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ON THE USE OF WATER-ICE JETS IN THE PURIFICATION OPERATIONS OF TURBINE UNITS

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ABSTRACT

The paper deals with the use of water-jet means for cleaning operations of turbine units. To activate the process and improve the quality of purification, it is proposed to use a water-ice jet formed by mixing a water jet with a cryogenic liquid (liquid nitrogen). At the same time, the factors that influence the efficiency of ice formation, the size of ice floes and their ability to perform the work of destroying layers of pollution are analyzed. Models of formation of water-ice jet are developed and regularities of its influence on the surface are established. The influence of the conditions of formation of a water jet on its cleaning ability is revealed. It is shown that along with the flow of cryogenic fluid, in particular liquid nitrogen, the geometry of the mixing chamber has an important influence. Thus, the position of the point of introduction of nitrogen into the cavity of the chamber determines both the amount of ice formed and the size of the particles. The farther the nozzle slice, the larger the particle size of the ice forms. Fractograms of the generated ice flow were also obtained and their functional conditionality was determined by the modes of generation and the parameters of the mixing chamber. Multiple factorial planning of the experiment was performed and dependencies were obtained to establish technological modes of processing. Using surface model reproduction tools, it is shown that the use of water-iced jet not only improves the environmental friendliness of the method, but also provides the highest quality surface cleaning without changing the parameters of microgeometry.

INTRODUCTION

Water Jet surface cleaning processes are widely used in technologies for restoration of protective coatings of trunk pipelines [1] now, such using for cleaning containers in the processing industry [2], during restoration work and cleaning the facades of buildings and structures from dirt and dust, when washing parts and assemblies from preservation grease, etc. The liquid jet in this case is used as a kind of point tool, under the influence of which the surface film of contamination receives initial damage, and the spreading stream does the work of developing the formed defects with the separation of fragments and particles from the surface.

Saturation of the jet stream with abrasive particles significantly increases the productivity of the process, however, the surface itself also perceives the hydrodynamic and abrasive effects. as a result, in addition to removing the film, there is a change in microgeometry, residual stresses in the surface layer; in some cases, deformation of non-rigid shell elements is possible.

In addition, the Abrasive Water Jet method has limited use, since the sludge formed after cleaning includes not only the products of destruction, but also the abrasive itself, which in some cases is quite difficult to separate. This feature reduces the environmental cleanliness of blasting, requires additional material and labor costs to reduce the harmful effects of the process on staff and the environment.

Analyzing the options for cutting materials with a waterjet, the feasibility of using ice-water cleaning of critical products is considered. These include elements of turbine units of various applications.

The essence of the process is that, like a waterjet system, an ice-water jet head consists of a high-pressure nozzle assembly, a mixing chamber in which a cryogenic liquid (usually liquid nitrogen) is mixed with a high-speed jet, as well as a calibrating tube used for straightening and ensure directional movement of the two-phase flow. The result is a universal tool capable of performing controlled destructtion of the processed material [3].

EXPOSITION

For carrying out experimental studies, the universal laser-jet complex LSK-400-5 [4] was used, which makes it possible to use various types of activators of the jet process (flow of abrasive particles, including finely dispersed, cryogenic liquid, laser beam introduced into the stream).

The working pressure in the hydraulic system was varied within the range of 25-90 MPa; jet sapphire nozzles

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of the standard profile with a diameter of 0.28 mm were used on the slice; the diameter of the flow part of the calibrating tube was 1.25 mm, and the cryogenic liquid flow rate was from 3 to 15 cm^3/s. Flat parts with a thickness of up to 0.2 mm, with mechanical pollution with a thickness of 1.0-2.0 mm, and also with oil and fat contamination with a surface layer thickness of up to 3.5 mm (with various paraffin inclusions) were cleaned.

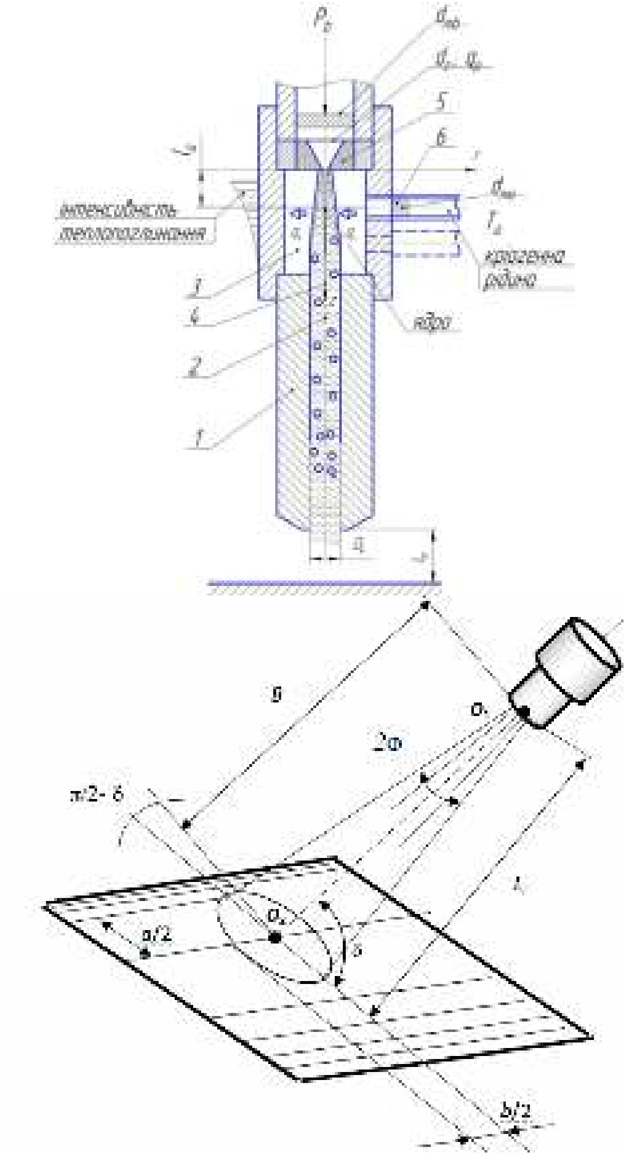

Fig. 1. The formation of a cutting water jet and its effect on the surface

In this case, the cleaning area to the base was controlled, varying by technological factors and the speed of movement of the jet head. We also proceeded from the fact that the speed of movement directly affects the quality of cleaning (completeness of removal of contamination) and in some cases it is necessary to repeatedly pass the jet system over the surface to ensure the required level of cleaning.

Subsequently, the surface condition was monitored by electron microscopy, and the presence of contamination on the surface by energy dispersive microanalysis with the construction of a surface map using the Femtoscan 3.0 program.

Model of water-ice flow were including some assumptions: 1) the jet flows from the nozzle with a circular outlet, has a cylindrical shape, the radius of cross section of the jet r_b is equal to the radius of the outlet opening of the nozzle r_c ; 2) the velocities of all the points of intersection of the jet are the same and equal to the average flow velocity v_b , including the particles of the ice; 3) accept the stew $r_b = r_c$, $f_b = f_c = \pi r_c^2$; 4) the loss of cross flow of water from friction in the air and the walls of the channel of the calibration tube are neglected; 5) It is also assumed that, upon cooling, the heating stream of liquid nitrogen completely converts it to a gaseous state with the formation of dry ice particles. It is taken into account that heat exchange occurs when mixing flows, due to the active movement of liquids with each other. The fluid flow is considered homogeneous only in the nucleus of the jet, in the areas near the periphery is a discrete phase (the movement of individual droplets and particles of ice).

The simulation also takes into account the non-stationary thermal conductivity, which is described by the corresponding equation, $\frac{\partial T_h}{\partial \tau} = \alpha L(T_h) + f(\Delta T_h)$, where $\alpha = \frac{\lambda_h}{c_h \rho_h}$, $f(\Delta T_h) = \frac{q_+ - q_-(\Delta T_h)}{\delta_h c_h \rho_h}$, $L = \frac{\partial^2}{\partial x^2} + \frac{1}{r_z}\frac{\partial}{\partial r}$, T_h is the water temperature when passing through the nozzle, ΔT_h is the temperature head; λ_h is the coefficient of thermal conductivity, c_h is the heat capacity, ρ_h is the density, δ_h is the thickness, x is the coordinate along the contact surface of the fluid flows. The intensity of heat sink q was modeled on the well-known recommendations of researchers of watercourses; when describing heat absorption, it was taken into account that water, cooled from the initial temperature T_h of the nozzle outflow, changed its aggregate state at $T_e = 273\,K$ and then the icebergs were cooled to the temperature T_k .

The total energy of the analyzed system, taking into account the variable thermal balance of mixing, was described by the corresponding equations of exchange. The calculated values of the thermophysical parameters of the system were as follows:

$\delta_h = 0{,}5.10^{-3}\,m$, $L_h = (25...70).10^{-3}\,m$,

$\lambda_h = 18\,W/(m.K)$, $c_h = 245\,J/(kg.K)$,

$\rho_h = 1000\,kg/m^3$, diameter and length of mixing chamber $12.10^{-3}\,m \times 20.10^{-3}\,m$; the diameter and length of the tube - $1{,}2.10^{-3}\,m \times 75.10^{-3}\,m$. The value of the flow rate of liquid nitrogen in the mass fraction of fluid flow (for the experiment flow rate qb set $0.12\,kg/s$ was: $q_1 = q_3 = 0.013\,kg/s$, $q_2 = q_4 = 0.025\,kg/s$ q2, the first indices correspond to the distance from the nozzle $l_a = 2.0\,mm$, the last - $l_a = 16.0\,mm$.

In doing so, they take into account that the average value of the kinetic energy possessed by the jet will be:

$$K = \frac{m\bar{v}^2}{2} = \frac{\bar{v}^2}{2}\frac{\pi\rho H}{3}\left(\frac{d_c^2}{4} + R^2 + R\frac{d_c}{2}\right) =$$

$$\frac{\pi\rho H}{24}\left(\frac{d_c^2}{4} + R^2 + R\frac{d_c}{2}\right) v_c^2 (1 + k_p)^2$$

where $k_p = \frac{d_c^2}{4\left[\frac{d_c}{2} + H\sin\left(\frac{\phi}{2}\right)\right]^2 \cos^2\delta}$.

As a result, the model behind the principe scheme of the small chamber is eliminated in terms of heat flow at winter temperature of the point of low nitrogen and the second cycle at constant speed, the caller can be relieved. Also, the oath of ace K_t (at the mass part) was ascertained in potency after the appearance of the calybruvial tube. The results were determined to be clear, the point of introduction of the critical oxygen flux, the maximum flow rate for the heat flux I and with the increased values at the measurement ranges between 15 and 25% (up to 25/25%) (up to 15-25%), fig. 2. The growth of the mass-in-consumption of nitrogen in the nitrogen from 10% to 20% of the non-emissions is achieved with an instantaneous increase in heat flow. Farther away from the vitality of the cryogenic fluid is practically not pouring in on the first, because working whith consumption more 30% is undervalued.

Behind the theoretical aspects, it is obvious that the point of introduction of the cryogenic fluid is guilty, for the possibility sets near closer to the distance of the string nozzle; The largest possible amount of nitrogen is reduced to the predicted total liability of the generation of ice. At the same time, the experimental process of generating the most critical analysis and the most important analysis is completed.

Fractional analysis of ice sizes, present on Fig. 3. It is divided by 5 fractions: other incorrect forms (up to 0.1 mm), other correct forms (the form is close to the correct bagatokutnik, up to 0.15 mm), middle (0.22 mm); medium-large 0.3 mm) and large (0.4 and larger mm).

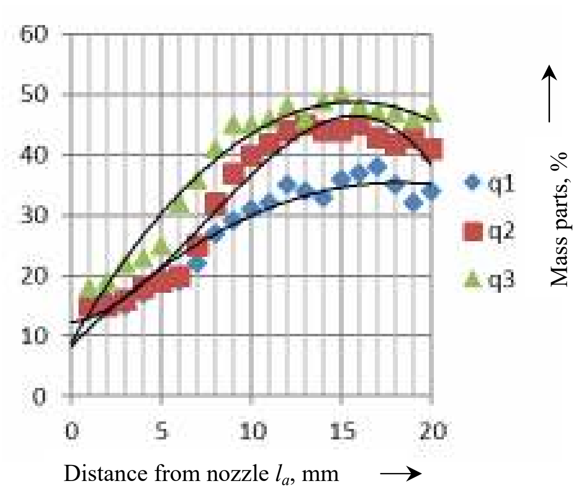

Fig. 2. Change in the proportion (in%) of medium- and large-sized mallets performing maximum micro-fracture work

As a result of the simulation according to the design scheme of the mixing chamber, the expected heat flux density was obtained with changes in the liquid nitrogen supply point and its flow rate with constant fluid twisting, which allows to establish the volume of ice floes formed up to the moment of leakage from the calibration tube. Also, the volume of K_t mallets (in mass fraction) in the flow section of the calibration tube was determined. The obtained results showed that the point of introduction of the flow of cryogenic fluid has a significant effect on the density of heat flow *I* and with the increase of this value within the mixing chamber there is a decrease in density within 15-25% (up to $(25...35).10^3 W/m^2$, Fig. 2. Increasing the mass flow rate of liquid nitrogen from 10% to 20% counteracts this effect while increasing the heat flux density. Further increase in the consumption of cryogenic liquid practically does not affect the growth of *I*, so working with costs over 30% is inappropriate.

The volume of the mass fraction of mallard Kt correlates with the heat flux density and increases as I increases, but its increase is more linear, which can be explained by the cooling of the liquid droplets even after evaporation of the liquid phase of nitrogen.

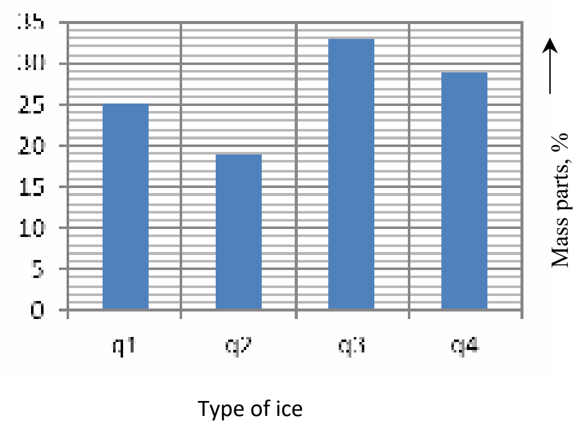

Fig. 3. Volume of ice Kt (mass fraction) in the stream along the section of the calibration tube

If we characterize the purification efficiency by the ratio of the kinetic energy of the jet J to the jet action area $I_c = \frac{J}{f_i}$ then it is advisable to associate with this parameter the speed of movement of the scrub head: $s = b_0 + b_1 I_c$

To perform a series of experiments on surface cleaning and obtaining multidimensional linear regression equations covering the main technological factors, the Planet-Berman Plan of Form $2^6...3/8$ was formed, which allowed the selected 6 significant factors to detect the regression coefficients of influence on the controlled indicator - velocity of motion of the injectors on the treated surface, s, m/min.

The following factors were taken into account during the model experiment: pressure of process fluid p, MPa; flow rate of cryogenic fluid Q_c, cm^3/s; the thickness of the layer of deposits on the surface h, mm; strength limit of glue σ_a, MPa; tensile strength σ_m, MPa; Nozzle section diameter, D, mm.

The degree of residues was determined by estimating the area of the area where adhesion was not detected, attributed to the area of he correct geometric shape (rectangle), on which such removal should be. The value of residue s was estimated for the 20.0 cm section, for which the number of nodes at which the adhesive sleeve was not destroyed was calculated. Grid pitch - 2 mm. It was assumed that *I* should not be less than *I* = 0.95.

After cleaning, no significant defects were observed on the surface (Fig. 4), and the energy-dispersive analysis did not reveal significant residues of surface dirt (Fig. 5).

Statistical analysis of the data allowed us to postulate the following regression equation to determine the recommended feed rate, assuming that the coefficient *Is* = 0.95:

$$s = 0.47 + 0.00279 p_b + 0.0576 Q - 0.011 h -$$
$$0.0013 \sigma + 0.000 D$$

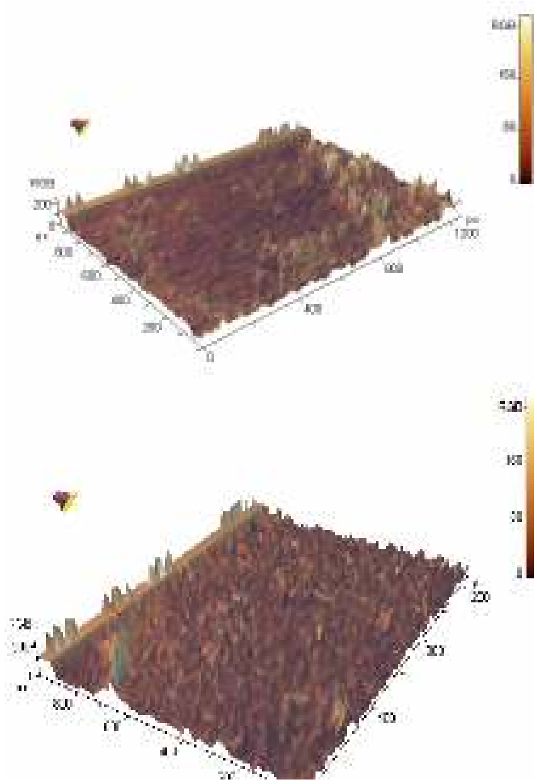

Fig. 4. Model of surface after cleaning water-ice flow

On the presented spectrum, there are no clear lines of individual elements other than the iron lines (metal samples were examined) as well as other elements present in the test sample. The silicon line can be explained by the fact that the sample was under conditions of active action of the flow of abrasive-contaminated substance.

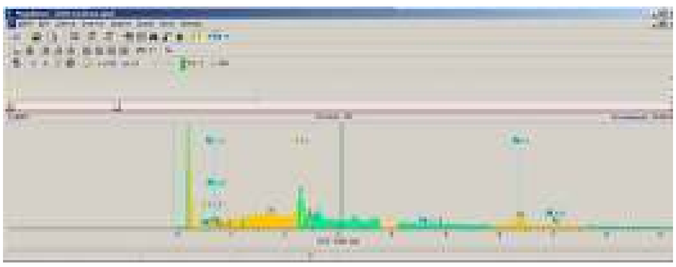

Fig. 5. The characteristic spectrum of the surface layer

Thus, we have proved the feasibility of using water-ice facilities for the operations of surface cleaning of the responsible elements of the turbine units, including internal cavities. Further studies should aim to identify patterns of surface cleaning in closed cavities, provided that fluid is minimized.

CONCLUSION

Models of formation of water-ice jet are developed and regularities of its influence on the surface are established.

The influence of the conditions of formation of a water jet on its cleaning ability is revealed. It is shown that along with the flow of cryogenic fluid, in particular liquid nitrogen, the geometry of the mixing chamber has an important influence. Thus, the position of the point of introduction of nitrogen into the cavity of the chamber determines both the amount of ice formed and the size of the particles. The farther the nozzle slice, the larger the particle size of the ice forms. This is extremely important because they have a higher kinetic energy and therefore perform cutting more efficiently. The regularities of the change of heat transfer intensity in the stopping space were obtained, the dependence of the temperature of the ice floes on the conditions of their generation is shown.

Fractograms of the generated ice flow were also obtained and their functional conditionality was determined by the modes of generation and the parameters of the mixing chamber

Multiple factorial planning of the experiment was performed and dependencies were obtained to establish technological modes of processing. Using surface model reproduction tools, it is shown that the use of water-iced jet not only improves the environmental friendliness of the method, but also provides the highest quality surface cleaning without changing the parameters of microgeometry.

REFERENCE

[1] Vijay M.M., Combustion and Fluids Engineering, National Research Council of Canada Ottawa, Ontario, Canada, 1994 KLA OR6

[2] Buchen Tank- and Turnaround Service GmbH Эмденер Штр. 278 50735 Koln, Germany http://www.buchengroup.ru/-images/about/BTTS_23-04-15_BRO_Leistungsuebersicht_-RUS_web.pdf

[3] Burnashov M. A., Determination of cutting force at cutting of floorings of materials by a high-pressure water 4 (2008) 17-20

[4] Salenko A.F., Shchetinin V.T., Fedotyev A.N., Improving accuracy of profile hydro-abrasive cutting of plates of hardmetals and superhard materials, Journal of Superhard Materials 36 (3) (2014) 199-207