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CLASSIFICATION OF N-LINE STATIC CAVITATION MIXERS (SURVEY OF DESIGNS)

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A classification of the heat exchangers of capacitance apparatuses with rotary mixers for use in mixing liquid media is described. A critical survey of the most characteristic heat exchangers now available is performed.

Keywords: liquid medium, cavitation mixer, classificationi, designs.

Effective mixing of liquid media in chemical engineering is achieved in equipment provided with mixers [1–3]. One of the drawbacks of equipment that incorporates mixers derives from the presence of moving parts with transmissions, a circumstance that complicates operation of the equipment [4–6].

Devices without individual transmission for flow-type processing of liquid media with the use of cavitation, i.e., a procedure involving processing of gaseous and/or steam bubbles (pockets) in liquid media with subsequent collapsing or cavitation of the bubbles and liberation of energy represents the simplest of these types of devices [7].

From an analysis of the structural implementation of static cavitation mixers we are led to suggest the following classification of these types of mixers (Fig. 1).

By the shape of the cavitator in outline, in the form of a disk, cylinder, sphere, cone, prism, ellipsoid, body of other shape, or in an assembly of discrete elements.

In Patent No. RU2158627C1 the cavitator is in the form of the mixer of a round disk with numerous channels present in a cylindrical channel.

Cavitators are presented in the form of a cylindrical (Patent No. UA52136A) or conical (Patent UA10859U) disk with channels in each of which is found an embedded cavitator.

In Patent No. UA1398C a cavitator is in the form of a round disk with expanded conical channels possessing different angles of taper and mounted in the cylindrical channel of a round disk. The mixing process intensifies through the formation of pulsating and nonuniform cavities (in the axial and diametrical directions) behind the disk.

In Patent No. UA20265A the cavitator is in the form of a hollow cylinder with conical frontal part mounted in a cylindrical working chamber.

Cavitators in the form of a sphere mounted in a cylindrical channel are presented in Patent No. RU2134611C1, Patent No. UA90264U, and Patent No. UA94955U.

In Patent No. RU268284C2 the cavitator is in the form of the frustum of a cone that expands in the direction of flow and is mounted in a cylindrical channel.

Cavitators of analogous form with numerous longitudinal cylindrical channels are found in Patent No. RU2079350C1, Patent No. RU2081688C1, Patent No. 2081689C1, Patent No. 2097408C1, Patent No. 2105042C1, Patent No. UA9648A, and Patent No. UA20323A.

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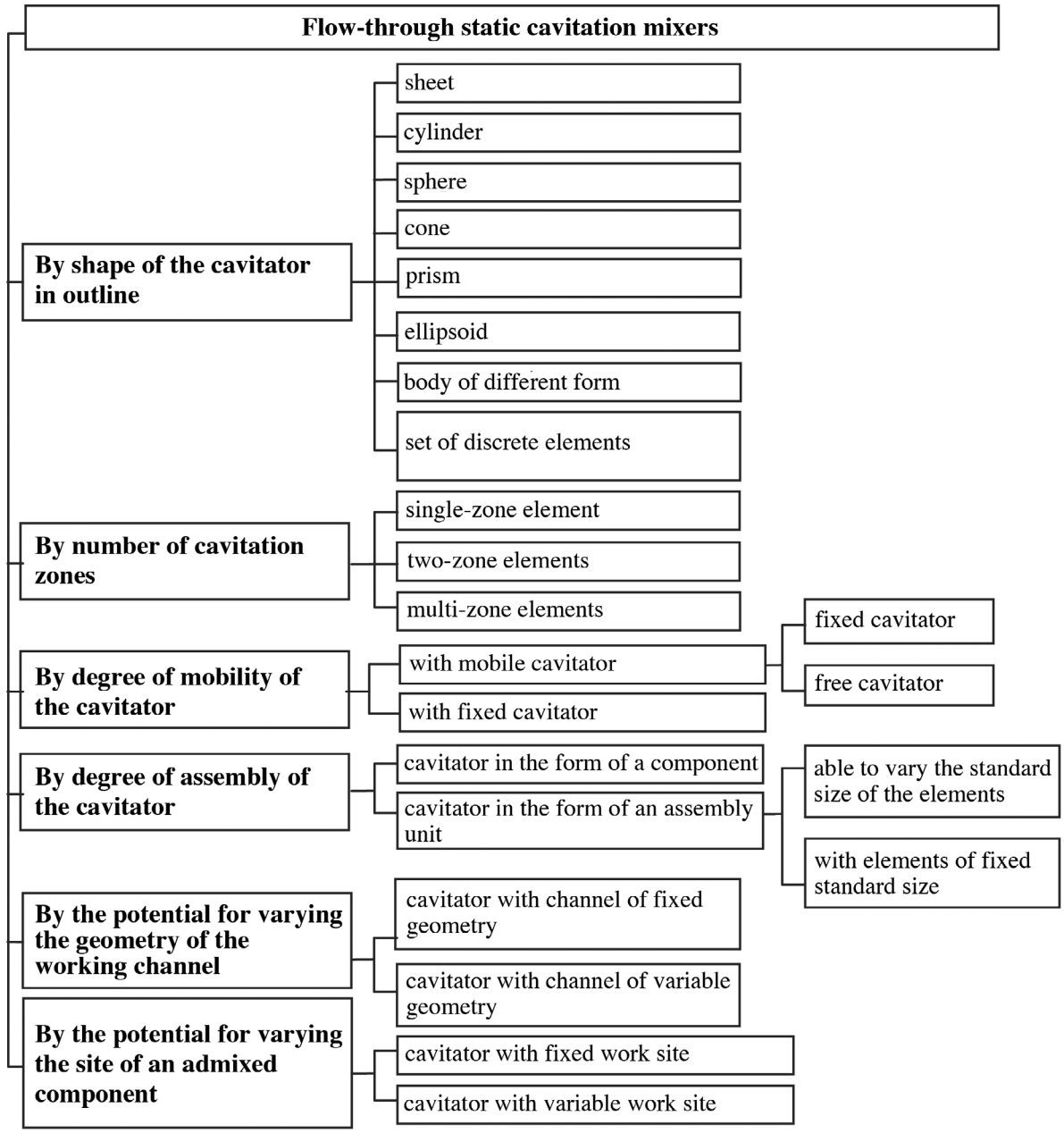

Fig. 1. Classification of flow-through static cavitation mixers.

A cavitator in the form of the frustum of a cone that expands in the direction of the flow along with a gasket situated behind the cavitator with conical channel that contracts in the direction of the flow) is found in Patent No. UA1017C. The bubbles generated by the cavitator fall into the cavity of the gasket where the constriction of the channel and increase in the rate of flow also collapse at the exit from the gasket as a consequence of constriction of the channel and the increase in the rate of flow.

A cavitator in the form of a frustum of a cone which expands in the direction of the flow along with a gasket with set of cylindrical through holes situated behind the cavitator are mounted in the cylindrical channel of a mixer in Patent No. SU1790558A3 and Patent No. UA1035C.

Grooves in a rectangular (Patent No. UA31086U) and Patent No. UA41126U) and triangular (Patent No. UA52855U) transverse section that shrink down to naught in the direction of the lesser base of the corresponding cavitator and expand at an acute angle to its longitudinal axis, which corresponds to the formation of a spiral-like cavity, are produced on the surface of conical cavitators.

A perforated cylindrical shell with cavitator situated in the shell having the form of a coaxially mounted perforated cylindrical shell with cavitator situated in it having the form of an expanded frustum of a cone is presented in Patent No. UA1397C in the cylindrical channel of a mixer. Microgrooves in the flow entering through perforations inside the shell interact, accompanied by the formation of a cavity behind the cavitator, which as a result intensifies the mixing process.

A cavitator in the form of a regular truncated quadrangular pyramid with grooves of a triangular transverse section on its lateral faces that converge to naught on the sides of its lesser base of the pyramid is presented in Patent No. UA52856A.

A cavitator with frontal elliptical part and planar rear part perpendicular to the longitudinal axis of the cavitator is presented in Patent No. CN104591315A.

A cavitator in the form of a streamlined body of irregular shape (several trowels of supercavitating profile) is presented in Inventor's Certificate No. SU1401667A1.

A cavitator in the form of screw-like trowels with sharpened leading edge attached to a longitudinal rod is presented in Patent No. UA44179A.

A cavitator is presented in Patent No. UA52910A in the form of screw-like perforated trowels with toothed outer edge attached to a longitudinal rod.

A cavitator in the form of a streamlined body with smooth wave-like generatrix and mounted in a streamlined channel is presented in Patent No. RU2155633C2.

A cavitator of composite form, mounted as a hollow cylinder in a cylindrical channel with conical frontal part, is found in Patent No. UA20265A.

A cavitator of composite form, presented in the form of a cylinder mounted in a cylindrical channel with frontal part and annular baffles on the lateral surface, is displayed in Patent No. UA51798U.

A conical cavitator and annular baffles are presented in Patent No. UA11842U, moreover, grooves in the form of a spherical segment are produced on the lateral surface of the cavitator and the internal surface of the baffle. A spherical cavity open on opposite sides of the cavity in which intensive eddy formation arises is formed by means of grooves.

A conical cavitator with grooves in the form of a spherical segment is mounted in a conical channel and attached to a hollow plunger through which delivery of an admixed component to the groove is realized is presented in Patent No. UA11842U.

A cavitator in the form of a set of short dowels of round transverse section (set of discrete elements) directed along the radius of the working chamber and secured to its inner surface uniformly circumferentially along one or several diametrical planes is presented in Patent No. RU2419745C1.

In Patent No. UA1396C the cavitator is in in the form of a set of diametrical rods of round cross-section uniformly (in the circumferential direction) fastened to the inner surface of the working chamber of a mixer. Some of the rods are made hollow with perforated walls for delivery of an admixed component.

By number of cavitation zones, one- or two- component zones or multi-component zones.

In Patent No. EP2165745A1 the first cavitation zone of a two-zone mixer is formed by a round disk with one or more through holes, while the second zone is formed as a cone behind the disk. An intermixed component enters the first and/or second cavitation zone through channels in the round disk and/or the cone.

A conical converging tube, stepwise channel of rectangular cross-section, and conical diverging tube are mounted in a two-zone mixer in the path of the flow of a suspension in Patent No. KR101052838B.

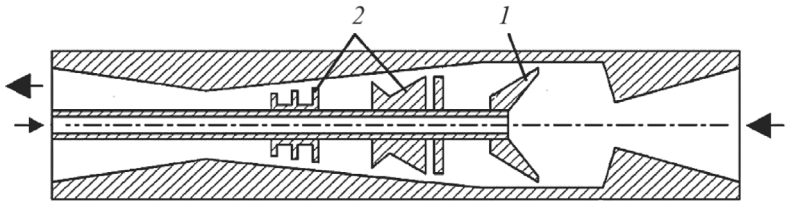

Fig. 2. Schematic diagram of multi-zone mixer with convex shock plate 1 and cavitators 2 of different forms (Patent No. EP1749564A2).

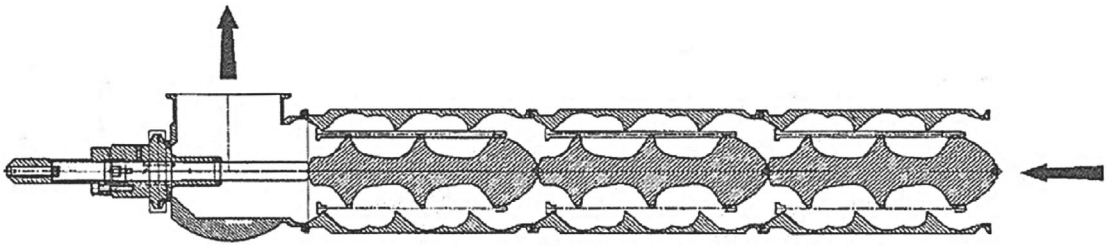

Fig. 3. Schematic diagram of multi-zone mixer (Patent No. EP2433706A1).

Two cavitators in the form of cylinders situated across the channel and rotated 90° to each other are successively mounted in a multi-step channel.

In Patent No. US2007/041266A1; Claim No. US2007/041266A1; Fig. 2) several cavitators are successively mounted in a multi-zone mixer in the cavity of a variable cross-section in a lengthwise hollow rod in order to deliver the component of a previously prepared mixture.

Cavitators are produced in the form of round disks and frustums of a cone forming sections of a channel with the walls of the cavity of the housing a section of the channel in the form of alternating diverging and converging tubes. A drawback of the mixer is seen in the high level of hydraulic resistance, since the first cavitator is produced in the form of a shock plate that runs concave to the flow.

A multizone mixer in which assemblies of foreign cavitators that are difficult to manufacture and repair are situated in the cavity of a framework of complex form in Patent No. EP2433706A1 (Fig. 3).

Cavitators produced in the form of frustums of a cone with different angles of taper and secured by means of large bases to the walls of the channel and to small bases to the overall hub are secured in the cylindrical channel of a multi-zone mixer in the diametrical plane (Patent No. UA1394C, Patent No. RU2032455C1). A set of cavities that affect each other accompanied by the pulsating effect of the mixing of the flow is formed in the course of streamlining of the cavitators.

Conical cavitators are situated in the cylindrical channel of a multi-zone mixer on mobile coaxial plungers in Patent No. UA1399C and Patent No. RU2032456C1. Variation of the distance between the cavitators in the axial direction in order to regulate the intensity of cavitation in each of the zones is achieved by the relative displacement of the plungers in the axial direction. A drawback of the mixer is the need for careful compaction of the plungers at the sites of their passage through the wall of the framework of the mixer.

Combined converging-diverging inserts are situated in Patent No. UA15403A in the cylindrical channel of a multi-zone mixer with a conical cavitator coaxially mounted in the diverging section of each of the inserts. Insertion of component, which is mixed into the basic flow, is provided behind each cavitator.

By the degree of mobility of the cavitator in the course of operation, mixers are provided with fixed cavitator (free or attached to the working chamber and capable of movement).

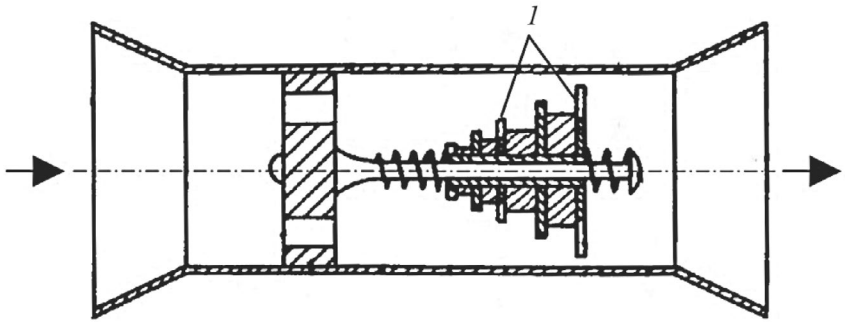

Fig. 4. Schematic diagram with vibrating disks 1 (Claim No. WO96/09112A1, Patent No. DE4433744A1).

In Patent No. EP3725932A1 a mixer is accompanied by a mobile cavitator in the form of a small sphere freely located in the working chamber. A Venturi channel is formed with the wall of the cavity of the working chamber by the oscillation of the sphere under the effect of the flow of liquid, which at the same time realizes an intensive combined mixing and dispersing effect.

In Patent No. GB2348377A a mixer is accompanied by a mobile cavitator in the form of a small sphere freely situated between two springs in a cylindrical working chamber. The sphere rotates turbulently under the effect of the flow.

A mixer with mobile cavitator in the form of two disks suspended by springs from a longitudinal rod is found in Patent No. UA70660U. Back-and-forth oscillation of the disks is achieved by the effect of the flow.

A mixer with bundle of spring-loaded round disks forming a cone that expands in the direction of the flow is presented in Claim No. WO96/09112A1, Patent No. DE4433744A1; Fig. 4). Ultrasonic cavitation is also realized in the travelling flow besides hydrodynamic cavitation.

Cavitators in the form of a round disk with an oscillating strap situated behind it designed to disintegrate the cavity formed in the flow of liquid are presented in Patent No. CN104591315A, Patent No. CN104591315A.

A cavitator is in the form of a sphere mounted in a combined cylindrical-conical channel along a radial axis and capable of rotation under the effect of a flow is presented in Patent No. CN107737563A.

In Patent No. CN107737563A elements that oscillate under the action of a flow and effectively destroy a cavity are established in an improved mixer together with a rotating sphere in the working chamber.

In Inventor's Certificate No. SU1718419A1 two impellers are installed in the framework of a mixer with cylindrical channel and are capable of traveling in opposite directions under the effect of the flow, moreover, one of the impellers is mounted inside the other.

By the degree of assembly of the cavitator, mixers possessing a cavitator in the form of a component and mixers with a cavitator in the form of an assembled unit.

Cavitators in the form of a component mounted preferably in mixers for the purpose of processing certain media are the simplest types of cavitators. A cavitator of similar design is present in mixers with cavitators in the form of an assembly unit and containing elements of fixed standard dimension.

In Patent No. EP2165745A1 the cavitator is in the form of a round disk (with one or more through holes) situated perpendicular to the axis of a cylindrical channel.

Despite the simplicity of the design, this type of cavitator is characterized by a high level of hydraulic resistance.

Cavitators in the form of an assembly unit with interchangeable elements of different standard dimensions are a more universal type of cavitators.

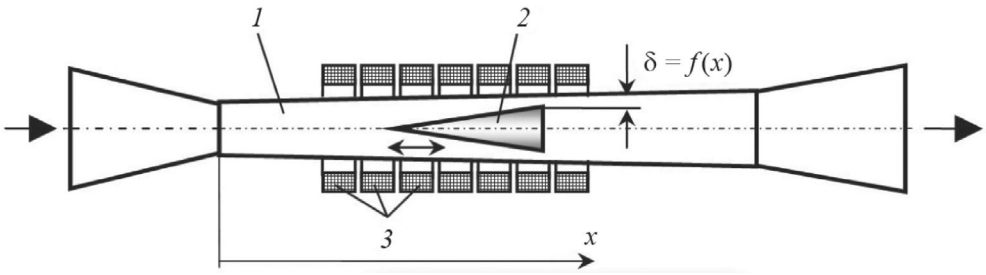

Fig. 5. Schematic diagram with variable cross-section of annular channel between cavitator and working chamber in Patent No. UA68821U: *1* – conical working chamber; *2* – cavitator; *3* – electromagnets

A mixer with working chamber that expands in the direction of travel of the flow in which the cavitator is situated is classified as belonging to such designs (Patent No. 1280598A2, Claim No. WO01/62373A1, Claim No. US2003/147303A1). The cavitator is mounted on a hollow longitudinal rod in order to feed one of the components of the resulting mixture and is produced in the form of an assembly of disks of different diameters with conical peripheral parts and is also situated as an element behind the disks as an element in the form of a body of revolution of complex form. A required degree of mixer hydrodynamics in the working chamber of the mixer is achieved by substitution of the disks as well as by situating spacing sleeves between the disks. A drawback of the design lies in the complexity of the manufacture of the body of the mixer.

By the potential for varying the geometry of the working chamber, we distinguish between mixers with channel of fixed geometry and mixers with variable geometry.

Most static mixers possess a channel with fixed geometry. These types of mixers are characterized by simplicity of design and ease of use, though they usually are designed for processing of particular types of flow.

In Patent No. RU2009709C1 a cavitator in the form of a hollow cone which is designed to enable entry of an admixed component into a basic flow is mounted in a mixer of fixed geometry along the axis of a cylindrical channel.

A peripheral annular reflector and central disk reflector to enable repeated variation of the direction of flow are mounted in the channel behind the cavitator. The mixer exhibits a high level of hydraulic resistance and intensive erosion of the reflectors.

Mixers with channel of variable geometry are more universal mixers and more appropriate for effective processing of different types of flows.

The cone of a mixer with channel of variable geometry is situated in a movable axial plunger in an expanding axial channel in Inventor's Certificate No. SU781240A1 and Patent No. UA54917U. The magnitude of the annular space between the cone and conical channel is regulated by the axial displacement of the plunger.

A cavitator in the form of body of revolution (made of a magnetic material) and instrument for displacement of the cavitator through the framework (in the form of annular electromagnets around the body) is presented in Patent No. U68821U (Fig. 5) are situated in the conical cavity of the housing of the mixer. The position of the cavitator along the length of the housing and the magnitude of the annular gap between the wall of the conical cavity and the cavitator is regulated by linking in a particular number of electromagnetics. The advantage of the cavitator is that there are no devices present in the channel for the purpose of clamping the cavitator and that would vary the hydrodynamics of the flow.

In Claim No. DE102007052642A1 a multi-step cavitator in the form of an assembly of round disks is mounted on a longitudinal rod in the conical channel of the mixer, moreover, regulation of the annular gaps between the elements of the cavitator and the surface of the working chamber is achieved by the drive of the axial displacement of the rod.

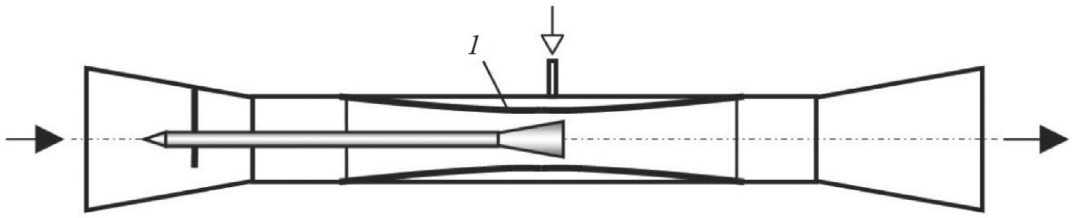

Fig. 6. Schematic diagram with variable section of annular channel between the cavitator and working chamber (Patent No. UA106510U): *1* – flexible elastic shell.

In Patent No. UA99790U the framework of a mixer is produced by telescopic cavitators attached within each section of the framework.

The distance between the cavitators is regulated by the displacement or bifurcation of the sections of the framework.

The thin-walled working chamber of the mixer is produced by means of ring-shaped corrugations in Patent No. UA99791U.

The distance between the cavitators is varied by regulating the length of the corrulated working chamber by means of threaded tie rods.

A cavitator and flexible elastic shell the ends of which are hermetically sealed to the housing are situated in the cylindrical cavity of the hull of a mixer in Patent No. UA106510U. Moreover, the annular cavity between the housing and the shell is linked to a pneumatic pipeline (Fig. 6). The magnitude of the cross-section of the mixer channel is regulated by varying the pressure in the annular cavity.

In Patent No. CN105352704A a cavitator is created in the form of an assemblage of round disks (attached to a common rod) forming a cone. In the course of displacement of the disks the angle of taper of the cavitator decreases, making it possible to adjust the form and dimensions of the cavitation cavity.

In Inventor's Certificate SU1401667A1 the cavitator is shaped as a body of streamlined form with blades of hypercavitation profile attached to it, moreover, a mobile (travelling through the channel) hollow plunger for introducing liquid of the component into the flow travels along the axis of the cavitator.

A conical hood situated within the limits of the converging tube of the working chamber of the mixer is attached to the end of a hollow hood. Two zones of cavitation are provided in the mixer, the first a channel of fixed geometry, the second with a channel of variable geometry.

By the potential for varying the site where an admixed component is introduced into the basic flow – mixers with fixed site for introduction of an admixed component and mixers with variable site for introduction of an admixed component.

A mixer with variable site for introducing an admixed component into the basic flow, either oncoming into the basic flow or in the course of the travel of the basic flow (Patent No. US7897121B1, Claim No. WO2009/021148A1.

The component is introduced through the channel in the carrier of a cavitator constructed in the form of a round cylinder with conical bases and situated along the axis of the working chamber.

Despite the host of designs of static cavitation mixers that are available today, the simplest, most effective, and most sufficiently universal remain continuous-flow mixers in the form of sections of pipeline containing at least a single cavitator in the pipeline and in the shape of a body of streamlined form.

Moreover, thanks to the capabilities of mathematical modeling, improvements continue to be made in traditional continuous-flow cavitators.

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