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СЕРИЯ ГЕОЛОГИИ И ТЕХНИЧЕСКИХ НАУК

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НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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DEVELOPMENT OF AN EXPERIMENTAL PLANT OF A NON-NOZZLE POROUS FOAM GENERATOR FOR PRODUCING WITH FOAM GENERATING AND DEFOAMING STRUCTURES

Abstract. On the basis of studies of heat-mass exchange processes by boiling of pure liquids and with the addition of surface-active agents, a new class of non-nozzle porous foam generator for producing of air (steam) and mechanical foam was developed. The results of the experiment are generalized by the criteria equations of heat-mass exchange with an accuracy of ± 20% with respect to the processes of bubbling, foam generation, pseudo-fluidization and boiling. The combined action of capillary and mass forces for capillary-porous structures of the 3x0,4 type made it possible to boost the operating mode of the foam generator by 1,5-2 times and reduce the consumption of the foam generating agent and reduce the hydraulic resistance tenfold. The nozzle-free foam generators of air mechanical foam were designed along with its case, inlet and outlet nozzles, a set of grids and sprayer. They help to conduct foam generation processes with high effectiveness under low hydro-and-gas dynamic resistance. For further enhancement of the combined processes of gas mechanical foam and collecting micro-and-ultramicroscopic dust, a dust collector along with its case, inlet and outlet nozzles, a set of grids and sprayer was proposed, which is equipped with defoaming grid porous structure, whereas foam generating and defoaming structures are installed into in case consequently as per the dusty gas movement and sludge collector. Besides, each subsequent grid of foam generating porous structure is made with the increased size of cells following the cleanable gas; e.g. made of metal cells for clearance 0,08*0,14*1, and defoaming made of grids with decreasing size of cells following the cleanable gas, e.g made of metal cells for clearance 0,4*0,14*0,08.

Key words: porous foam generator, foam generation, foaming, defoaming, heat-mass exchange, capillary-porous structures.

Study of the heat and mass exchange of boiling pure liquids in capillary porous structures, development of control methods for these processes [1] allowed to summarize trials with pure foam and dust-foam flows and study a single equation for calculation of the heat and mass exchange with an accuracy up to ±20 % [2], whereby boiling processes, bubbling, pseudofluizidation and foam generation were summarized as well.

A new class of nozzle-free foam generators and foam-dust catchers along with bubbling capillary porous grids were invented [3], as well as foam generating and defoaming structures located vertically. Due to the controlling internal characteristics of two-phase flows [4] different types of foam-dust catchers were designed [5-13]. It is possible to increase effectiveness of dust-gas catching because of controlling geometry of microchannels of porous material [6], separation of flow into wave energy and gas (steam) energy [7, 11], forming generator with the help of power (without incoming flotation) [8], design of turbulizers as foam generating and defoaming structures using a joint action of gravitation and capillary forces, pressure and vibration forces.

In accordance with the article No.358012, 1972 a method of electrostatic gas cleanup was described where electrization of settling elements was produced using a tribo effect. This effect was used earlier, though during electrization of filter elements they had a conductive layer on their surface, which reduced the electrostatic filtration component. The reviewed method describes that an effectiveness of electrostatic filters will be increased because it is recommended to implement electrization with the help of circulation of weight fine grained electrified agent in hollow settling elements.

Method of electrostatic gas cleanup as per the article No.358012, 1972 in terms of dust settling effectiveness exceeds the known methods. However, in comparison with the known methods, it has a low dust settling productivity.

Therefore, it is possible to increase the effectiveness of dust electrization in air flow by using a tribo effect. Though it requires solving a problem of dust cleanup productivity.

In addition to methods of gas cleanup from dust there is a method /article No. 247241, 1969/, where it is suggested to catch thin aerosol sprays with the help of charging aerosol spray particles when the electrostatic sprayed easily evaporating liquids are settled on them, hence a liquid vapor in a form of condensate will be re-used. Such method has an advantage over the method of dust catching by charging electrostatic sprayed water, because a mutual attraction of dust particles and drops of sprayed water leads to their adhesion and growth of particles along with charge neutralization.

A common disadvantage of electric methods is a minor size and porous structure of formed aggregation of dust particles. Under impaction, they can be easily destroyed. Low effectiveness of dust suppression process could be expected from settling of fine dust. Thus, it is required to develop a dust suppression method, which would allow significantly increase resistance to destruction of formed dust aggregation whilst processing an air dust flow by electric field with retention of high productivity of dust cleanup.

It is interesting to see the air dedusting method using porous blankets /article No. №368413, 1973/. In order to increase an effectiveness of dust catching, a dust flow goes through the parallel blankets that moist liquid. A moving air flow helps to vibrate blankets due to the irregular speeds. Dust particles located in air turbulent flow are being moisturized and coagulated. Fiber is moisturized by water supply to pipe frame where the blankets are fixed.

To achieve a required effectiveness of dust catching, it is necessary to conduct multiple test researches in various mode parameters, as well as to perform new design studies for forming an aerodynamic structure of air dust flow.

There is a dust suppression method based on enriched water steam. With a steam condensate, the area of low pressure is formed where all particles move and could be caught. The disadvantage of such method is its low effectiveness that is caused by unreasonable use of generated steam for the purposes of dust suppression. Besides, to achieve a required norm of dust content large steam resources are required, and that result in unreasonable costs for steam generation.

Similar method to the above-mentioned method is a method (article No.130461), where air dust flow is mixed with steam spray with further settling of steam-dust flow by the sprayed water.

Under such process, it is expected to obtain a low degree of dust catching. Condensate effect will be shown in unstable way, takes probabilistic nature depending on random contact of water sprayed drops with water steam molecules and will be determined by turbulence degree of air dust flow. Dust coagulation effectiveness is expected as minor in conditions of enriching air dust flow by steam. That is why water steam and sprayed water are used unreasonably, and there is increased consumption of steam and water.

When studying a movement of aerosol particles in the steam diffusion field it was evident that the aerosol particles are intensively remote from a cold surface. Aerosols with speed 1 m/s were put through the condenser of 0.5 m long and $5x10^{-3}$ m wide. Metal wall is washed by water with the temperature at condenser inlet 20°C and outlet about minus 70°C. Particle concentration was 1012 particles/m^3. Catching degree varied in large limits 75-95%. Mechanism of the dust suppression process is based on two principles: I) condensate enlargement of aerosol particles like condensation nucleus; 2) directed movement of steam particles mainly towards a cold surface.

Mechanism of the dust suppression process is very complicated, though the main acting factors could be indicated such as Stefan flow of condensed steam as a driving force of aerosol particles. Also, it is enforced by the available diffusion, thermophoretic forces and convective flows, large particles are removed from flow due to the gravitation and centrifugal forces; some particles in air steam flow are minimized because of the coagulation process.

Study of the mechanism of dust suppression in the steam diffusion field requires further development, in particular, it is related to the enhancement of the steam condensation process, steadiness of liquid film distribution, development of new devices for feeding air dust flow by the enriched steam.

Some enhancement of the dust suppression processes could be achieved by additional power sources /article No.1032197, 1983/. It is suggested to charge water steam and dispersed water oppositely, whereas water should be previously magnetized. Steam is injected to a tank with hot mass, which goes through the electric field formed at the steam nozzle outlet. Steam-air-dust flow leaving a tank is condensed at sprayed drops of electrically charged and magnetized water.

Under the weight steam consumption equal to $7x10^{-3}$ kg/f and over, a relative air dust content reaches up to 3-6% and becomes self-simulated in relation to steam consumption. The increase of process effectiveness in the described condensate system of dust suppression occurs 1.5-2 times (probably in relation to condensate system without electric charge of steam, water and magnetization of water). Also, it is unclear how it impacts upon the process of water magnetization, and what contribution of electric charge separately for steam and water is.

The reached effect is explained by the fact that when oppositely electrically charged sprays of water and steam are injected to the dust source due to electric gravity forces between steam molecules and water drops it leads to more enhanced and ordered steam condensation at water drops. At condensate surface, a larger hydrodynamic flotation occurs rather than at non-charged aerosols, which directs to drops that collects dust particles and tends to their catch by drops. Due to that, massive dust particles are settled. Capture rate of dust particles by water drops also is increased due to minimizing forces of the surface tension of electrically charged drops.

The described method of dust suppression has an additional effect on settling dust particles. However, it is achieved by huge efforts as it requires the electric charge of steam, water, water magnetization that significantly complicates a condensate system of dust suppression, and extra costs for establishing electric fields and ensuring electrical safety of manpower.

Therefore, further theoretical and experimental studies of the dust suppression processes should be aimed at new design solutions that are based on the reviewed methods using evaporator-condensing multiphase systems of dust collection and surface-active agents.

Basically, in terms of the existing types of foam generating agents we could hope for the new aerodynamic diagrams and structures, which will determine a behavior of dust suppression process, significantly increasing a cleanup degree of dust flow, and become reliable and easy to fabricate and operate and meet safety requirements whilst operating the equipment [8-13].

Figure 1 demonstrates a new class of nozzle-free foam generator with foam generating capillary porous structure.

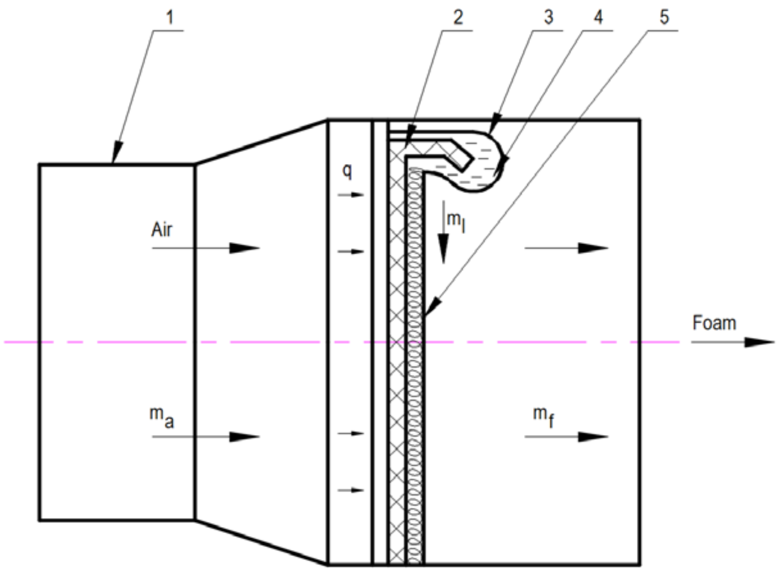

Figure 1 – Nozzle-free capillary porous foam generator of air (steam) mechanical foam:
1 – cylindrical case; 2 – capillary porous structure; 3 – spray device (feeding artery); 4 – foam generating solution;
5 – air (steam) – mechanical foam; ma, ml, ms – consumption of air (steam), liquid (foam generating solution), foam;
q – incoming (foam generating) flow energy density

Figure 2 demonstrates a test facility for research of air (steam) generation processes - mechanical foam.

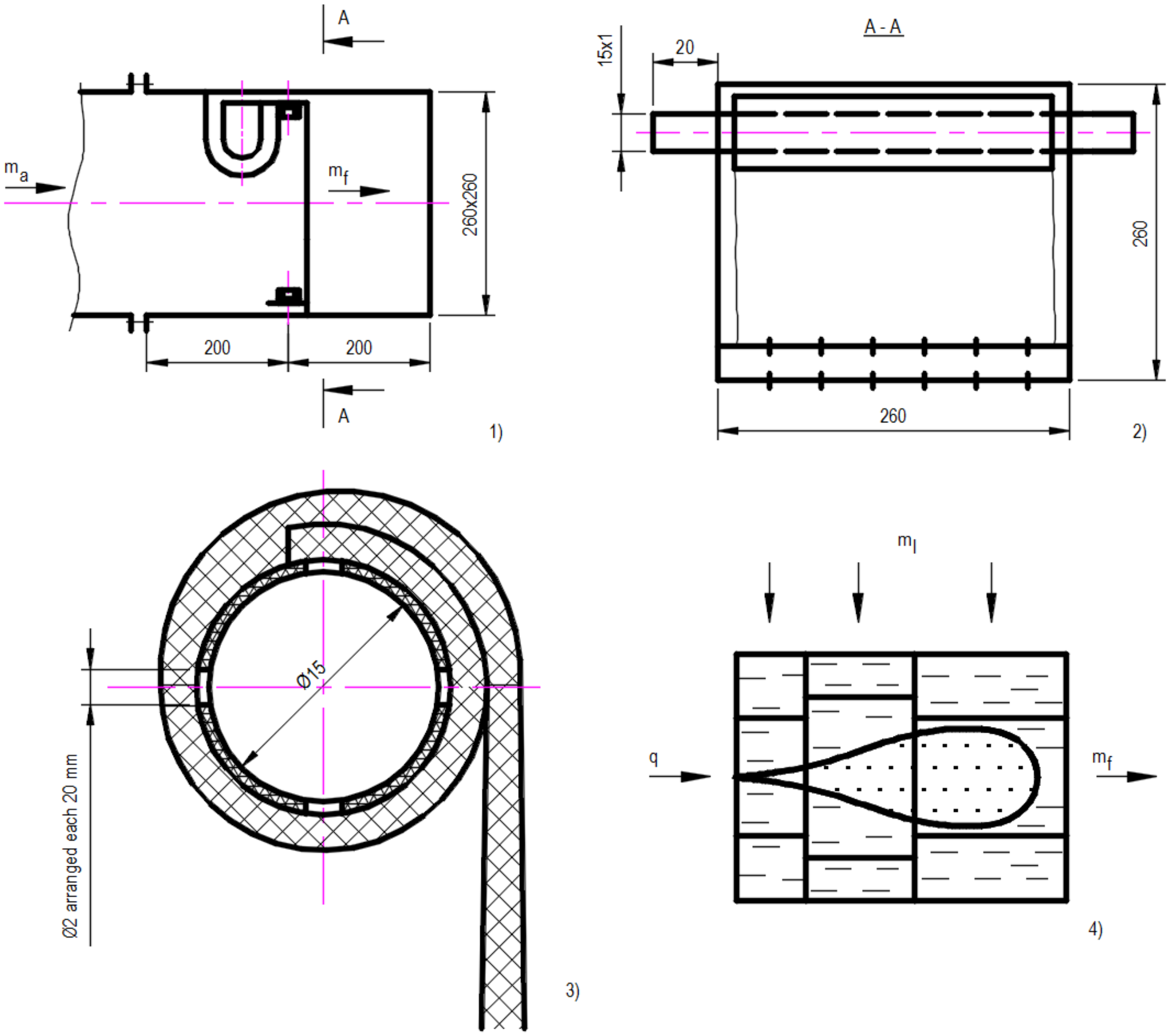

Figure 2 – Test facility for research of foam generation process:
1 – foam generator; 2 – spray device; 3 – connection of capillary porous structure; 4 – bubble dynamics in structure

The combined use of mass and capillary forces ensures the formation of uniform and stable film for distribution of the foam generation solution throughout all capillary porous structure 3x0,4 (three layers of grid where cell width in light is $0{,}4x10^{-3}$ m). This allows to increase operational mode of foam generator up to 1,5-2 times, reduce consumption of foam forming agent whilst retaining foam stability, dispersion and high expansion rate.

Value of hydraulic resistance will be a few times less because of nozzle unavailability rather than in foam generators GVPV-400 or PGG-4.

Research of heat-mass exchange processes by boiling of pure liquids in capillary porous structures revealed a behavior of the internal (thermal hydraulic) characteristics, generation of vapor phase, density of generation centers, discharge of drops from the structure, bubble departure diameter and frequency of bubble departure, speed of bubble growth [11, 13-16]. The different porous systems were developed applicable to heat and power units [17] and the relevant calculations were performed to verify trial data with accuracy ±20% in a form of criterial equation for bubbling, injection, suction, pseudo fluidization, foam generating [18] and focused on highly effective nozzle-free capillary porous dust-and-gas collectors with foam generating and defoaming structures [3, 6-8, 12].

Let's review a new class of nozzle-free dust-and-gas collectors. Invention called "Dust Collector" [article No.1456608, MKI E21F 5/04, 1989] refer to the different industries of national economy for highly effective gas (air) cleanup from micro-and ultramicroscopic dust (size of fractions less than $5*10^{-6}$ m and $0,25*10^{-6}$ m accordingly), for example, in fuel combustion, processing and transportation of dusty materials, removal of vent emissions.

There is a known device for collecting gases and aerosols [article No.309717, kl.V. OId 47/04, 1971], which contains inlet and gas removal nozzles, case, fiber attachment located in case, gasket and baffle, mist separator.

The disadvantage of this device is its low effectiveness for collecting micro-and ultramicroscopic dust, defined by the size of nozzle pores, that leads to a high material consumption, high hydraulic resistance as per the liquid movements and gas dynamic resistance whilst flushing gas (air).

A short duration of operations between generations due to pore plugging of fiber attachment causes a significant problem. Foam is generated outside of porous body and attacks its surface. That reduces the effectiveness of dust collection and enhancement of the mass transfer process, which increases material consumption, dimensions and weight of the device.

Gas flow penetrating a fiber attachment overcomes a high gas dynamic resistance. It is due to the excess energy and its boosting. Duration of operations between generations of such device will be low because pores in fibers tend to be blocked by dust particles. This leads to the complicated operations of the device, and minimizes its reliability.

In the suggested capillary porous structures of nozzle-free dust-and-gas collector [3, 6-8, 12] a high effectiveness for collecting micro-and ultramicroscopic dust could be explained by diffusion mechanism of dust settling in the foam flow and at the structure surface, when dust particles are under continuous influence of gas molecules, which are in the Brownian movement, whereas mobility of particles will be increased with the help of thermophoresis due to difference of temperature between skeleton of porous structure, foam flow and dust particles on the one hand, and due to diffusiophoresis caused by the gradient of concentrated components of foam flow, enforced with vapor process of foam forming solution within a porous structure and partial steam condensate of foam flow on the other hand.

High resistance and stability of liquid film in cells of grid structures is ensured with an equal injection of the sprayer liquid and allows to reduce a consumption of foam forming solution 1,5 to 2 times retaining the foam stability, dispersion and multiplicity of foam formed in foam generating structure [3, 6-8, 12].

As shown in trials [7, 12] hydraulic resistance of the grid porous structures in comparison with the fiber attachment is reduced a few times, as well as a gas dynamic resistance a few times. Since the suggested porous structures have large cell sizes in comparison with pores of the fiber attachment that tend to increase a duration of grid regeneration, and thus it simplifies operations and enhances the reliability of dust collector and its service life.

It is impossible to organize a stable process in multiphase layer with the help of fiber and filter materials similar to them (metal ceramic, sintered powders) as foam bubbles block nozzle pores and stop access of fresh portions of foam generating liquid to bubble generating pores at loads 2 to 2,5 times less than for the grid structures.

Dust collector operates in the following way as below.

Flow contaminated by dust is injected through the nozzle of dusty gas 1 into dust collector case 2 (figure 3). Gas cleanup from microscopic dust is performed in foam generating porous structure 3 of type 0,08*0,14*1. Gas mechanical foam 10 is blown by gas flow from the structure cells, supplied by foam forming solution 9, for example, 110-12, supplied by sprayer 4.

Porous structure in comparison with isotropic structure helps significantly enhance mass exchange processes flown in their volume and on the surface because of simplified growth of bubbles 8 from top of the cone to its base, that increases coagulative feature of foam. Therefore, enhancement of processes leads to higher effectiveness of catching microscopic dust due to raising rate of catching dust by foam in the volume of structure and on its surface.

Gas mechanical foam 10 will be destroyed from the surface and in the volume of defoaming porous structure 5 of type 0,4*0,14*0,08. Foam bubbles 11 start intensively burst in structure due to the growth of resistance from the cone base to its top. Microscopic dust contained in destructive gas mechanical foam under influence of gravity and pressure leaking from sprayer along the porous surface moves towards sludge collector 7.

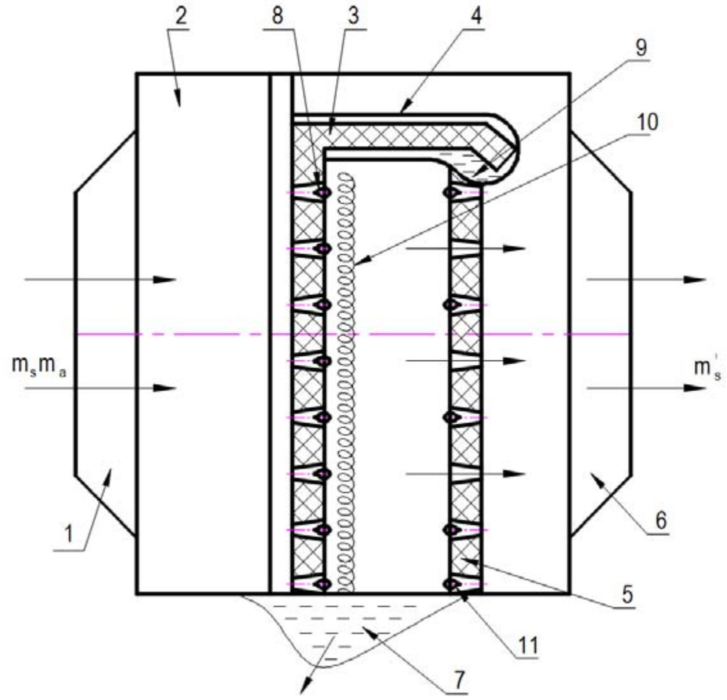

Figure 3 – Nozzle-free capillary porous dust collector with foam generating 3 and defoaming 5 structures:
1 – inlet nozzle; 2 – dust collector case; 3 – foam generating porous structure; 4 – sprayer; 5 – defoaming porous structure;
6 – outlet nozzle; 7 – sludge collector; 8 – bubble; 9 – defoaming porous structure; 10 – gas mechanical foam;
11 – foam bubbles; mf, ma, m^I_s, – consumption of foam, air (steam)

Gas will be additionally cleaned up from microscopic dust in defoaming structure where the destructive process of gas mechanical foam is significantly enhanced because grids are collected with minimized cell sizes.

This results in increasing effectiveness of collecting microscopic dust on its surface and in volume due to raising rate of catching dust and increases coagulative feature of the destructive foam flow.

Gas cleaned up from the microscopic dust is removed from the device through the outlet nozzle of clean gas 6.

Test demonstrated [8, 12] that in comparison with the filtering materials such as metal ceramic and sintered powders, consumption of form forming solution is reduced 1,5 to 2 times retaining the foam stability, dispersion and multiplicity of foam, hydraulic resistance for transportation of foam forming liquid is reduced 10 to 20 times, gas dynamic resistance 1,8 times that minimizes pump and fan (smoke exhauster) capacity, material consumption and dimensions 2 to 2,5 times, weight of device 3 to 4 times.

Time between regeneration significantly increases, as well as the effectiveness of catching microscopic dust, which could reach values up to 99,6-99,8%, thus it simplifies operations and enhances reliability of dust collector and its service life, which is proved by relevant acts of Trust Alma-AtaInzhstroi and Almaty Heat & Power Plant-2.

Cost of implementing the suggested dust collector will be saved because of reduced consumption of foam forming solution 1,5 to 2 times, minimized hydraulic resistance for transportation of foam forming liquid up to 10 to 20 times, gas dynamic resistance for pumping of dusty flow up to 1,8 times, material consumption and dimensions up to 2 to 2,5 times, weight of device 3 to 4 times. Also the device operations are getting simplified, duration between regenerations increases, and thus it enhances reliability and service life of the device, which saves capital and operational costs.

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КӨБІК ӨНДІРЕТІН ЖӘНЕ КӨБІК СӨНДІРЕТІН ҚҰРЛЫМДАРЫ БАР АУА (БУ)-МЕХАНИКАЛЫҚ КӨБІКТІҢ БҮРІККІШСІЗ КЕУЕК КӨБІК ГЕНЕРАТОРЫНЫҢ ЭКСПЕРИМЕНТТІК ҚОНДЫРҒЫСЫН ӘЗІРЛЕУ

Аннотация. Таза сұйықтықтарды қайнатумен және қабатты-белсенді заттарды қосумен жылу-салмақ алмастырғыш үдерісті зерттеу негізінде ауа(бу)-механикалық көпірікті бүріккішсіз капиллярлы-борқылдақ көпірік генераторларының жаңа класы әзірленді. Эксперимент нәтижелерін жылыну мен масса тасымалының критикалық теңдеулеріне көбік, поролон жасау, псевдоожолдау және қайнау процестеріне қатысты ±20% дәлдікпен қорытылады. Капиллярлы-бұрқылдақ құрылымдар үшін 3х0,4 түріндегі капиллярлы және салмақты бірыңғай әрекеттер көпірік генераторының жұмыс режимін 1,5-2 есе тездетуге, көпірік қалыптастырушының шығындарын қысқартуға және гидравликалық қақтығысты он есе азайтуға мүмкіндік берді. Корпус, кіру және шығу келте құбырлары, торшалар топтамасы, тозаңдатқыштан тұратын ауа-механикалық көбікке арналған бүркігішсіз көбік генераторлары әзірленді. Олар аз гидро және газдинамикалық қарсылықтарда жоғары тиімділікпен көбік өндіру процестерін жүргізуге мүмкіндік береді. Газ-механикалық көбікті өндіру мен микро және ультрамикроскопиялық тозаңды тұту бірлескен процестерін әрі қарай сәйкестендіру үшін көбік сөндіретін торкөзді кеуекті құрылыммен және қақ жинағышпен жабдықталған корпус, кіру және шығу келте құбырлары, торшалар топтамасы, тозаңдатқыштан тұратын тозаң тұтқыш ұсынылды, бұл ретте көбік өндіретін және көбік сөндіретін құрылымдар корпусқа тозаңдатылған газ қозғылысының бағытын бойлай орнатылды. Бұдан өзге, көбік өндіретін торкөзді кеуекті құрылымның кейінгі торшасы тазартылатын газдың қозғалыс бағыты бойымен ұяшықтардың ұлғаятын өлшемімен, мысалы, саңылауға ұяшықтарының өлшемі:

0,08*0,14*1 болатын метал торлардан, ал көбік сөндіретін торша - тазартылатын газдың қозғалыс бағыты бойымен ұяшықтардың кішірейетін өлшемімен, мысалы, саңылауға ұяшықтарының өлшемі: 0,4*0,14*0,08 болатын метал торлардан орындалды.

Түйін сөздер: борқылдақ көпірік генераторы, көпірік генерациясы, жылу салмақ алмастырғыш, капиллярлы-борқылдақ құрылымдар.

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РАЗРАБОТКА ЭКСПЕРИМЕНТАЛЬНОЙ УСТАНОВКИ БЕЗФОРСУНОЧНОГО ПОРИСТОГО ПЕНОГЕНЕРАТОРА ВОЗДУШНО(ПАРО)-МЕХАНИЧЕСКОЙ ПЕНЫ С ПЕНОГЕНЕРИРУЮЩИМИ И ПЕНОГАСЯЩИМИ СТРУКТУРАМИ

Аннотация. На основе исследований процессов тепло-массообмена кипением чистых, жидкостей и с добавкой поверхностно-активных веществ разработан новый класс безфорсуночных капиллярно-пористых пеногенераторов воздушно(паро)-механической пены. Результаты эксперимента обобщаются критеристыми уравнениями тепло- и массообмена с точностью ±20% применительно к процессам барботажа, пеногенерации, пвсевдоожижения и кипения. Совместное действие капиллярных и массовых сил для капиллярно-пористых структур вида 3х0,4 позволило форсировать в 1,5-2 раза режим работы пеногенератора, сократить расход пенообразователя и в десятки раз уменьшить гидравлическое сопротивление. Разработаны безфорсуночные пеногенераторы воздушно-механической пены, содержащий корпус, входной и выходной патрубки, пакет сеток, распылитель. Они позволяют проводить процессы генерации пены с высокой эффективностью при малых гидро- и газодинамических сопротивлениях. Для дальнейшей интенсификации совместных процессов генерации газомеханической пены и улавливания микро- и ультрамикроскопической пыли предложен пылеуловитель, содержащий корпус, выходной и выходной патрубки, пакет сеток, распылитель, который снабжен пеногасящей сетчатой пористой структурой, причем пеногенерирующая и пеногасящая структуры установлены в корпусе последовательно по ходу движения запыленного газа, и щламосборником. Кроме того, каждая последующая сетка пеногенерирующей сетчатой пористой структуры выполнена с увеличивающимся размером ячеек по ходу движения очищаемого газа, например, из металлических с размером ячеек на просвет: 0,08*0,14*1, а пеногасящая – из сеток с уменьшающимся размером ячеек по ходу движения очищаемого газа, например, из металлических с размером ячеек на просвет: 0,4*0,14*0,08.

Ключевые слова: пористый пеногенератор, пеногенерация, пенообразование, пеногашение, тепломассообмен, капиллярно-пористые структуры.

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