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INFLUENCE OF ULTRASONIC OSCILLATIONS ON FLUIDITY
OF HEAVY FUEL OIL AT LOW TEMPERATURE

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In laboratory installation the rotation effort of the tube is monitored during starting its rotation in the studied medium as a dependence on longitudinal ultrasonic oscillations of the tube providing shift oscillations of the studied medium in near-wall layer of the tube. Statistically significant decrease of rotation effort normalized to reference temperature of the medium (mazut M-100, temperatures from -10°C up to -18°C) has been revealed, after 2-minute influence of ultrasonic oscillations (frequency 32.5 kHz) with acoustic power being no more than $0.008\text{ W}/\text{cm}^2$. On the basis of statistical modeling experimental data informative linear regression dependence (determination factor 0.8) of the ratio of normalized rotation effort to current of consumption of acoustic unit on reference temperature of the medium has been developed.

Transportation of heavy fuel oil (mazut) is made in technological pipelines of tank farms and thermal power stations. A problem is in weak fluidity of heavy mazut, especially under low ambient temperature when it becomes jelly-like. Usually to decrease resistance of mazut propulsion through technological pipelines warming is applied. However, this technology is power consuming, expensive and owing to high thermo insulating properties of the medium is ineffective. Recently the effect of double drop of propulsion resistance has been shown for oil at temperature about -7°C in the highway pipelines by means of creation shift or torsion ultrasonic oscillations in pipeline walls [1]. Thus, the effect of acoustic stimulating fluidity in oil with temperature of fusion up to 29°C has been proved experimentally. The objective of this work is application of acoustic method to especially heavy and low fluid mazut (temperature of fusion about 40°C) at lower ambient temperatures. This causes necessity of carrying out additional study.

To carry out experiments laboratory installation [2] has been developed. It contains glass-like capacity for working medium. On the axis of rotation of external support the rotating acoustic unit is mounted. It contains P-shaped suspension, in which studied metal tube with pasted to its top end piezoceramic cylinder, excited on high-altitude mode of oscillations, is mounted. Piezoceramic cylinder together with the studied metal tube form 1/2-wave transducer of excitation system, which punctually fastens to the edge of P-shaped suspension in the zone of minimum of oscillatory rate. This provides free oscillations of excitation system relatively other parts of device. Laboratory installation is equipped with sensors of temperature in volume of working medium and on the wall of studied metal tube.

The glass-like capacity is filled by working medium at temperature above a melting point. The acoustic unit is fixed in the capacity with working medium by means of auxiliary fastenings. Then installation is cooled to the required temperature. After extraction from refrigerator the rotating part of installation is bridged to axis of rotation of external support, and auxiliary fastenings are taken out. The lever, to which on the fixed distance from the axis of rotation the force sensor is attached, is rolled in lateral wall of P-shaped suspension. Electric ultrasound signal is fed to piezoceramic cylinder from electronic generator during adjustable time. This results in development of shift oscillations of working medium in near-wall layer of studied metal tube. On the lever through the force sensor operator develops the effort, at which the studied tube together with all rotating acoustic unit starts to rotate in working medium (in horizontal plane). This effort is recorded by the force sensor. Let's notice, that the circuit of installation is based on a principle of inversion of geometry of the task about propulsion of working medium into the tube [1,2].

Installation is filled with mazut M-100. For frequency of ultrasonic oscillations value 32.5 kHz [2] has been chosen. At the end face of the tube in working medium, according to indications of control accelerometer, under room temperature and generator voltage 50 V, oscillatory acceleration of $750\text{ m}/\text{s}^2$ has been developed. The temperature of mazut in volume was measured by means of thermoresistor ($-15^{\circ}\text{C} - 86$

k Ω ; +12°C – 22.5 k Ω). Bilateral area of the studied tube immersed in mazut (external diameter 25 mm, internal – 24 mm, depth of immersion 10 mm) makes $S = 9.43 \text{ sm}^2$.

Sensor of the effort of studied tube rotation is made on the basis of force sensor SBA-100L (CAS Corporation), connected through the bridge amplifier to electronic recorder PowerLab-8/30 (ADInstruments). Sensor of the effort in horizontal position through draft, fixed on the lever (25 mm from the axis of rotation), is moved in direction tangent to circular trajectory of the rotating unit when force data are being recorded on electronic recorder. After starting rotation of the tube (shift 3 - 10 mm) the effort is stopped. Typical response of the force sensor is represented on fig. 1.

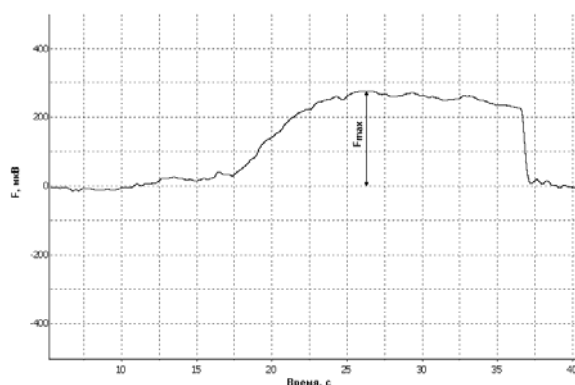


Figure 1. Time series of force sensor response during rotation of laboratory installation in cooled mazut M-100:

F_{\max} – maximal force.

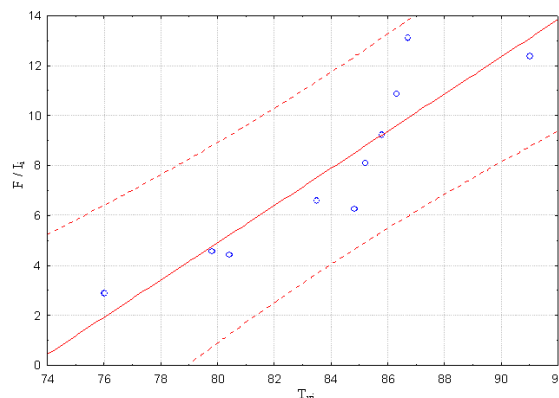


Figure 2. Scatter plot

$F_{\max}(\mu\text{V})/I(\mu\text{A}) - T_v(\text{k}\Omega)$:

circles – experimental points;

line – dependence of equation (3);

dashed lines – 95% prediction limits.

As an estimate of rotation effort the maximal force F_{\max} (fig. 1) is used. Calibration of the force sensor is made by suspension of known loads, its sensitivity has made $0.2 \mu\text{V/g}$. Levels of rotation effort in mazut has been predefined at room temperature (about $3 \mu\text{V}$), and at -15°C (about $300 \mu\text{V}$). It is obvious, that so essential difference of indications allows to fix reliably changes of medium condition in near-wall layer of the studied tube.

Cooling of the installation filled with mazut was made in the freezing chamber of refrigerator not less than 5 hours. Achievable values of temperatures made near -15°C (86 k Ω). However statistical fluctuations were observed (table).

Besides rotation effort of the tube (F_{\max} , μV) temperature of mazut in volume (T_v , k Ω), reference temperature of the tube (T_t , Ω) and initial current of consumption of piezotransducer (I , μA) are registered. 11 attempts of rotation after 2-minute influence of ultrasound and 7 attempts of rotation without influence of ultrasound have been carried out (table).

When estimating reliability of differences between cases of influence of ultrasound and its absence (nonparametric Mann-Whitney criterion, Statistica) statistically significant differences are not revealed in rotation effort, reference temperature of mazut in volume, reference temperature of the tube, ratio of rotation effort to reference temperature of the tube. However significant differences in ratio of rotation effort to reference temperature of mazut in volume (F_{\max}/T_v), $p = 0.077$ has been found. Taking into account small sample size value $p < 0.1$ can be considered as statistically significant. Averaged on samples ($n=11$ and $n=7$) value of the effect of influence of ultrasound on ratio F_{\max}/T_v has made 17 %.

When estimating factor of Spearman correlation in group of readings with influence of ultrasound ($n = 11$) statistically significant correlations between rotation effort and reference temperature of mazut in volume ($r = 0.79$, $p = 0.004$), reference temperature of mazut in volume and reference temperature of the tube ($r = 0.68$, $p = 0.022$), reference temperature of mazut in volume and current of consumption of piezotransducer ($r = -0.64$, $p = 0.035$) have been revealed. Scatter plot of parameters T_v and I testifies, that value of current of consumption $65 \mu\text{A}$ (the 11-th line in the table) is doubtful. Rejecting this line ($n = 10$) grows the factor of correlation between reference temperature of mazut in volume and current of consumption up to $r = -0.85$ ($p = 0.002$), that makes possible construction of informative linear regression model (normality of distributions is checked up by Shapiro-Wilk's criterion, Statistica):

$$T_v = (94.8 \pm 2.3) - (0.36 \pm 0.07)I \quad (1)$$

$r_{\text{adj}}^2 = 0.73$; $p = 0.001$; members of regression are determined with statistical significance $p < 0.001$ (standard error is in brackets). In absence of ultrasound ($n=7$) statistically significant correlation between parameters represented in the table are not observed.

Table. Characteristics of rotation effort of the studied tube of laboratory installation

No	$F_{\text{max}}, \mu\text{V}$	T_t, Om	T_v, kOm	Ultrasound (2 min)	$I, \mu\text{A}$	F_{max}/T_t	F_{max}/T_v
1	300	-	86.2	-	-	-	3.48
2	340	563	86.6	-	-	0.60	3.93
3	268	615	82.5	-	-	0.44	3.25
4	185	730	86.3	+	17	0.25	2.14
5	178	610	80.4	+	40	0.29	2.21
6	193	590	86.4	-	-	0.33	2.23
7	145	509	76	+	50	0.28	1.91
8	200	618	84.8	+	32	0.32	2.36
9	165	610	83.5	+	25	0.27	1.98
10	277	580	85.8	+	30	0.48	3.23
11	185	620	86	+	65	0.30	2.15
12	260	737	91	+	21	0.35	2.86
13	249	610	86.7	+	19	0.41	2.87
14	161	599	79.8	+	35	0.27	2.02
15	235	650	85.2	+	29	0.36	2.76
16	210	648	83.4	-	-	0.32	2.52
17	183	695	83.3	-	-	0.26	2.20
18	230	544	85.2	-	-	0.42	2.70

According to experimental data (table) it is also possible to construct informative linear regression models:

– between reference temperature of mazut ($\text{k}\Omega$) and rotation effort (μV)

$$T_v = (-489.3 \pm 201.0) + (8.2 \pm 2.4)F_{\text{max}} \quad (2)$$

$r_{adj}^2 = 0.52$, $p = 0.007$, $n = 11$, members of regression are determined with significance $p < 0.01$.

– between rotation effort, normalized to current of consumption (μA), and reference temperature of mazut in volume (fig. 2)

$$F_{\max}/I = -(54.7 \pm 10.5) + (0.75 \pm 0.13)T_v \quad (3)$$

$r_{adj}^2 = 0.79$, $p = 0.0003$, $n = 10$, members of regression are determined with significance $p < 0.001$.

Thus, stimulated by ultrasonic oscillations augmentation of fluidity of mazut M-100 in near-wall layer of rotating metal tube of laboratory installation at temperature about -15°C is possible, however the achieved value of the effect does not exceed 17 %. Note that electric power of piezotransducer is about 0.75 W (voltage 50 V, average current of consumption $29.4 \mu\text{A}$, $\cos \varphi \approx 0.5$). The electroacoustical efficiency of acoustic unit with piezoceramic cylinder working on high-altitude mode (transversal piezoeffect), hardly exceeds 10 %. Then in view of efficiency acoustic power normalized to S, developed by laboratory installation in the cooled mazut, can make about $0.008 \text{ W}/\text{sm}^2$.

Dependence of current of consumption on temperature (1) testifies to correctness of choice of acoustic unit mode of oscillations, in which amplitude depends on change of pliability of the working medium growing with rise in temperature. From regression equation (2) follows, that rotation effort, as well as has been supposed, increases as a measure of dropping mazut temperature. Notice that limits of work of developed regression dependences (1-3) lay in a range of temperatures approximately from -10°C (75 k Ω) up to -18°C (92 k Ω), and are determined, strictly speaking, only for the given laboratory installation. However, normalizing rotation effort in the equation (3) to constant S, we can slightly generalize it. Having divided both numerator, and denominator of the right part of the equation (3) to S, after obvious transformations and substitution of numerical value S, obtain:

$$f/I = -(5.8 \pm 1.11) + (0.079 \pm 0.014)T_v, \quad (4)$$

where f - rotation effort to unit of area of contact surface of the tube. According to obtained in our experiment small value of the effect of drop of rotation effort, expression (4) provides an upper estimation of critical value of the ratio f/I.

Thus, it is experimentally shown, that 2-minute influence of shift ultrasonic oscillations (frequency 32.5 kHz, acoustic power about $0.008 \text{ W}/\text{sm}^2$) results in 17 % reduction of mazut M-100 resistance, normalized to initial temperature about -15°C , in near-wall layer of rotating tube of the laboratory installation. Regression dependence (4) of rotation effort of the tube normalized to current of consumption of the ultrasonic transducer on reference temperature of mazut has been developed. Further study is necessary to estimate opportunities of intensifying revealed effect.

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