^{-3}$	$a, \times 10^{-2}$	$b, \times 10^{-3}$
VAZ-2107	5.08	1.33	3.34	2.43
VAZ-2109	5.09	1.37	4.40	2.64
VAZ-2121	5.53	1.45	3.76	2.43
GAZ-31029	4.08	1.65	3.97	2.69
UAZ-31512	3.93	1.71	2.54	2.53
ZiL-130	0.16	10.6	0.11	14.0
LiAZ-677	0.17	8.7	0.15	13.0
KAMAZ-5320	0.32	14.86	0.27	20.9

Testing the model for adequacy, performed by the Fisher criterion and the mean error of approximation, showed that the values of variance Fisher ratio do not exceed critical values while the mean error of approximation is within 1.4...5.4 %, which testifies to the adequacy of model (12). The resulting mathematical model is consistent with the previously proposed hypothesis on the exponential form of engine cooling rate dependence on wind speed. The limit of change in the cooling rate is determined by the thermal conductivity of the engine.

6. Discussion of results of studying the adaptability of automobiles to operation under winter conditions based on the rate of engine cooling

Temperature mode of automobile engines undergoes constant change temperature during operation. The temperature mode either grows as a result of heat transfer due to fuel combustion, or decreases as a result of natural and forced cooling. Intensity of the course of processes in the engines of different vehicles differs. One of the aspects of this issue is being examined in the present study.

The research focuses on the process of engine cooling after its operation stops. We use cooling rate as a criterion of the temperature regime. The choice of this particular indicator is predetermined by its constancy under a regular mode when excess temperature at any point of the engine is the same. The study has shown different impact of wind speed, the mass of engine and its heat insulation, arrangement density in the under-hood space on the rate of cooling. This explains different adaptability of automobiles to operation under winter conditions based on engine cooling rate. To estimate the differences in adaptability, we proposed a coefficient and grading for different levels.

The results obtained could be used to assess the limits of operating conditions of the rational use of automobiles of different makes and models in different designs.

According to the technical-economic requirements put to vehicles operating under severe climatic conditions, the rate of fall in the temperature of liquid in the cooling system of idle engine should not exceed 1 °C/min [8]. That is why the rational use of a vehicle under given harsh climatic conditions is predetermined by meeting a condition:

$$\nu_t = \frac{t_i - t_f}{\tau} \leq 1, \qquad (13)$$

where ν_t is the speed of fall in the engine coolant temperature, °C/min; t is the duration of engine cooling from initial temperature t_i to final temperature t_f, min.

If we accept engine's operating temperature as an initial temperature, and critical temperature of cooling as the final temperature, then the duration of cooling under the assigned conditions will determine the feasibility of using the automobile for the proposed criterion. To determine it, it is necessary to employ the previously proposed mathematical model (12) and information about the predicted conditions of automobile operation in terms of air temperature and wind speed, which can be derived from data about multi-year observations over climatic conditions in a representative area of operation.

The study conducted does not allow us to suggest completeness of the scientific search. We have not tackled issues on a temperature mode change in the automobile engines during warmup [20]. Important factors that determine the rate of the process [20] remain unidentified. We have not explored the mechanism of change in the thermal field of engine with an internal source of heat. The questions specified are the object and the subject of further research.

7. Conclusions

1. We devised an indicator of the adaptability of an automobile to operation under winter conditions based on the engine cooling rate, and a procedure of its estimation. For the examined automobiles, adaptability factor in the absence of wind assumes values from 0.30 to 0.76. Among the automobiles studied, the lowest values of adaptability factor are demonstrated by the automobiles VAZ (K = 0.31...0.33), though using heat insulation for engine helps improve adaptability factor by 50...80 %. The highest adaptability by this indicator is demonstrated by the vehicles ZiL-130 (K = 0.67)

and KAMAZ-5320 ($K=0.60$). Thermally insulation of the engines of these automobiles helps increase the adaptability by 20 %.

2. Three levels of vehicle adaptability to operation under winter conditions based on the engine cooling rate were established: low – $K=0...0.33$; medium – $K=0.34...0.66$; high – $K=0.67...1$. We determined significance of their difference based on statistical verification.

3. We established an exponential form of the mathematical model of change in the automobile engine cooling rate under the influence of wind speed, mass of the engine, its heat insulation, arrangement density in the under-hood space. For the examined automobiles, parameters of the mathematical model have the following intervals of variance: a – from $0.11\cdot10^{-2}$ to $5.53\cdot10^{-2}$; b – from $1.33\cdot10^{-3}$ to $20.90\cdot10^{-3}$ at the adequacy level from 0.90 to 0.99.

4. A procedure is proposed for determining the limits of operational conditions of the rational use of automobiles which is based on the application of the obtained mathematical model for estimating engine cooling rate under assigned operating conditions and meeting the condition for critical velocity of temperature fall not exceeding 1 °C/min.

References

1. Dedyukin, V. V. Temperaturnyy rezhim osnovnyh agregatov i toplivnaya ekonomichnost' avtomobiley [Text] / V. V. Dedyukin, L. G. Reznik, L. I. Vilenskiy et. al. // Problemy adaptatsii avtomobiley k surovym klimaticheskim usloviyam Severa i Sibiri. – 1977. – P. 20–29.
2. Abram, C. Temperature measurement techniques for gas and liquid flows using thermographic phosphor tracer particles [Text] / C. Abram, B. Fond, F. Beyrau // Progress in Energy and Combustion Science. – 2018. – Vol. 64. – P. 93–156. doi: 10.1016/j.pecs.2017.09.001
3. Dascalescu, S.-C.-D. Air Flow Control Servomechanism for Cooling the Radiator of a Car Engine [Text] / S.-C.-D. Dascalescu, M. Receanu // SAE Technical Paper Series. – 2013. doi: 10.4271/2013-01-1296
4. Lin, C. Effect of Cross-Winds on Motor Car Engine Cooling [Text] / C. Lin, J. W. Saunders, S. Watkins // SAE Technical Paper Series. – 1997. doi: 10.4271/970138
5. Tharayi, R. A. Development of a Cost Effective Power Train Cooling System for a Passenger Car with Rear Engine [Text] / R. A. Tharayi, S. Pol // SAE Technical Paper Series. – 2009. doi: 10.4271/2009-01-0169
6. Charkov, S. T. Obobshchennaya otsenka prisposoblennosti avtomobiley k osobym usloviyam ekspluatatsii. Vol. 2 [Text] / S. T. Charkov // Tez. dokl. 2-oy Vsesoyuznoy nauch. konf. Neft' i gaz Zapadnoy Sibiri. – Tyumen', 1989. – P. 171.
7. Reznik, L. G. Koeffitsient adaptatsii avtomobiley [Text] / L. G. Reznik // Avtomobil'nyy transport. – 1974. – Issue 27. – P. 3–9.
8. Buyanov, E. V. Transport dlya severa [Text] / E. V. Buyanov. – Moscow: Transport, 1970. – 36 p.
9. Teploenergetika pri ekspluatatsii transportnyh sredstv v neftegazodobyvayushchih rayonah Zapadnoy Sibiri [Text]: sprav. pos. / O. A. Stepanov (Ed.). – Moscow: Nedra, 1997. – 269 p.
10. Kolchin, A. I. Raschet avtomobil'nyh i transportnyh dvigateley [Text]: ucheb. pos. / A. I. Kolchin, V. P. Demidov. – 2-e izd., pererab. i dop. – Moscow: Vyssh. shkola, 1980. – 400 p.
11. Pang, S. C. A review on air flow and coolant flow circuit in vehicles' cooling system [Text] / S. C. Pang, M. A. Kalam, H. H. Masjuki, M. A. Hazrat // International Journal of Heat and Mass Transfer. – 2012. – Vol. 55, Issue 23-24. – P. 6295–6306. doi: 10.1016/j.ijheatmasstransfer.2012.07.002
12. Chen, X. Study of different cooling structures on the thermal status of an Internal Combustion Engine [Text] / X. Chen, X. Yu, Y. Lu, R. Huang, Z. Liu, Y. Huang, A. P. Roskilly // Applied Thermal Engineering. – 2017. – Vol. 116. – P. 419–432. doi: 10.1016/j.applthermaleng.2017.01.037
13. Isachenko, V. P. Teploperedacha [Text]: ucheb. / V. P. Isachenko, V. A. Osipova, A. S. Sukomel. – Moscow: Energoizdat, 1981. – 416 p.
14. Kast, W. Convective heat and mass transfer – a Uniform representation for flow channels and flow-around bodies of any shape and arrangement [Text] / W. Kast. – Berlin: Springer-Verlag, 1974.
15. Kondrat'ev, G. M. Regulyarnyy teplovoy rezhim [Text] / G. M. Kondrat'ev. – Moscow: GITTL, Gostekhizdat, 1954. – 408 p.
16. Zukauskas, A. Heat Transfer in Turbulent Fluid flows [Text] / A. Zukauskas. – Berlin: Springer, 1987.
17. Churchill, S. Free convection around immersed bodies [Text] / S. Churchill. – New York: Begell House, 2002.
18. Cebeci, T. Physical and Computational Aspects of Convective Heat Transfer [Text] / T. Cebeci, P. Bradshaw. – New York: Springer, 1988. doi: 10.1007/978-1-4612-3918-5
19. Datla, S. A Comprehensive Analysis of the Association of Highway Traffic with Winter Weather Conditions [Text] / S. Datla, P. Sahu, H.-J. Roh, S. Sharma // Procedia – Social and Behavioral Sciences. – 2013. – Vol. 104. – P. 497–506. doi: 10.1016/j.sbspro.2013.11.143
20. Zaharov, N. S. Vliyanie rezhimov progreva avtomobil'nogo dvigatelya zimoy na raskhod topliva [Text] / N. S. Zaharov, A. V. Manyashin, I. M. Titla, V. A. Tyul'kin. – Tyumen': TyumGNGU, 2015. – 149 p.
21. Tyul'kin, V. A. Metodika eksperimental'nyh issledovaniy po opredeleniyu tempov progreva dvigateley avtomobiley [Text] / V. A. Tyul'kin, S. A. Ertman // Problemy ekspluatatsii transportnyh sistem v surovyh usloviyah: Mater. Mezhdunar. nauch.-prakt. konf. Ch. 3. – Tyumen': TyumGNGU, 2002. – P. 131–134.
22. Zaharov, N. S. Programma «REGRESS». Rukovodstvo pol'zovatelya [Text] / N. S. Zaharov. – Tyumen': TyumGNGU, 1999. – 39 p.
23. Vedenyapin, G. V. Obshchaya metodika eksperimental'nogo issledovaniya i obrabotki opytnyh dannyh [Text] / G. V. Vedenyapin. – 2-e izd., dop. – Moscow: Kolos, 1967. – 159 p.
24. Gmurman, V. E. Teoriya veroyatnostey i matematicheskaya statistika [Text]: ucheb. pos. / V. E. Gmurman. – 6-e izd., ster. – Moscow: Vyssh. shk., 1998. – 479 p.