Впечатляющие показатели холодильного цикла системы наддува с глубоким охлаждением надувочного воздуха допускают возможность параллельного использования агрегатов наддува двигателя в качестве холодильной установки автомобильного или железнодорожного рефрижератора для перевозки скоропортящихся грузов.

Заключение

1. Применение систем наддува каскадного обмена давлением с глубоким охлаждением раскрывает перспективу значительного улучшения тяговых и экономических показателей дизельного двигателей, работающих в сложных климатических и эксплуатационных условиях.

2. Представленная имитационная модель с достаточной, для практических целей, точностью позволяет определить параметры составных агрегатов КДВС с СНГО КОД на нерасчетных режимах.

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FUEL OIL ATOMIZATION CHARACTERISTICS SMOOTHED BY A LOGARITHM NORMAL DISTRIBUTION FOR MARINE DIESEL ENGINES

Introduction

The quality of fuel oil atomization is characterized by many indexes, the most important of which are *dispersion* (fineness) and *uniformity of the atomization*, length, operating action range, and flame cone angle. For objective estimation of the atomization quality by the dispersion and uniformity of the atomization at the final adjustment of the engine fuel oil equipment, it is used atomization characteristics [1, p. 100].

In the view of the coming energy crisis due to crude oil depletion the one of the possible alternatives is to introduce coal-water slurries as a fuel for internal combustion engines [2, p. 74]. That kind of fuel has its own reologic and atomization peculiarities. Thus researches of the atomization characteristics of different alternative fuels are urgent. The urgency of the researches is also dictated by a periodically partially incorrect representation of the characteristics.

Naturally, accepting one or another sort of a fuel for burning in the internal combustion engines of one or another type is the matter of time and cost of the fuel. Undoubtedly, subjective preferences of a decision making person will also play some specific role [3, 4].

The innovation of the given article is in trying to use a logarithm normal distribution for smoothing the atomization characteristics of the fuel oil or coal-water slurries for a certain example of the assumed experimental data. It is also important to test a hypothesis on a certain theoretical distribution by a statistical criterion.

The problem setting in the general view relates to some important science and practical problems of the fuel oil or coal-water slurries atomization optimization.

Analysis of the latest researches and publications

In the study book [1, p. 100-104] it is shown atomization characteristics of some fuel oil dependently on the number and diameter of the nozzles on condition of equal summarized cross-section for fuel oil flow fig. 1, [1, p. 101, fig. 39].

On the fig. 1: the characteristic 1 is for 4 nozzles with the diameters of 0.4 mm (4x0.4), 2 – 2x0.57 mm, 3 – 1x0.8 mm. Summarized cross-section for fuel oil flow is the same in all three cases.

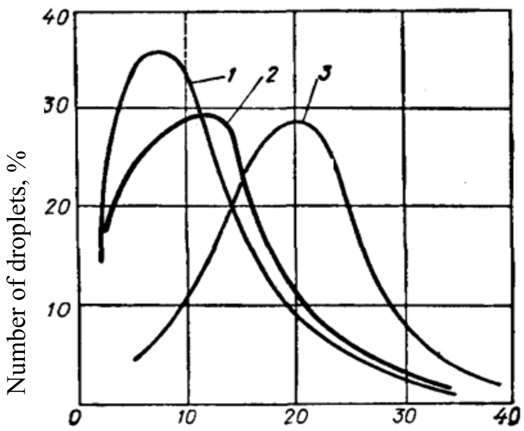

Fig. 1. Fuel oil atomization characteristics

It is also described different factors and their influence upon the dispersion and uniformity of the atomization there. But probably units on the vertical coordinate axis on fig. 1 cannot be expressed in %. And therefore the diagrams can be referred to as just a preliminary image of atomization characteristics.

In the monograph [2, p. 166-197] it is considered problems of coal-water slurries atomization quality. There are criterion relationships for a spray droplets mean diameter by *Sauter*. But there are no curves of a density of the droplets diameter distribution there.

In the study guide [5, p. 192-197] attention is paid to fuel oil atomization and it is shown on fig. 2, [5, p. 195, fig. 7.4] the fuel oil atomization characteristic for a six-cylinder four-stroke supercharged diesel engine with 25 cm bore and 34 cm stroke.

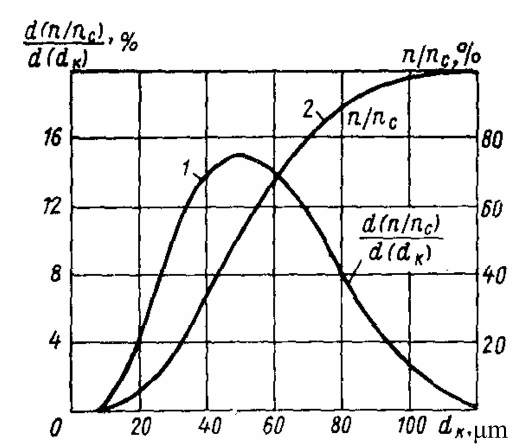

Fig. 2. Fuel oil atomization characteristic

On the fig. 2: 1 – relative frequencies curve of the characteristics, 2 – relative summary curve. For the summary curve: d_k – diameters of droplets, n – total number of droplets that have dimensions form minimum up to the given diameter, n_c – the total number of droplets. For differential curve 1: d_k – given value of droplets sizes, $d(n/n_c)$ – the increase of the droplets number, $d(d_k)$ – the increase of the diameter.

However like in the work [1, p. 101, fig. 39] the density of the distribution measured in % which apparently is not correct. Moreover in the related text block it is mixed numbers that denote differential and cumulative curves.

In the newest publication [6, p. 174] denoted the utmost importance of the size of the fuel droplets for the combustion process quality. Although there is no any curves of the size distribution.

An attempt to analyze some parametric researches on reologic properties of coal-water slurries for their use in ships' internal combustion engines was made in the paper [7]. It is quite natural to continue analytical researches in the field of fuel supply flow, injection, and spraying.

Analytical researches was made in the monographs [3, 4], where it was given a theoretical background for solving problems of a technical state on the basis of *subjective analysis* and *problem-resource approach*.

As it is seen from above mentioned speculations there is a necessity to remind principles of statistical estimations and using them to get the low of distribution.

Problem setting

The intention of the given paper is to research the adequacy between experimental and theoretical distributions for fuel oil atomization characteristics. Also it is to plot diagrams of distribution curves and test the hypothesis of a logarithm normal distribution.

Main material

It is necessary to determine droplets diameter of a spray before plotting atomization characteristics. It can be used one of the simplest and most commonly used way of putting a smoked plate into the spray. Then the droplets dimensions have to be measured with the help of a microscope [1, p. 101; bilo, p. 174].

After this procedure we get so-called "simple statistical sample" or "simple statistical series". The simple statistical sample is a primary form of a statistical material registration and can be proceeded in different ways. One of the ways of such a treatment is plotting a statistical function of a distribution of the random variable [8, p. 134].

Statistical function of a random variable D_k is a frequency of the event $D_k < d_k$ in the given statistical material:

$$F^*(d_k) = P^*(D_k < d_k), \qquad (1)$$

where $F^*(d_k)$ – statistical function of the distribution,

P^* – statistical frequency.

In order to determine the value of the statistical function of the distribution at the corresponding d_k, it is just enough to calculate the number of droplets with the value of D_k less than d_k and divide the number in the total number of droplets.

When the number of observations is quite large (a few hundreds) a simple statistical sample becomes an inconvenient form of registration of the statistical material – it becomes inexpressive and poor for presentation.

To get it more compact and good looking the statistical material should undergo an additional treatment – it is to be plotted a so-called "statistical series". Assume we have some results of observations on the random variable D_k, performed in a simple statistical sample. Then we divide all diapason of the observed values of D_k into intervals and calculate the number of values m_i, for each i^{th} interval. We divide these numbers into the total number of the observations n and get the frequency, corresponding to the given interval:

$$p_i^* = \frac{m_i}{n}. \qquad (2)$$

Total sum of all intervals, obviously, should equal one.

Plotting a table in which it is given intervals in the way of their appearance on the abscise axis and corresponding frequencies we get a statistical series.

Assumed experimental data

First we plot a statistical series.

According to the curve 1 on fig. 1 it probably was implied some distribution there. Let us assume it was primary experimental data performed in a simple statistical sample. The table 1 is performed as a statistical series correspondingly. In the table 1 I_i depicts the intervals of droplets diameter in the spray.

Table 1

Assumed experimental data																	
##	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Σ
I_i	0-1	1-2	2-3	3-5	5-7	7-9	9-10	10-11	11-14	14-17	17-20	20-25	25-30	30-35	35-40	40-45	0-45
m_i	0	3	28	230	492	630	321	312	828	633	480	540	270	150	80	45	5042
p_i^*	0	0.000595	0.005553	0.045617	0.09758	0.12495	0.063665	0.06188	0.164221	0.125545	0.0952	0.1071	0.05355	0.02975	0.015867	0.008925	1

When grouping the observed data of the random value into an interval, there is a question arising about what interval the value, which is precisely on the border of the two intervals, should be kept to. In such a case we conditionally reckon it belonging to both intervals and add to the numbers m_i of the one and the other interval $\frac{1}{2}$.

The number of intervals which the statistical material has to be divided into does not have to be too great (then the series of the distribution becomes inexpressive, and frequencies in it show irregular oscillations); on the other hand the number of the intervals does not have to be too small (when we have few intervals properties of the distribution is described too rough by such a statistical series). Practice proves that in most cases it is rationally to choose the number of the intervals from 10 to 20.

The more representative and uniform the statistical material the bigger number of the intervals can be chosen when composing the statistical series. The lengths of the intervals can be both the same and different. It is easer, of course, to choose them equal. However, when forming information about random values, distributed utmost irregularly, sometimes it gets convenient to choose in areas of the highest density of distribution intervals narrower than in areas of low density.

Then we perform the statistical series graphically in the shape of a histogram. We have done it like this. On the abscise axis we put intervals, and on each interval as on the basis we plot a rectangle, the area of which equals the frequency of the given interval. To plot the histogram it is necessary to divide the frequency of each interval into its length and use the acquired value as the height of the rectangle.

In case of equal by length intervals the heights of the rectangles are proportional to corresponding frequencies. It comes out of the histogram plotting that its total are equals one.

In this example of the assumed statistical data the length of intervals are not equal because the prototype distribution has a very sharp increase of the distribution density in the area from 4 to 12 μm (see fig. 1, curve 1). Therefore the intervals from # 1 up to # 8 are narrower than from # 9 up to # 16.

In the table 2 it is given data for plotting the histogram.

The histogram constructed accordingly to the data given in the table 2 is shown on fig. 3.

On the fig. 3: x – d_k, $N_{kp}^{\langle 0\rangle}$ – I_i, $f(x)$ – a smoothing curve, $N_{kp}^{\langle 4\rangle}$ – the frequency, $N_{kp}^{\langle 2\rangle}$ – the number of droplets.

In principle plotting the statistical function of the distribution already solves the problem of a description of the experimental material preliminary illustrated on fig. 1, 2. However plotting the function of distribution with the aid of the equation 1 is not so convenient – in the sense of imagination ability. Often it is better to use other characteristics of statistical distributions, analogous not to the function of a distribution but the density of the distribution. This method uses the equation (2).

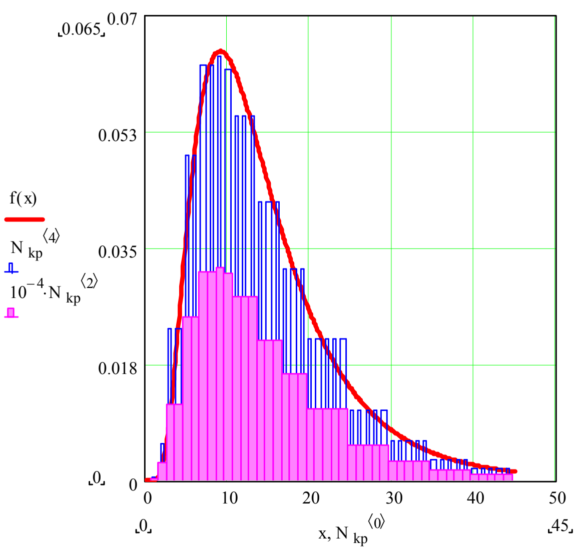

Fig. 3. Distribution, histogram, and smoothing curve

Table 2

Data for plotting the histogram

##	I_i	m_i		p_i^*	
1	0-1	0	0	0	0
2	1-2	3	3	0,000595	0,000595
3	2-3	28	28	0,005553	0,005553
4	3-4	230	115	0,045617	0,022808
5	4-5		115	0	0,022808
6	5-6	492	246	0,09758	0,04879
7	6-7		246	0	0,04879
8	7-8	630	315	0,12495	0,062475
9	8-9		315	0	0,062475
10	9-10	321	321	0,063665	0,063665
11	10-11	312	312	0,06188	0,06188
12	11-12	828	276	0,164221	0,05474
13	12-13		276	0	0,05474
14	13-14		276	0	0,05474
15	14-15	633	211	0,125545	0,041848
16	15-16		211	0	0,041848
17	16-17		211	0	0,041848
18	17-18	480	160	0,0952	0,031733
19	18-19		160	0	0,031733
20	19-20		160	0	0,031733
21	20-21	540	108	0,1071	0,02142
22	21-22		108	0	0,02142
23	22-23		108	0	0,02142
24	23-24		108	0	0,02142
25	24-25		108	0	0,02142
26	25-26	270	54	0,05355	0,01071
27	26-27		54	0	0,01071
28	27-28		54	0	0,01071
29	28-29		54	0	0,01071
30	29-30		54	0	0,01071
31	30-31	150	30	0,02975	0,00595
32	31-32		30	0	0,00595
33	32-33		30	0	0,00595
34	33-34		30	0	0,00595
35	34-35		30	0	0,00595
36	35-36	80	16	0,015867	0,003173
37	36-37		16	0	0,003173
38	37-38		16	0	0,003173
39	38-39		16	0	0,003173
40	39-40		16	0	0,003173
41	40-41	45	9	0,008925	0,001785
42	41-42		9	0	0,001785
43	42-43		9	0	0,001785
44	43-44		9	0	0,001785
45	44-45		9	0	0,001785
Σ	0-45	5042	504 2	1	1

Smoothing the statistical series by a logarithm normal distribution

Often it happens to be desirable to compare to experimental data such a distribution of a random value x in an interval (a, b), so that some function g(x) would have a normal distribution, i. e. for the class of distributions by Captain [9, p. 613]:

$$\Phi_x(x) = \Phi_u\left[\frac{g(x)-\mu}{\sigma_g}\right], \quad (3)$$

where $\Phi_x(x)$ – integral of probabilities, Φ_u – normal function of distribution, μ – expectation, σ_g – standard deviation.

The density of the distribution:

$$\varphi_x(x) = \frac{1}{\sigma_g\sqrt{2\pi}}\exp\left\{-\frac{1}{2}\left[\frac{g(x)-\mu}{\sigma_g}\right]^2\right\}\left|\frac{dg}{dx}\right|. \quad (4)$$

The random variable x, described by distribution (3, 4), can be considered as the limit of the sequence of the random values

$$x_{r+1} = x_r + z_{r+1}h(x_r) \quad (r = 0, 1, 2, \ldots),$$

each of which is the result of an action of small independent impulses $z_1, z_1, \ldots, z_1$, that satisfy conditions of the limit theorems (by Chebyshev, central limit theorem), moreover

$$z_1 + z_2 + \ldots + z_r = \sum_{i=0}^{r-1}\frac{x_{i+1}-x_i}{h(x_i)} \approx \int_{x_0}^{x}\frac{dx}{h(x)} = g(x).$$

In particular, if $h(x) = x$, that is the effect of an impulse action is proportional to already achieved value of the random variable, and $x_0 = 1$, then g(x) = lnx, and we have logarithm normal distribution

$$\varphi(x) = \begin{cases} 0 & (x \le 0), \\ \frac{1}{x\sigma\sqrt{2\pi}}\exp\left\{-\frac{1}{2}\left[\frac{\ln x-\mu}{\sigma}\right]^2\right\} & (x > 0). \end{cases} \quad (5)$$

According to the shape of the histogram $N_{kp}^{\langle 4\rangle}$ on the fig. 3, and theoretical reasons (5), we choose μ = ln12,661 and σ = 0,5765 in such a way that the curve f(x) on the fig. 3 would have similar shape to the $N_{kp}^{\langle 4\rangle}$.

The hypothesis test of a logarithm normal distribution

To test the hypothesis about accordance between the theoretical distribution (5) and assumed experimental data we use one of the most commonly used tests: the chi-square goodness-of-fit test.

The Pearson criterion χ^2 is calculated by the formula [8, p. 152]

$$\chi^2 = n\sum_{i=1}^{k}\frac{\left(p_i^* - p_i\right)^2}{p_i}, \quad (6)$$

where k – the number of intervals, p_i – theoretical probability for random variable D_k to get to the specified i^th interval of the testing distribution given by the density (5).

Or on the condition of (2) the measure of diversity (6) has the view of

$$U = \chi^2 = \sum_{i=1}^{k}\frac{(m_i - np_i)^2}{np_i}. \quad (7)$$

Distribution of χ^2 (6, 7) depends on a parameter r, which is called "the number of degrees of freedom" of the given distribution. It is calculated by the formula

$$r = k - s, \quad (8)$$

where s – the number of imposed restrictions.

In this problem setting it is just one

$$\sum_{i=1}^{k}p_i^* = 1. \quad (9)$$

In the table 3 it is illustrated the results of calculations. The sum of p_i: $\sum_{i=1}^{k}p_i = 0{,}986086 \ne 1$ because the normalizing condition for the case of the logarithm normal distribution (5) means

$$\int_0^\infty f(x)dx = 1,$$

which accomplishes.

The number of degrees of freedom (8) with respect to the restriction (9) at the $k = 16$

$$r = 16 - 1 = 15.$$

Using special tables composed for χ^2 distribution for the values of $\chi^2 = 10{,}24$ and r = 15 we get probabilities p = 0,8 at the $\chi^2 = 10{,}31$ and p = 0,9 at the $\chi^2 = 8{,}55$.

Thus with the probability more than 0,8 the diversities between experimental and theoretical data occur due to random factors and the hypothesis of the logarithm normal distribution of fuel droplets sizes in a spray with the parameters of μ = ln12,661 and σ = 0,5765 can be recognized as the one that does not contradict to the experimental data.

Table 3

Calculations for chi-square goodness-of-fit test				
##	I_i	p_i^*	p_i	$\frac{\left(p_i^* - p_i\right)^2}{p_i}$
1	0-1	0	0,000005	0,000005
2	1--2	0,000595	0,000679	1,04957E-05
3	2--3	0,005553	0,005566	2,81096E-08
4	3--5	0,045617	0,04728	5,85062E-05
5	5--7	0,09758	0,09846	7,85931E-06
6	7--9	0,12495	0,12493	3,33654E-09
7	9--10	0,063665	0,06426	5,50533E-06
8	10--11	0,06188	0,06247	5,56838E-06
9	11--14	0,164221	0,16558	1,11614E-05
10	14--17	0,125545	0,12616	2,9939E-06
11	17--20	0,0952	0,09075	0,00021824
12	20--25	0,1071	0,09489	0,001571217
13	25--30	0,05355	0,0517	6,6212E-05
14	30--35	0,02975	0,02839	6,51592E-05
15	35--40	0,015867	0,01588	1,11064E-08
16	40-45	0,008925	0,009085	2,82971E-06
Σ	0-45	1	0,986086	0,002031122
χ^2				10,24091577

Subjective preferences of fuel atomization quality accordingly to the shape of the droplets sizes distributions

According to the theory of fuzzy sets it is formulated functions of belonging. There is an arbitrary subjective approach in that portrays some personal ideas about uncertainty. The newly developing theory of subjective analysis [3, 4] offers introduction of subjective preference functions which allows estimation in a real view the influence of psychological factors upon a decision making person.

There is a formal analogy between the distribution of some preferences and distribution of probabilities, and we can use many results of the theory of probabilities, mathematical statistics, and the theory of information, giving them, although, every time an interpretation in terms of the subjective analysis [3, p. 115].

Here it is used some variation principle of the maximum of the subjective entropy of certain subjective preferences. The corresponding functional taken in a rather general view [3, p. 119, (3.38)]:

$$\Phi_\pi = \alpha H_\pi + \beta\varepsilon + \gamma \mathrm{H}\,, \qquad (10)$$

where H_π – the subjective entropy; ε = ε(π, *U*, …) – a function of subjective effectiveness; *N* – normalizing condition; α, β, γ – structural parameters, they can be considered in different situations as Lagrange coefficients, weight coefficients or endogenical parameters which represent certain psychic properties.

The optimal distribution that we get as the result of using the variation principle has the view of:

$$\pi^-(\sigma_i) = \frac{e^{-\beta_L L(\sigma_i)}}{\sum_{j=1}^{N} e^{-\beta_L L(\sigma_i)}}\,, \qquad (11)$$

where $\pi^-(\sigma_i)$ – a function of negative preferences of a subject concerning achievable for him alternatives σ_i; $L(\sigma_i)$ – a function of losses («harmfulness»).

When considering required for each alternative resources – $R^{req}(\sigma_i)$ $(\sigma_i \in S_a)$, where S_a – a set of achievable for a person's goals alternatives, we have a problem-resource situation. In every problem-resource situation there is its own distribution of the required resources. It is also there is a possibility together with the use of absolute required resources to use normalized resources. If

$$R^{req} = \sum_{j=1}^{N} R^{req}(\sigma_j), \qquad (12)$$

then normalized resources

$$\overline{R}^{req}(\sigma_i) = \frac{R^{req}(\sigma_i)}{\sum_{j=1}^{N} R^{req}(\sigma_j)}\,. \qquad (13)$$

We can make an assumption, that $L(\sigma_i) = R^{req}(\sigma_i)$, or $L(\sigma_i) = \overline{R}^{req}(\sigma_i)$. Then a function of the negative preference [3, p. 127, (3.64)]

$$\pi^-(\sigma_i) = \frac{e^{-\beta R^{req}(\sigma_i)}}{\sum_{j=1}^{N} e^{-\beta R^{req}(\sigma_j)}}\,, \qquad (14)$$

The sense of this distribution – the more the required resources needed for achieving the σ_i alternative the less that alternative preferable to a person.

It can be chosen an exceeding value or an increase of some disposable resources over required as a function of positive preferences. There are two possible variants. Disposable resources: R^{disp}, if they are universal (for example money), do not depend upon the alternative being chosen by a subject. Then the increase is

$$R^{d+}(\sigma_i) = R^{disp} - R^{req}(\sigma_i).$$

If disposable resources are specialized, then [3, p. 127, (3.65)]

$$R^{d+}(\sigma_i) = R^{disp}(\sigma_i) - R^{req}(\sigma_i)\,. \qquad (15)$$

According to an accepted technical and economical strategy a subject chooses fuel atomization quality by the shape of fuel atomization characteristics as a kind of alternatives portrayed by curves fig. 1-3 based on the constructed distributions and histograms with the aid of the formulas (1-5) and tested by the procedure (6-9) in accordance with a certain criterion.

Conclusions

The experimental data for fuel oil or coal-water slurry atomization characteristics, assumed accordingly to [1, 5] can be in the view of the sense of the formulated problem smoothed by a logarithm normal distribution.

The ordinate axis measurement units for differential curves of the droplets sizes distributions should be expressed in $\frac{\%}{\mu m}$ in [1, 5]. Apparently there is a misprinting in the books.

Testing the hypothesis of the logarithm normal distribution with the parameters of $\mu = \ln 12{,}661$ and $\sigma = 0{,}5765$ by the Pearson criterion χ^2 allows to accept the hypothesis. Chi-square goodness-of-fit test gives values of $\chi^2 = 10{,}24$, and at r = 15 we get probabilities: p = 0,8 at the $\chi^2 = 10{,}31$ and p = 0,9 at the $\chi^2 = 8{,}55$.

Concerning following researches the quality of the fuel spray, which depends upon fuel oil or coal-water slurry characteristics, injectors tips, injectors apertures, pressures, temperatures, viscosities, and other reologic characteristics, as well as the technical state versus economical factors, will exert an influence upon a decision making person subjective preferences. There is a tool for such researches in the view of (10-15), that is a kind of a variation problem which includes the subjective entropy of the subjective preferences.

<u>The literature list:</u>

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ВЛИЯНИЕ ТЕМПЕРАТУРЫ СТЕНОК КАМЕРЫ СГОРАНИЯ НА ИСПАРЕНИЕ И ВЫГОРАНИЕ ТОПЛИВА В ФОРСИРОВАННЫХ ДИЗЕЛЯХ

Анализ развития форсированных дизелей показывает, что значительное повышение температур поршня приводит к необходимости использования их тепловой защиты из условий обеспечения надежности и долговечности. Для тепловой защиты огневой поверхности камеры сгорания (КС) обычно применяются вставки из термостойких сталей, составные поршни с накладками и др. Например, в конструкции высокофорсированного дизеля [1] температура монометалического поршня ограничена 620К. Применение жаростойких накладок на поршнях позволяет повысить допускаемую температуру стенок КС четырехтактного дизеля до 820 К, двухтактного до 1220 К [1] . В разрабатываемых двигателях для применения альтернативных дизельных топлив, в частности растительных масел, биотоплив высокие температуры стенок КС оказываются необходимыми для организации качественного рабочего процесса [2].

Однако, обеспечение высоких показателей рабочего процесса при теплоизоляционной защите поршня связано с решением целого ряда проблем. На кафедре ДВС НТУ «ХПИ» были проведены комплексные испытания дизеля 4ЧН12/14 с серийными и с теплоизолированными элементами рабо-