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ABOUT THE RELATIONSHIP BETWEEN THE RADII OF BUBBLES IN THE CONDESATOR OF THE DRIVE WHEEL OF A VIBRATION-PNEUMATIC MACHINE AND AT THE ENTRANCE TO THE NOZZLE

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ПРО ЗАЛЕЖНІСТЬ МІЖ РАДІУСАМИ БУЛЬБАШОК У КОНДЕСАТОРІ ПРИВОДНОГО КОЛЕСА ВІБРАЦІЙНОПНЕВМАТИЧНОЇ МАШИНИ ТА НА ВХОДІ В СОПЛО

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О ЗАВИСИМОСТИ МЕЖДУ РАДИУСАМИ ПУЗЫРЬКОВ В КОНДЕСАТОРЕ ПРИВОДНОГО КОЛЕСА ВИБРАЦИОННОПНЕВМАТИЧЕСКОЙ МАШИНЫ И НА ВХОДЕ В СОПЛО

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Abstract. To increase the efficiency of vibration-pneumatic machines, it is proposed to use the heat generated during the operation of their compressor. The processes of converting the thermal energy of heated water into useful mechanical work are analyzed. The process of converting thermal energy into mechanical work during the implementation of a "triangular" thermodynamic cycle was taken into account. To organize this cycle, it is proposed to introduce a wheel into the design of the vibration-pneumatic machine, which provides the drive of the vibration mechanism. Previously, an electric motor was used for this purpose. The exclusion of the electric motor increases the efficiency of the machine and reduces its categorization due to the secondary energy resource.

The analysis of the literature showed a rather arbitrary approach to determining the parameters of steam-air bubbles at the inlet to the nozzle of the impeller of the machine. The aim of the work was to establish the dependence of the ratio of the radii of steam-air bubbles at the inlet to the nozzle of the impeller of the machine and in the condenser on the degree of expansion of the "triangular" thermodynamic cycle. The expansion parameter of the cycle is the ratio of the water pressure in the inlet section of the nozzle to the pressure of the vapor-air medium in the condenser of the machine.

A physical and mathematical model of the formation of vapor-air bubbles-nuclei of the heterogeneous boiling in the upper layer of water in the condenser pan by "capturing" air when drops are falling into the pallet is proposed. As well as changes in parameters of the vapor-air bubbles before entering the nozzles installed on the drive wheel of vibration-pneumatic machine. Based on the physical model, a system of algebraic equations is constructed to determine the composition of the vapor-air medium and the radius of bubbles in the inlet section of the nozzles. Solutions of this system of equations are investigated by numerical methods.

It was established for the first time that the ratio of the radii of bubbles in the condenser and at the inlet to the nozzle of the drive wheel of machine is proportional to the expansion parameter of the thermodynamic cycle of the machine with an indicator of the degree of 0.3. Establishing the relationship between the radius of steam-air bubbles in the condenser and at the inlet to the nozzle will allow us to scientifically determine, and not to arbitrarily set the parameters of the discrete phase in the inlet section of the nozzle of the machine. This improves the accuracy of the entire algorithm for determining the parameters of the wheel of the machine, depending on the parameters of the working fluid at key points of its circulation circuit.

Keywords: vibration-pneumatic machine, drive wheel, steam-air bubbles, radial feed tubes, nozzles of drive wheel, condenser, two-phase flow.

Introduction. The activities of mining enterprises produce a large amount of waste in the form of mine rocks, mineral processing waste, slag, and so on. Waste is stored in dumps that occupy large areas and dramatically worsen the ecological condition in mining sites: dust and gas contamination of the air basin, pollution of water resources and other similar processes. The increase in the depth of development leads to a wider use of mining technologies with the backfilling of mined-out. Limited stocks of raw materials for the preparation of stowing materials cause the need to increase the volume of use of mine rocks for these purposes. To solve the problem of disposal of environmentally significant waste from mineral mining is possible by reducing the volume, and, ultimately, by complete exclusion of rock feeding to the surface.

One of the options for mechanization of the technology for leaving rock in the mined-out space is the use of a vibration-pneumatic method [1] for its stowage. The use of vibration-pneumatic machines (VPM) at mining enterprises can be significantly expanded. To do this, it is necessary to use the secondary heat that is formed during the operation of the VPM compressor. Therefore, the processes of converting the thermal energy of heated water into useful mechanical work are of scientific and practical interest.

From these positions, attention was drawn to the process of converting the thermal energy of heated water into mechanical work during the implementation of a "triangular" thermodynamic cycle [2]. Thus, it is proposed to introduce a wheel into the design of the VPM to provide it with the drive of the vibration mechanism. So, during its operation, the drive wheel of machine (DWM) implements a "triangular" thermodynamic cycle due to the heat of secondary energy resources (SER), which are developed during the operation of the compressor.

The physical and mechanical process of the VPM drive wheel is as follows. In the nozzles of the wheel, the working medium (water heated to a certain temperature) expands into the region of two-phase states in the diagram "p-υ". The nozzles are located on the periphery of the radial feed (heated water) tubes (RFT).Heated water enters through the wheel axle and moves in the RFT. The DWM is located in the cylinder, where the required vacuum level is maintained. At the exit from the nozzles, a two-phase vapor-air and drip flow moves towards to condenser located at the base of the cylinder, whose axis is horizontal.

To close the circulation circuit of the working fluid in a "triangular" cycle, a pump is used, which supplies water cooled in the condenser to the heat exchanger. In this heat exchanger, the heat of the SER, which should be usefully used, is transferred to the working body of the DWM. An analysis of the literature has shown that when designing the drive wheel of the VPM, it is necessary to solve a number of scientific problems. One of them is to determine the parameters of vapor-air microbubbles, which serve as boiling centers in the nozzles according to the heterogeneous theory, which we apply, giventhe low temperature of the SER. In solving this problem, some ambiguities have been established.

Sometimes there is even an arbitrary choice of the radius of micro-bubbles of the order of one micron [3] without taking into account the conditions of their formation.

General statement of the problem.The two-phase flow undergoes changes in its mechanical structure when moving in the nozzle of the machine. When boiling, the initially bubbly structure of the flow during its movement along the nozzle turns into a vapor-drop structure. Let us consider in more detail the transformations of the mechanical structure of the two-phase flow in the DWM nozzle. Water heated to temperature T_0 enters the confusor of the nozzle under pressure p_0. The pressure is decreasing. Under the influence of heat and mass transfer processes between the phases, bubbles grow until the mechanical structure of the flow is inverted. After inversion, the bubble structure of the flow turns into a drop-vapor structure, i.e. the carrier and dispersed phases of the bubble flow change places in the already drop-vapor flow.

These two two-phase flow structures are distinguished by a certain limit value of the volume concentration of the dispersed phase B_I in the bubble flow. R.I.Nigmatulin recommends [3] to use $\pi/\left(3\cdot\sqrt{2}\right)$ for the limit value, which corresponds to the volume concentration of spheres when they most densely fill the space. A.A. Nakorchevsky and B.I. Basok recommend [4] to use for the limit value $\pi/6$, which corresponds to the volume concentration of spheres when they fill the space at the nodes of the cubic lattice. We believe that the limit value of B_I, which is equal to $\pi/6$, is more justified for the inversion of a two-phase flow. At this value of the volume concentration of the vapor phase, the stability of the water partitions between the bubbles becomes extremely low. It can be assumed that at B_I, which is equal to $\pi/6$, the rapid transformation of water partitions into droplets already begins.

It is obvious that the correct and scientifically justified choice of the parameters of the two-phase flow at the nozzle inlet is of great importance in order to develop modes that increase the efficiency of the DWM.

Analysis of research and publications. The temperature of the heated water after the heat exchanger at the entrance to the wheel of the machine is significantly lower than the critical water temperature. Therefore, when determining the parameters of bubble nuclei of boiling, it is necessary to proceed from the general ideas of the heterogeneous theory of nucleation in [3,5]. R.I. Nigmatulin in his research recommends using a radius value of the order of 1 microns for bubble nuclei, and a concentration from 10^{10} to 10^{12} bubbles/m^3.

However, it think that these parameters are taken very arbitrarily, based on information about the size distribution of gas bubbles in water of various origins [5]. There are known works [6,7] in which the stability of the existence of gas bubbles in water with a radius of about a nanometer is explained by the adsorption of sodium ions on the surface of the bubbles. Sodium and chlorine ions are inevitably present in water of any degree of purification. The ions adsorbed on the surface lead to electrostatic repulsion, which prevents the bubbles from closing. The model of formation of gas bubbles [6,7] was developed to explain the phenomena of "breakdown" of water by a laser beam. These experiments are carried out in stationary cuvettes of small volume. The interaction between atmospheric air and the water layer in the cuvette is completely different in comparison with the hydro- and gas-dynamic situation in the DWM condenser. Therefore, the model [6,7] is hardly applicable for the formation of vapor-air bubbles in the DWM condenser. For the DWM condenser, it is necessary to formulate a well-defined physical model of their formation based on the provisions of the heterogeneous theory of nucleation to determine the parameters of microbubbles-nuclei with taking into account the unavoidable presence of a certain amount of air in the internal space of the DWM and possible features of its ingress into water.

Upon exiting the wheel nozzle, a two-phase mixture of water droplets and water vapor enters the neck of the condenser. Water vapor condenses, and a layer of water is formed in the condenser pan. Due to the inevitable inflows of air above the mirror of the water layer, air is present along with water vapor. This air dissolves in condensed water.

Therefore, it is necessary to determine the amount of air that can be "captured" by the vapor-air bubbles in the upper layer of water located in the condenser tray.Based on the analysis of the literature available to us, no such study has been conducted. Thus, the absence of scientifically based methodology for determining the parameters of vapor-air bubbles at the entrance to the nozzle constrains the wider use of VPM. Therefore, the determination of the dependence of the radius of vapor-air bubbles in the inlet section of the nozzle of the drive wheel of VPM on their radius in the condenser is an urgent scientific task.

Highlighting the unsolved problem. Based on the analysis of previously performed research and publications, we come to the formulation of the scientific task: to investigate the influence of the parameters of the vapor-air mixture located in the internal space of the DWM on the parameters of the vapor-air bubbles-nuclei of the boiling process in the inlet section of the nozzles.

The aim of the work is to establish the dependence of the ratio of the radius of bubbles at the inlet of the DWM nozzle to the radius of bubbles formed in the condenser on the degree of expansion of the "triangular" thermodynamic cycle. The degree of expansion of the cycle is the ratio of the water pressure in the inlet section of the nozzle to the pressure of the vapor-air medium in the DWM condenser.

Research methods. To obtain this dependence, methods of analysis and generalization of the results of well-known theoretical and experimental studies, mathematical modeling based on the fundamental laws of mechanics and thermodynamics were used. The tested solution algorithms were used

Presentation of the main material. Figure 1 shows the basic arrangement of the evacuated cylinder *1* with a rotating turbine wheel *2* and a condenser connected to the cylinder *3*. Figure 2 also shows a pump *4* for returning cooled water through a heat exchanger to the DWM nozzles and the tube *5* for pumping cooling water. A stream (two-phase and two-component) of vapor-air and drip mixture falls on the surface of the water in the condenser *3* at the exit from the DWM nozzles *2*. The formation of vapor-air bubble nuclei *7* in the upper layer of the liquid phase of water in the condenser *3* can be explained by the capture of air when drops *6* fall on the water surface.

This process is the content of the first stage of the formation of vapor-air bubbles, which will be the nuclei of subsequent boiling in the nozzle of the machine. It is known that when a drop falls and it is further immersed in water, a small "pocket" is formed on the surface of the water [8]. This "pocket", when closed due to the forces of gravitational collapse of its edges and the forces of surface tension, forms a bubble already under the surface of the water.

It is clear that the gas composition of the "pocket" and the subsequent bubble is determined by the composition of the vapor-air mixture above the water surface. Therefore, based on the above, the first stage of the formation of vapor-air bubbles can be mathematically modeled by the equations

$$p_s\left(T_{1,c}\right)+\rho_{1,a}\cdot\left(U_g/\mu_a\right)\cdot T_{1,c}=\left(2\cdot\sigma\left(T_{1,c}\right)\right)/b_{1,c}\,, \tag{1}$$

$$m_c=\rho_{1,a}\cdot(4/3)\cdot\pi\cdot b_{1,c}^3\,, \tag{2}$$

where $p_s(T_c)$ − is the pressure of saturated water vapor in the vapor-air mixture above the surface of the water in the condenser at temperature T_c, (Pa); U_g is the universal gas constant, (J/mol·K); p_{1a} − is the density of air in the vapor-air mixture in the condenser and bubble,(Pa); $\sigma(T_c)$ − is the coefficient of surface tension of water, (N/m); b_{1c} − is the radius of the bubble, (m); m_c − is the mass of air in the vapor-air bubble, (kg).

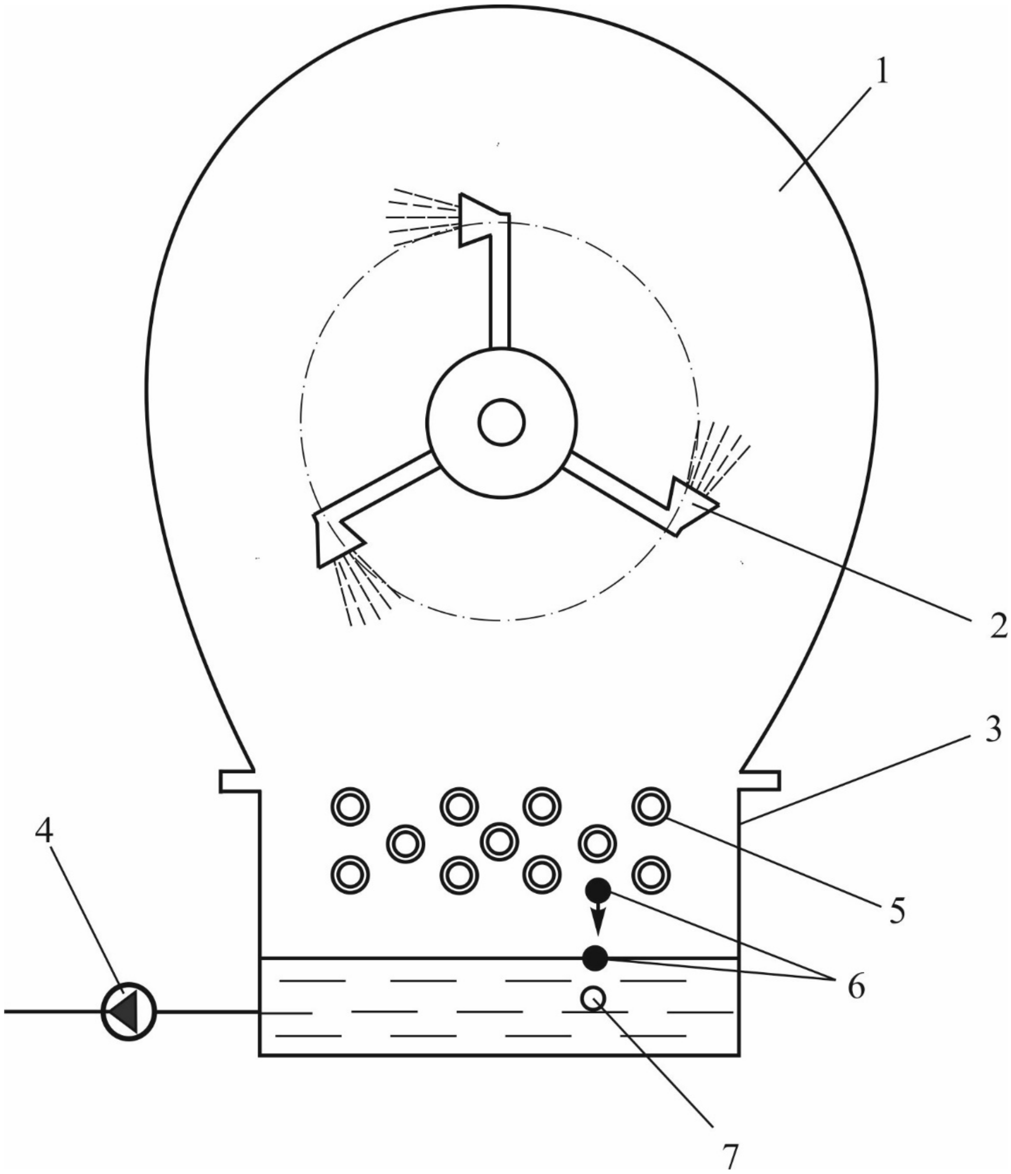
For calculations according to equation (1), an approximation of the pressure of saturated water vapor as a function of temperature was developed

$$\begin{aligned} p_{s,v}\left(T_{1,c}\right)=5{,}477\cdot 10^{10}\cdot\exp\left(\frac{T_{1,c}}{4923}\right)\cdot\left(\frac{T_{1,c}}{383}\right)^{0.065}\exp\Big\{5{,}2\cdot 10^{-5}\cdot\left(T_{1,c}-373\right)\times \\ \times\left[7{,}65385\cdot\left(T_{1,c}-373\right)^2+23{,}08\cdot\left(T_{1,c}-373\right)+1000\right]\cdot 10^{-3}\Big\}, \end{aligned} \tag{3}$$

which, in the temperature range from 25°C to 110°C, provides an accuracy of at least 0.1% in comparison with experimental data on the water vapor tables. For σ(TC), we use the dependence recommended in [9].

A vapor-air bubble with parameters b_{1c}, and m_c, which are determined by equations (1) and (2), is actually formed during the immersion of a drop of water at the outlet of the nozzle into the water layer in the condenser. It is important that these equations allow us to calculate the amount of air captured by the vapor-air bubble at the first stage of its formation. This value is essential for the subsequent stages of bubble formation and its transformation on the way to the inlet section of the nozzle. To represent the progress of the process, we present the calculation results according to equations (1) and (2). At T_c = 298 °C (25 °C) and $p_{1,a}$ = 103 Pa, $p_{2,a}$ = 3.62

micrograms, the calculation according to equations (1) – (3) leads to the following values $b_{1,c}$ = 42.5 microns, m_c = 1.16 picograms.



1-vacuum cylinder, 2-DWM nozzles, 3-condenser, 4-pump, 5-cooling water pumping tubes, 6-water droplets, 7-steam-air bubble

Figure 1 - To the process of saturation of water in the condenser with air

Let's consider the second stage of the formation of vapor-air bubbles in the condenser. A bubble with parameters formed when a drop is immersed begins to experience an external hydrostatic pressure of a very thin, about one millimeter thick, upper layer of water in the condenser and, under this pressure, the bubble begins to shrink to a radius b_{2c} of temperature T_{2c} and density p_{2c}, which are determined by the equation of mechanical equilibrium. In order to determine all three quantities, this equation should be added by the equations of the first law of thermodynamics and the law of conservation of the amount of air in the bubble. Immersion of the formed bubble in the water layer in the condenser is provided by two factors. The bubble is formed from a "pocket" [8], which is formed when the drops *6* are immersed in water after they fall from the tubes *5*. In addition, the pump *4* creates a sufficiently intense hydrodynamic movement directed against the forces of Archimedean buoyancy. Under the action of hydrostatic pressure in the upper water layer of the condenser, the vapor-air mixture in the bubble is heated by the compression of the bubble, when immersed in water.

The third stage of bubble formation consists in isobaric cooling of the bubble to the temperature of the water in the condenser, which leads to its significant compression. After the completion of the third stage of the formation of a vapor-air microbubble nucleus, its radius is determined by the root of the equation

$$p_s(T_{1,c}) + \left(3 \cdot m_c / 4 \cdot \pi \cdot b_{3,c}^3\right) \cdot R_{\mu,a} \cdot T_{1,c} = \rho_w \cdot g \cdot h_C + \left(2 \cdot \sigma(T_{1,c})\right) / b_{3,c}, \quad (4)$$

where, ρ_w − is the density of water, (kg/m^3); gis the acceleration of gravity, (m/s^2); h_c −is the thickness of the upper layer of water in the condenser.

For $T_{1,c}$ = 298 ° C (25 ° C), h_c 500 microns and m_c = 1.16 pg, the root of the equation (4) b_{3c} = 12.9 microns determines the radius of the micro-bubble nucleus upon completion of all three stages of its formation in the upper layer of water by "capturing" air when drops fall into the condenser pan. To estimate the hydrostatic pressure acting on the vapor-air bubble-nucleus after the second stage of formation, we take in equation (4) the thickness of the upper layer of water in the HC condenser of the order of 500 microns. This number is approximately 12 times larger than the radius of the bubble at the end of the first stage of its formation.

Further, vapor-air bubbles with parameters b_{3c}, m_c, formed in the water condensed after the nozzle, enter the circulation pump, the water heating heat exchanger, the radial tube of the wheel of the machine, where centrifugal forces act, and the inlet to the turbine nozzle. With vapor-air bubbles with the parameters b_{3c}, m_c, in these elements of the equipment, the processes of adiabatic compression, isobaric cooling, isobaric heating (in the heat exchanger), adiabatic compression when moving along the radial feed tube and isobaric cooling are carried out immediately before entering the nozzle. According to the known equations of mechanics and thermodynamics, with taking into account R_{3c}, m_c, the parameters of bubbles can be determined for all the above processes. However, to determine the radius b_0 of the bubbles at the inlet to the nozzle of the wheel of the machine, this is not necessary. Because the radius b_0 is determined based on the condition of mechanical equilibrium, and to find the air pressure in the bubbles, it is enough to know m_c.

The pressure at the inlet to the nozzle of the wheel of the machine under the action of centrifugal forces can vary in the range from 50 atm to 350 atm. A greater value is limited by the conditions for the strength of the DWM material. Therefore, for the equation of the mechanical equilibrium of the bubble at the nozzle inlet, it is necessary to choose some equation of the air state for high pressure. The Van der Waals equation for air has a section of pressure reduction with increasing density. The Betty-Bridgman equation for air has no such disadvantage. But the isotherms of the Betty-Bridgman equation have significant quantitative discrepancies with the isotherms of virial equation of state (VES) of air [10], developed for the system of standardized reference data. We will use the VES for calculations with high pressure.

Now the radius of the bubble b_0 at the inlet to the nozzle of the DWM can be determined by the root of the algebraic equation

$$p_{a,VESA}\left(3\cdot m_c/\left(4\cdot\pi\cdot b_0^3\right),T_0\right)+p_s(T_0)=p_{DWM}+(2\cdot\Sigma)/b_0\,, \qquad (5)$$

where $p_{VESA}(p,T)$ − is the analytical form [10] of the equation of state of the air of the virtual type, (Pa); T_0 − is the temperature of the heated water (after the heat exchanger) at the inlet to the nozzle of the machine, (K); p_{DWM} − is the water pressure at the inlet to the nozzle, (Pa).

According to equation (5), the radius b_0 was calculated depending on the change in the water pressure at the nozzle inlet in the range from 50 atm to 350 atm.

The results of the calculations and their comparison with the calculations for the below established dependence (6) are presented in Table 1.

Table 1 - Results of numerical calculations and relative error of the established dependence (6)

№ in\or	Pressure at the nozzleinlet, atm	Degree of expansion DWM cycle	Radius of bubble on (5), mkm	Ratio of radii	Ratio of radii on (6)	Relative errorin %
1	50	1547	1,67	7,67	7,76	1,2
2	100	3094	1,34	9,62	9,61	0,1
3	150	4640	1,17	11,02	10,87	1,35
4	200	6187	1,07	11,99	11,86	1,1
5	250	7734	1,01	12,77	12,68	0,7
6	300	9281	0,96	13,40	13,3	0,008
7	350	10828	0,92	13,92	14,03	0,8

Further, according to Table 1, the ratio b_{3c} to b_0 was calculated and the dependence of this ratio on the degree of expansion of the "triangular" cycle underlying the work of the DWM was analyzed.

It is established that the obtained dependence can be approximated by the following expression

$$b_{3,c}/b_0=(\varepsilon_P)^{0,2885}-0,553\ , \qquad (6)$$

where ε_P − is the degree of expansion of the "triangular" thermodynamic cycle, which is implemented during the operation of the drive wheel of VPM.

The data in Table 1 show the validity of expression (6) with an accuracy of at least 1.5%. The exponent is calculated by the least squares method by processing the data in Table 1. Thus, when determining the radius of vapor-air bubbles in the inlet section of the DWM nozzle on the basis of the heterogeneous theory of nucleation and the fundamental laws of mechanics and thermodynamics, a new dependence has been established, which is formalized by the relation (6).

Conclusion and direction of further research. A mathematical model was developed for the formation of vapor-air bubbles-nuclei of heterogeneous boiling in the upper layer of water in the condenser pan by "capturing" air when drops fall into the pan.

According to the results of the work, it was found that the ratio of the radii of bubbles in the condenser and at the inlet to the nozzle of the drive wheel of VPM is proportional to the expansion parameter of the "triangular" thermodynamic cycle with an exponent of 0.2885.

In the future, it is advisable to determine the conditions that ensure a continuous increase in the speed of the two-phase flow in the DWM nozzles.

It is also necessary to solve the problem of deriving an expression for calculating the reactive force developed by a two-phase flow in the nozzles of the drive wheel of the vibration-pneumatic machines.

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Анотація. Для підвищення ефективності роботи вібраційно-пневматичних машин запропоновано використовувати теплоту, яка утворюється при роботі її компресора. Проаналізовано процеси перетворення теплової енергії нагрітої води в корисну механічну роботу. Був узятий в увагу процес перетворення теплової енергії в механічну роботу при реалізації «трикутного» термодинамічного циклу. Для організації цього циклу в конструкцію вібраційно-пневматичної машини запропоновано додати робоче колесо, що забезпечує привід вібраційного механізму. Раніше для цієї мети застосовувався електродвигун. Виключення електродвигуна за рахунок вторинного енергетичного ресурсу підвищує ефективність машини.

Аналіз літератури показав досить довільний підхід у визначенні параметрів пароповітряних бульбашок на вході в сопло робочого колеса машини. Ціль роботи полягала у встановленні залежність відносини радіусів пароповітряних бульбашок на вході в сопло робочого колеса машини й у конденсаторі від ступеня розширення «трикутного» термодинамічного циклу. Параметр розширення циклу – відношення тиску води у вхідному перетині сопла до тиску пароповітряного середовища в конденсаторі машини.

Запропоновано фізико-математичну модель формування пароповітряних бульбашок-зародків гетерогенного скипання у верхньому шарі води в піддоні конденсатора шляхом «захоплення» повітря при падінні крапель у піддон, а також зміни їх параметрів до вступу у сопла, що встановлені на робочому колесі машини. На основі фізичної моделі побудовано систему алгебраїчних рівнянь для визначення складу пароповітряного середовища й радіуса бульбашок у вхідному перетині сопел. Чисельними методами досліджені розв'язки цієї системи рівнянь.

Уперше встановлено, що відношення радіусів бульбашок у конденсаторі й на вході в сопло РКМ пропорційне параметру розширення термодинамічного циклу машини з показником ступеня 0,3. Установлення взаємозв'язку радіуса пароповітряних бульбашок у конденсаторі й на вході в сопло дозволить науково визначати, а не довільно задавати, параметри дисперсної фази у вхідному перетині сопла машини. Це підвищує точність усього алгоритму визначення параметрів робочого колеса машини залежно від параметрів робочого тіла в ключових точках його контуру циркуляції.

Ключові слова: вибраційно-пневматична машина, робоче колесо, пароповітряні бульбашки, радіальні подавальні трубки, сопла робочого колеса, конденсатор машини, двофазний потік.

Аннотация. Для повышения эффективности работы вибрационно-пневматических машин предложено использовать теплоту, образующуюся при работе ее компрессора. Проанализированы процессы превращения тепловой энергии нагретой воды в полезную механическую работу. Был взят во внимание процесс превращения тепловой энергии в механическую работу при реализации «треугольного» термодинамического цикла. Для организации этого цикла в конструкцию вибрационно-пневматической машины предложено добавить рабочее колесо, обеспечивающее привод вибрационного механизма. Раньше для этой цели применялся электродвигатель. Выключение электродвигателя за счет вторичного энергетического ресурса увеличивает эффективность машины.

Анализ литературы показал достаточно произвольный подход в определении параметров паровоздушных пузырей на входе в сопло рабочего колеса машины. Цель работы заключалась в установлении зависимости отношения радиусов паровоздушных пузырей на входе в сопло рабочего колеса машины и в конденсаторе от степени расширения «треугольного» термодинамического цикла. Параметр расширения цикла – отношение давления воды во входном сечении сопла к давлению паровоздушной среды в конденсаторе машины.

Предложена физико-математическая модель формирования паровоздушных пузырей-зародышей гетерогенного вскипания в верхнем слое воды в поддоне конденсатора путем «захвата» воздуха при падении капель в поддон, а также изменения их параметров к поступлению в сопла, установленные на рабочем колесе машины. На основе физической модели построена система алгебраических уравнений для определения состава паровоздушной среды и радиуса пузырей во входном сечении сопел. Численными методами исследованы решения этой системы уравнений.

Впервые установлено, что отношение радиусов пузырей в конденсаторе и на входе в сопло РКМ пропорционально параметру расширения термодинамического цикла машины с показателем степени 0,3. Установление взаимосвязи радиуса паровоздушных пузырей в конденсаторе и на входе в сопло позволит научно определять, а не произвольно задавать параметры дисперсной фазы во входном сечении сопла машины. Это повышает точность всего алгоритма определения параметров рабочего колеса в зависимости от параметров рабочего тела в ключевых точках его контура циркуляции.

Ключевые слова: вибрационно-пневматическая машина, рабочее колесо, паровоздушные пузыри, радиальные подающие трубки, сопла рабочего колеса, конденсатор машины, двухфазный поток.

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