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# DESCRIPTION

Description

## BACKGROUND OF THE INVENTION

**[0001]** The present invention relates to an improved mixer duct. The present invention also relates to a process for using said mixer duct.

**[0002]** Static mixers are of interest for all industries concerned with mixing and dispersing, gas liquid contacting, or turbulent mixing applications. Static mixers are generally tubular internals that produce desired mixing and dispersion effects as the fluid flows around motionless mixer parts. The fluid flow is provided by pumping. Static mixers have advantages over other mixing systems in that they require only small volumes, low maintenance, and they have a simple installation and cleaning, as well as excellent reliability.

**[0003]** A typical static mixer is disclosed in US6830370B1. This document discloses a static mixer consisting of a pair of semi-elliptical vanes disposed crisscrossed to one another at an incline within a duct. Each pair of vanes thus generates a large vortex or swirling motion within the duct. Other representative types of static mixers are known from Sulzer Chemtech, such as those disclosed in EP0800857A1. Such static mixers comprise inclined parallel plates providing open narrow passages including a gap region running from wall to wall through the duct axis. Another similar static mixer is disclosed in US4758098 having at least three transversely spaced webs. The webs are spaced transversely from each other to provide gaps through which a fluid may pass during mixing. In addition, each web while being secured to the casing at the upper ends relative to a downward flow has lower terminal ends which are spaced from the casing to provide further gaps through which the liquid may pass during a downward descent.

**[0004]** The above-described mixers may often be effective and sufficient provided that enough mixing length is available within the duct as well as sufficient pressure head. However, in certain applications there may be insufficient available length or pressure head for their optimum performance. Therefore it would be desirable to have improved static mixers available to provide sufficient mixing performance under such stringent conditions. For example, when dosing an additive within the mixing duct, it can be quite important to rapidly homogenize the additive concentration within the fluid. This can be quite critical when adding additives that are quite reactive which may then lead to safety or quality issues if the additive is not rapidly and homogeneously distributed within the fluid. In other cases, it may be important to have a homogenous distribution of a reactive additive with the proper reaction stoichiometry before the fluid enters a subsequent reactor.

**[0005]** WO 2012/095623 A1 discloses an apparatus for mixing fluids flowing through a pipe, wherein the mixer duct contains a static mixer element comprising six segments, wherein a longitudinal gap is formed between the segments and wherein the segments are attached to the pipe wall. The segments of the first pair of segments form in cross section a triangle, wherein each of the segments comprises free edges.

#### **SUMMARY OF THE INVENTION**

**[0006]** Starting from this state of the art, it is a first object of the invention to provide an improved mixer duct for mixing of a turbulent flow to provide sufficient mixing performance under stringent conditions such as short available mixing length or limited available pressure head.

**[0007]** A second object of the invention includes providing an improved mixer duct for both mixing of a turbulent flow as well as for dosing an additive and rapidly homogenizing the additive concentration within the fluid, for example, when adding additives that are quite reactive or to provide a homogenous distribution of a reactive additive with the proper reaction stoichiometry before the fluid enters a subsequent reactor. Yet further additional objects of the invention are to provide a process for mixing a main fluid, optionally with an added additive, taking advantage of the favorable properties of the above mentioned favorable mixing properties of the improved mixer duct for mixing of a turbulent flow.

**[0008]** According to the invention, the first object is achieved by a mixer duct for turbulent flow according to claim 1.

**[0009]** Providing two segments inclined relative to the duct axis so that the leading edge is oriented up-stream in the duct has the technical effect that each segment produces a vortex. Each segment is fixed along the duct wall from the upstream portion to the downstream portion of the segment with the leading edge being a free edge located substantially perpendicular to the direction of fluid flow. The effect of the substantially perpendicular leading free edge of the segment is that the fluid is subsequently deflected by the segment leading to an increased under-pressure along the downstream side of the segment and an increased over-pressure along the upstream side of the segment and contributing to the development of large-scale vortices in the fluid. Conventional static mixers lack this technical effect and thus produce lesser under-pressures and less intense vortices. One skilled in the art will understand that the process of using this mixer duct for mixing a main fluid in order to homogenize a characteristic of the main fluid will share these same just discussed advantages.

**[0010]** In one embodiment of the mixer duct of the present invention at least one segment, preferably the two segments, additionally comprises at least a third free edge. The provision of a third free edge advantageously allows the mixer to be shorter in length thus saving material and installation length and weight. This third free edge will typically be provided at the

downstream end of the segment. The vortexes responsible for the mixing are primarily generated in the upstream portion of the segment, and thus the downstream portion of the segment may be shortened, providing a third free edge, without significantly negatively impacting the mixing performance. The number of free edges is not specifically limited in the present invention and will depend largely on the simplicity or complexity of the shape of the segments of the static mixer element.

**[0011]** In another alternative embodiment, none of the two segments additionally comprises a third free edge. Joining the downstream portion of the segment to the duct wall prevents inhomogeneities in the flow distribution through the duct as the open area adjacent through a third free edge would allow the free flow of fluid through the duct there.

**[0012]** According to the present invention, each of the at least one static mixer element comprises exactly two substantially coplanar plate-like segments and no further segment in addition thereto.

**[0013]** According to the invention, the second object is achieved in one embodiment by providing the duct with at least one additional side inlet located substantially upstream of the static mixer element, preferably the leading edge, embodied for the addition of an additive. Feeding the additive in this way upstream of the static mixer element allows the mixing and homogenization process to take advantage of the large-scale vortexes generated by the segments. Furthermore by feeding the additives substantially upstream allows a pre-distribution of the additive across the duct cross section which allows for effective homogenization by the subsequent segments. One skilled in the art will understand that the process of using this mixer duct for mixing a main fluid and an additive in order to homogenize the composition of the main fluid and the additive will share these same just discussed advantages.

**[0014]** In a more specific embodiment of the mixer duct fulfilling the second object, the duct additionally comprises a deflection shield, having a width ( $W$ ), wherein the deflection shield is located substantially parallel to the side inlet axis and substantially perpendicular to the duct axis, wherein the width ( $W$ ) is at least as great in magnitude as the side inlet diameter, and the deflection shield is substantially located upstream from the side inlet, and the deflection shield is embodied so as not to substantially block the duct entrance of the side inlet and to simultaneously allow the additive to propagate into the central region of the mixer duct without being diverted by the main fluid flow through the mixer duct. The deflection shield acts to block the main fluid flow through the duct in the region near the side inlet so as to advantageously allow the additive entering via the side inlet to propagate further into the interior of the duct before it encounters the main flow. Without the provision of the deflection shield, the additive would simply creep along the duct wall adjacent to the side inlet, particularly for additives with low momentum.

**[0015]** In another more specific embodiment of the mixer duct fulfilling the second object, a splash plate is located substantially in the central region of the mixer duct, wherein the splash

plate is oriented substantially parallel to the duct axis so as to not substantially increase the resistance of the main fluid flow through the mixer duct, and wherein the splash plate is simultaneously located substantially perpendicular to the side inlet axis and the splash plate cross-section substantially overlaps the side inlet cross-section when viewed along the side inlet axis. The provision of a splash plate advantageously limits the propagation of the additive across the cross section of the duct. This is important in the case of additives having a high momentum as the risk would be that the bulk of the additive reaches the duct wall opposite the side inlet, which would hinder efficient mixing with the main fluid flow through the cross section of the tube.

**[0016]** According to the invention, the second object is achieved in one alternative embodiment by equipping the mixer duct instead with an additive injection tube having at least one injection tube outlet, wherein the additive injection tube is embodied for injecting an additive into the mixer duct substantially upstream of the static mixer element in a region substantially adjacent to at least one leading edge, preferably equidistant from both leading edges of the two segments, and wherein the at least one injection tube outlet is embodied so as to direct the additive to one or both leading edges, preferably wherein two injection tube outlets are each located equidistant from a leading edge. This alternative embodiment having an additive injection tube is particularly advantageous for adding additives to mixing ducts in the form of an open channel. In the case of open channels, side inlets are not easy to realize because the side inlet may need to be located under the surface adjacent to the channel, e.g. underground. Furthermore the liquid depth in an open channel may vary during operation, thus partially or even completely exposing any side inlets. Thus an additive injection tube may be readily constructed with its outlet located near the bottom of the open channel. In cases of open channels, the leading edges of the segments will also advantageously be located near the bottom of the open channel. One skilled in the art will understand that the process of using this mixer duct for mixing a main fluid and an additive in order to homogenize the composition of the main fluid and the additive will share these same just discussed advantages.

**[0017]** In a more specific embodiment of the previous alternative embodiment, the mixer duct is in the form of an open channel, preferably having a separating wall, wherein the additive injection tube preferably has at least a second injection tube outlet and the open channel preferably has at least a second static mixer element located adjacent to said static mixer element. This embodiment is particularly advantageous when the open channel is relatively wide relative to its depth, for example, twice as wide as deep or more. The vortexes generated are most efficient in the present invention when the cross-section of the duct is approximately square. Thus wider open channels may be effectively divided into smaller approximately-square cross-sections by means of one or more dividing walls. Each of these thus-created divided sections of the duct may be then conveniently fed by additional additive injection tube outlets located in front of or within each of these sections. Alternatively each or several sections could be fed by means of a single additive injection tube and its outlet(s).

**[0018]** Another general embodiment of the mixer duct of the present invention contains additional static mixer elements, preferably one to three additional static mixer elements, more

preferably one or two additional static mixer elements and most preferably one additional static mixer element, wherein the static mixer elements are arranged - viewed in the longitudinal direction of the mixer duct - spatially apart from each other one after another. Two or more static mixer elements being arranged spatially apart from each other one after another lead to a particular excellent mixing capacity. It is preferred in this embodiment that the static mixers are progressively rotated by between about 70 to about 110, preferably about 80 to about 100, more preferably about 90, degrees relative to each other around the duct axis proceeding in a downstream direction. This embodiment has the advantage that the orientation of the structure of the vortexes generated within the mixer duct does not remain constant along the length of the mixer duct, and instead, it is then systemically rotated along the length of the mixer duct which promotes a faster and more homogeneous mixing within the mixer duct.

**[0019]** In an alternative general embodiment of the mixer duct of the present invention, the mixer duct is in the form of an open channel containing additional static mixer elements, preferably one to three additional static mixer elements, more preferably one or two additional static mixer elements, wherein the static mixers are not substantially rotated relative to one another so that their cross-sections substantially overlap when viewed along the open channel axis. In open channels, the depth of the liquid may not be constant and in particular may not fill the channel completely. Therefore certain orientations of static mixer elements may be ineffective. In an open channel mixer duct, the level of the liquid is not defined and may vary, and therefore it is not possible to properly position the at least substantially coplanar plate-like segment along the top of the open channel as it may be exposed to varying levels of liquids. For this reason, it is preferred in open channel mixer ducts that the at least substantially coplanar plate-like segments are located along the vertical side walls.

**[0020]** One skilled in the art will understand that the combination of the subject matters of the various claims and embodiments of the invention is possible without limitation in the invention to the extent that such combinations are technically feasible. In this combination, the subject matter of any one claim may be combined with the subject matter of one or more of the other claims. In this combination of subject matters, the subject matter of any one mixer duct claim may be combined with the subject matter of one or more other mixer duct claims or the subject matter of one or more process claims or the subject matter of a mixture of one or more mixer duct claims and process claims. By analogy, the subject matter of any one process claim may be combined with the subject matter of one or more other process claims or the subject matter of one or more mixer duct claims.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0021]** The invention will be explained in more detail hereinafter with reference to various embodiments of the invention as well as to the drawings. The schematic drawings show:

Fig. 1

(a) shows a schematic view of one embodiment of a mixer duct according to the present

invention having one static mixer, (b) shows a schematic view of one of the vortexes generated by the mixer duct shown in Fig. 1(a).

Fig. 2

shows a schematic view of one embodiment of a mixer duct having a side inlet.

Fig. 3

shows a schematic view of a one embodiment of a mixer duct having a side inlet and a deflection shield and two static mixers, each having a third free edge.

Fig. 4

(a) shows a schematic view of one embodiment of a mixer duct having a side inlet, a deflection shield, a splash plate and three static mixers, each without a third free edge, (b) shows a schematic partial top view of this embodiment illustrating a splash plate having a cross-section substantially overlapping the side inlet cross-section.

Fig. 5

(a) shows a schematic view of one embodiment of a mixer duct in the form of an open channel and having an additive injection tube and two static mixers, (b) shows an expanded view of the region near the additive injection tube, (c) shows an alternative embodiment of an additive injection tube having multiple outlets, and (d) shows an alternative embodiment with multiple additive injection tubes.

Fig. 6

shows a schematic view of one embodiment of a mixer duct in the form of an open channel and having a separating wall, an additive injection tube with multiple outlets and two static mixers located adjacent to one another.

Fig. 7

shows a schematic view of one embodiment of a mixer duct in a flue gas denitrification (DeNox) application

## DETAILED DESCRIPTION OF THE INVENTION

### DEFINITIONS

**[0022]** As used in the specification and claims of this application, the following definitions, should be applied:

"a", "an", and "the" as an antecedent may refer to either the singular or plural unless the context indicates otherwise.

**[0023]** "Duct" as in "mixer duct" in the present application refers to any suitable duct for conveying a fluid which may contain one or more static mixer elements. Typical ducts may be closed ducts, such as a pipe having a substantially circular cross-section or a duct having other geometric cross-sections such as square or rectangular. Other suitable ducts for the present

invention may be in the form of open channels such as those having a bottom and two substantially vertical side walls. The "diameter" in the present application refers to the hydraulic diameter (see for example, [https://en.wikipedia.org/wiki/Hydraulic\\_diameter](https://en.wikipedia.org/wiki/Hydraulic_diameter)) for a non-circular duct.

**[0024]** "Static mixer element" in the present application refers to a static mixer type based on two at least substantially coplanar plate-like segments, such as those disclosed in US 4,758,098 and US 4,019,719. These segments may be unattached to each other or partially attached, as in a substantially U-shaped static mixer element.

**[0025]** "At least substantially coplanar plate-like segments" means in accordance with the present invention that the plate-like segments are inclined with each other with regard to the longitudinal plane of the outer duct wall by not more than 10°, preferably by not more than 5°, more preferably by not more than 2.5° and most preferably by not more than 1°.

**[0026]** "Segments" in the present application refers to a substantially flat plate having at least two free edges. In one embodiment it is a flat plate.

**[0027]** "Free edge" in the present application refers to an edge of the segment which is not attached to something, for example, is not attached to the mixer duct, in particular the mixer duct wall.

**[0028]** "Leading edge" in the present application refers to a free edge, which is oriented substantially upstream, thus towards the source of the fluid flow. It is noted that the leading edge is not required to be to be one single straight edge, but it may be curved or rounded or comprise multiple partial edges, like the edge of a polyhedron. It is important that the majority of the leading edge is substantially perpendicular to the direction of fluid flow.

**[0029]** "Leading edge substantially perpendicular to the direction of a main fluid flow" means in accordance with the present invention that the leading edges are inclined with regard to the plane being perpendicular to the direction of the longitudinal axis of the outer duct wall by not more than 20°, preferably by not more than 10°, more preferably by not more than 5° and most preferably by not more than 2°.

**[0030]** Generally, "substantially perpendicular" means that the concerned part is inclined with regard to the respective plane, to which it is substantially perpendicular, by 70 to 110°, preferably by 80 to 100°, more preferably by 85 to 95° and most preferably by more than 88 to 92°.

**[0031]** "Substantially parallel" means that one the concerned parts extends with a deviation of at most 20%, preferably of at most 10%, more preferably of at most 5% and most preferably of at most 2% parallel to the other part.

**[0032]** "Central region of the duct" in the present application refers to the region of the duct

located closer to the center of gravity of the duct than to a duct wall. In one embodiment it is the central core of the duct located within a distance of  $\frac{1}{2}$  of the radius for a circular duct or  $\frac{1}{4}$  of the hydraulic diameter for a non-circular duct.

**[0033]** "Longitudinal gap" in the present application refers to the open space between the two at least substantially coplanar plate-like segments. This open space or gap may or may not have a uniform width between the segments, and it may run the entire length of the segment for segments that are not attached to one another. Or it may be a partial length for two at least substantially coplanar plate-like segments that are partially attached to one another, for example, in the case of a substantially U-shaped static mixer element. "Substantially longitudinal gap" means in this connection that the length of the gap is longer than the width of the gap. If the length of the gap is not equal over the width of the gap and/or the width of the gap is not equal over the length of the gap, then the average length of the gap is longer than the average width of the gap.

**[0034]** "Side inlet" in the present application refers to an inlet through the wall of the duct, for example, for feeding of a fluid such as an additive. The cross-section of the side inlet is not specifically limited but it will be often substantially circular as in the case of a pipe for feeding a fluid via the side inlet.

**[0035]** "Additive injection tube" in the present application refers to a tube of circular or other cross-section for adding a fluid such as an additive into an interior portion of the mixer duct. In some embodiments it will be in the form of a sparger. In some embodiments it may have more than one outlet into the mixer duct in order to improve the pre-distribution of the additive as it enters the mixer duct.

**[0036]** Numerical values in the present application relate to average values. Furthermore, unless indicated to the contrary, the numerical values should be understood to include numerical values which are the same when reduced to the same number of significant figures and numerical values that differ from the stated value by less than the experimental error of the conventional measurement technique of the type described in the present application to determine the value.

**[0037]** FIG. 1 shows a schematic view of one embodiment of a mixer duct, which as a whole is labeled with reference number 1. The mixer duct 1 is not specifically limited as to form, shape, construction or composition unless specifically indicated otherwise. Any suitable material that can be fabricated can be made into mixer duct 1. For reasons of economy, such systems 1 are often made from stainless steel or another material indicated for the specific application.

**[0038]** In this figure, it is shown that a main fluid 20 enters the mixer duct 1 by means of mixer duct inlet 10 and flows through the mixer duct in the direction of the main fluid flow 30, which is generally parallel to the mixer duct axis 2. The main fluid flow 30 next encounters a static mixer element 50 which comprises two coplanar plate-like segments 70. The segments 70 have a substantially longitudinal gap 80 between them, and each segment 70 is attached to the mixer

duct wall 5 and comprises at least two free edges 72, 72'. One free edge 72 is the leading edge 74 and the other free edge 72' is adjacent to the longitudinal gap 80. It is shown that the two segments 70, 70' are inclined relative to the duct axis 2 so that the leading edge 74 is oriented up-stream in the duct 1 and substantially perpendicular to the direction of a main fluid flow 30. It is noted that the segments 70 and 70' of the static mixer element 50 in this embodiment both lack a third free edge 72". After encountering the static mixer element 50, the homogenized main fluid 20' propagates further through the mixer duct 1 and exits by means of mixer duct outlet 15.

**[0039]** The segments 70 and 70' in the present invention may be partially joined somewhat similarly as in the static mixer shown in Fig. 1 of EP0800857 (A1). In such embodiments in the present invention, however, the partial joining of the segments 70 and 70' will be on the downstream portion of the static mixer element 50 and thus not adjacent to the leading edge 74.

**[0040]** The angle of inclination is typically preferably between about 20 and about 50 degrees, and generally the segments 70 and 70' are substantially parallel to one another and thus have substantially the same angle of inclination relative to the duct axis 2. The length of the segments 70 and 70' is typically between about  $\frac{1}{2}$  and twice the average width or diameter of the mixer duct 1. The shape of the segments 70 and 70' is not specifically limited, and it may be semi-circular for substantially round mixer ducts 1, as shown in Fig. 1. Typically the width of longitudinal gap 80 may be between about 40 and about 70% of the average diameter or width of the mixer duct 1. The shape of the inner free edges 72 of the segments 70 and 70' defining the substantially longitudinal gap 80 between them is not specifically limited and may be substantially straight, curved, beveled, bent, and may comprise one or more discontinuities, curves, bends or angles.

**[0041]** Fig 1(b) shows a schematic view of one of the vortexes generated by one of the segments 70 in the mixer duct 1 shown in Fig. 1(a). In this figure, stream lines originating in a region directly upstream of the leading edge 74 are shown. It is shown that the vortex is formed along the back or downstream side of the segment 70 and its free edge 72' adjacent to the longitudinal gap 80. The vortex subsequently propagates further through the mixer duct 1 together with the main fluid 20 in the direction of main fluid flow 30.

**[0042]** Fig. 2 shows an embodiment of a mixer duct 1 having a static mixer element 50 made of two segments 70, 70' with an intervening gap 80 and both lacking a third free edge 72" as in Fig. 1. This embodiment additionally comprises an additional side inlet 100 located substantially upstream of the static mixer element 50 embodied for the addition of an additive 120. As shown and preferred the side inlet 100 is located substantially upstream of the leading edge 74, typically between about 50% and about 200% of the mixer duct 1. More than one side inlet 100 may be used in some embodiments, for example, for the injection or introduction of more than one additive.

**[0043]** Fig. 3 shows a further embodiment of a mixer duct 1 having two static mixer elements

50 and 50' and a side inlet 100 with a diameter 104 and having a deflection shield 200 located substantially parallel to the side inlet axis 102 and substantially perpendicular to the duct axis 2. The deflection shield 200 is substantially located upstream from the side inlet 100. The deflection shield 200 is embodied so as not to substantially block the duct entrance 106 of the side inlet 100. Thus the deflection shield 200 simultaneously allows the additive 120 to propagate into the central region 40 of the mixer duct 1 without being diverted by the main fluid flow through the mixer duct 1. The design of the deflection shield 200 is not specifically limited, and it may be round, V-shaped as in Fig. 3, U-shaped, and the cross-section may generally be, for example, rectangular, semicircular. The length of the deflection shield 200 in a direction perpendicular to the duct axis 2 and parallel to the side inlet axis will generally be between about 20% and about 60% of the diameter of the duct 1.

**[0044]** It is noted that the segments 70 of the static mixer elements 50 and 50' in this embodiment both have a third free edge 72". Similar to the shape of the segments 70 and 70' discussed in relation to Fig. 1, the free edges 72' defining the substantially longitudinal gap 80 are also not specifically limited, and the free edges may be substantially parallel or non-parallel to one another. In one embodiment, the angle between them may be up to  $\pm 15^\circ$ . The construction and fastening of the deflection shield 200 is not specifically limited, and it may be simply welded or glued into the duct 1 depending on the materials of construction, or it may optionally be mounted by means of brackets, for example, for larger-scale installations.

**[0045]** Fig. 4 (a) shows a schematic view of one embodiment of a mixer duct 1 having a side inlet 100, a deflection shield 200, a splash plate 300 and three static mixers 50, 50' and 50", each without a third free edge 72". The splash plate 300 is located substantially in the central region 40 of the mixer duct 1, and the splash plate 300 is oriented substantially parallel to the duct axis 2 so as to not substantially increase the resistance of the main fluid flow through the mixer duct 1. The splash plate 300 is simultaneously located substantially perpendicular to the side inlet axis 102 so as to advantageously limit the propagation of the additive across the cross section of the duct 1, as described earlier.

**[0046]** Fig 4 (b) shows a schematic partial top view of the embodiment of Fig. 4 (a) illustrating a splash plate 300 having a cross-section 305 substantially overlapping the side inlet cross-section 105 when viewed along the side inlet axis 102. As shown here, the width W of the deflection shield 200 is at least as great in magnitude as the side inlet diameter 104.

**[0047]** The construction and fastening of the splash plate 300 is not specifically limited, and it may be simply welded or glued into the duct 1 depending on the materials of construction, or it may optionally be mounted by means of brackets, for example, for larger-scale installations. The design of the splash plate 300 is not specifically limited, and it may be round, V-shaped, U-shaped as in Fig. 4 (a), and the cross-section may generally be, for example, rectangular, semicircular. The length of the splash plate 300 in the direction of the duct axis 2 will generally be greater than the side inlet diameter 104 and may extend up to one or two diameters of the duct 1.

**[0048]** Fig. 5 (a) shows a schematic view of one embodiment of a mixer duct 1 in the form of an open channel 1" having a mixer duct wall 5, a mixer duct inlet 10, and having an additive injection tube 400 and two static mixers 50 and 50'. As shown here, the static mixers 50 and 50' are not substantially rotated relative to one another so that instead their cross-sections substantially overlap when viewed along the open channel axis 2". The additive injection tube 400 will generally be located substantially upstream of the next closest static mixers 50 or 50', typically at a distance of between about 5% to about 200% relative to either the duct 1" width or depth. More than one additive injection tube 400 may be used in various embodiments, for example, for the introduction of more than one additive or for introducing an additive at different heights or depths below the surface of the main fluid 20 within the open channel duct 1". Furthermore the segments 70 and 70' have three free edges 72, 72', and 72" in this open channel embodiment. As seen here, the segments 70 and 70' may emerge from the main fluid 20 depending on the level of the main fluid 20 in the open channel 1".

**[0049]** Fig. 5 (b) shows an expanded view of the region near the additive injection tube 400, in which it may be seen that the two injection tube outlets, 402 and 402', are each located substantially equidistant from a leading edge 74. Fig. 5 (c) and (d) show alternative embodiments of additive injection tubes 400 having multiple outlets 402 and 402', in the case of Fig. 5 (c) the multiple outlets 402 and 402' are distributed substantially horizontally, and in Fig. 5 (d) they are distributed substantially vertically, in this case over multiple additive injection tubes 400, 400', and 400". Preferably, in both cases such as in Figs. 5 (c) and (d), they are distributed substantially homogeneously with a substantially regular spacing. In other embodiments the multiple outlets 402 and 402' may be distributed both horizontally as well as vertically over the same or multiple additive injection tube(s) 400, as is seen in Fig. 5 (d), as well as being distributed over the cross-section, optionally central region 40, of the open channel mixer duct 1". One skilled in the art will understand that analogous additive injection tubes 400 having multiple outlets 402 and 402' may also be employed in the case of other mixer ducts 1 in accordance with the present invention.

**[0050]** Fig. 6 shows a schematic view of one embodiment of an open channel mixer duct 1" having a separating wall 420, an additive injection tube 400 with multiple injection tube outlets 402 and 402' and two static mixers 50 and 50' located adjacent to one another. It may be seen that the multiple injection tube outlets 402 and 402' and the two static mixers 50 and 50' are distributed substantially homogeneously over the two open sub-channels created by the separating wall 420. The separating wall 420 will generally separate or divide the entire flow of the main fluid 20 through the open duct 1", and thus it will generally extend from substantially the bottom floor to the top level of the main fluid 20 during operation. In some embodiments the height of the separating wall 420 will be substantially the same as the height of the mixer duct wall(s) 5. The separating wall 420 will generally extend past any static mixers 50 and 50' present in the open duct 1", optionally past the first horizontally adjacent static mixers 50 and 50', for example, by a distance equivalent to 1x, 2x, or 3x the maximum length of the static mixers 50 and 50'. Such open channel mixer duct 1" embodiments featuring a separating wall 420 will typically be employed when the open duct 1" has a width that is substantially greater in length than the length of the height of the open duct 1". One skilled in the art will understand

that for the case of relatively wide open ducts 1" multiple separating walls 420 and 420' and multiple horizontally adjacent static mixers 50, 50' and 50" may be used.

**[0051]** One skilled in the art will understand that besides multiple adjacent static mixers 50, 50' and optionally 50" etc. being distributed horizontally along the duct axis 2", as for example in Fig. 5, or being distributed horizontally over the width of the open channel duct 1", as in Fig. 6, instead multiple adjacent static mixers 50, 50' and optionally 50" etc. may be distributed substantially vertically (over the height) within the open duct 1". In this manner, greater vortex generation and thus better mixing may be achieved within a shorter mixer duct 1" length along the duct axis 2", which beneficially would facilitate a more compact mixer duct 1". One skilled in the art will understand that similar embodiments and configurations of multiple static mixers 50, 50' and optionally 50" etc. may be employed for other mixer ducts 1 in accordance with the present invention.

**[0052]** Suitable main fluids 20 in the present invention are not specifically limited, and they may be in either liquid or gas form. Thus in many embodiments, the mixer duct inlet 10 will be in fluid communication with a source of a liquid or gas flow. Typical applications of the mixer duct 1 include mixing of reactants in front of a chemical reactor, temperature homogenization of fluids after a source of heating or cooling, for the homogenization of fluids with additives, for example, in chemical plants. Thus in some embodiments, the mixer duct inlet 10 will be in fluid communication with one or more sources of liquid and/or gas reactants, a source of liquid and/or gas heating or cooling, or a source(s) of a fluid and one or more additives. In some embodiments, the mixer duct 1 and these fluid sources will be part of a chemical plant comprising them. Other embodiments of the mixer duct 1 may find use in petrochemical refineries and plants for the admixture of various grades of crude oil or other petrochemicals in order to make a defined grade product. Thus in some embodiments, the mixer duct inlet 10 will be in fluid communication with a source of crude oil and/or crude oil grades and/or other petrochemicals. In some embodiments, the mixer duct 1 and these various oil and petrochemical sources will be part of a petrochemical plant or refinery comprising them. Embodiments of both mixer duct 1 and open channel mixer duct 1" may find application in water treatment, for example, for pH control and/or admixing of flocculants and/or biocides. Thus in many embodiments the mixer duct inlet 10 of the mixer duct 1 or open channel mixer duct 1" will be in fluid communication with a source of water, for example, waste or process water and optionally a source(s) of one or more additives. In some embodiments, the mixer duct 1 or open channel mixer duct 1" and these water sources will be part of a water or waste water treatment plant comprising them.

**[0053]** One skilled in the art will understand that the above discussed ducts 1 and 1", their sources and plants will also apply to process or method embodiments and claims.

**[0054]** Fig. 7 shows a specific embodiment of a mixer duct 1 with a rectangular cross-section for a gas as the main fluid 20. In this embodiment the main fluid 20 is a flue gas, for example, from an industrial burner. In a Selective Catalytic Reaction (SCR) reactor 500, which is in fluid communication with the mixer duct outlet 15, a reaction takes place in which nitrogen oxides

(NO<sub>x</sub>) are converted to water and nitrogen. In order to enable this reaction, ammonia (additive 120) needs to be added to the flue gas (main fluid 20) and well-mixed to give a homogenized main fluid 20' having the correct stoichiometric mixture of ammonia and NO<sub>x</sub> required for this reaction in the subsequent SCR reactor 500. Thus as shown in this figure, the untreated flue gas enters the mixer duct inlet 10 and flows upward towards the inlet of the SCR reactor 500. It is seen that the mixer duct 1 is divided into parallel closed rectangular sub-channels by means of separating walls 420. Next ammonia is added to the flue gas near the entrance to the sub-channels by means of the additive injection tubes 400 and their outlets 402. One skilled in the art will understand that alternatively the ammonia may be added within the sub-channels. Subsequently the ammonia and the flue gas are well-mixed by the static mixer elements 50 before they enter into the SCR reactor 500. Not only the ammonia and flue gas are well-mixed by this process, but also the concentration profile of the NO<sub>x</sub> and the temperature profile of the mixture are simultaneously and beneficially homogenized.

**[0055]** As is shown in Fig. 7, the two segments 70 in each sub-channel in this embodiment are unattached to each other, but they are attached to the separating walls 420 and/or the mixer duct wall 5. The longitudinal gap between them is also substantially straight and runs the entire length of the segment. The angle of inclination of the segments 70 are shown to be substantially the same as the segments 70 are substantially parallel to one another within the same plane.

**[0056]** While various embodiments have been set forth for the purpose of illustration, the foregoing descriptions should not be deemed to be a limitation on the scope herein.

### **Reference Symbols**

#### **[0057]**

1 mixer duct

1" open channel mixer duct

2 duct axis

5 mixer duct wall

10 mixer duct inlet

15 mixer duct outlet

20 main fluid

20' homogenised main fluid

30 direction of main fluid flow

40 central region of duct  
50 static mixer element  
70 and 70' segments  
72, 72', 72" free edges  
74 leading edge  
80 gap  
100 side inlet  
102 side inlet axis  
104 side inlet diameter  
105 side inlet cross-section  
106 duct entrance of side inlet  
120 additive  
200 deflection shield  
W width of deflection shield  
300 splash plate  
305 splash plate cross-section  
400 additive injection tube  
402 injection tube outlet  
420 separating wall  
500 Selective Catalytic Reaction (SCR) reactor

## REFERENCES CITED IN THE DESCRIPTION

Cited references

This list of references cited by the applicant is for the reader's convenience only. It does not

form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

**Patent documents cited in the description**

- [US6830370B1 \[0003\]](#)
- [EP0800857A1 \[0003\]](#)
- [US4758098A \[0003\] \[0024\]](#)
- [WO2012095623A1 \[0005\]](#)
- [US4019719A \[0024\]](#)
- [EP0800857A \[0039\]](#)

## Krav

1. Et blandingsrør (1) til blanding af en turbulent strømning med et indløb (10) og et udløb (15),  
  
indeholdende mindst et statisk blandeelement (50), som består af mindst to næsten koplanære  
5 pladelignende segmenter (70, 70'), hvilket betyder, at de pladelignende segmenter (70, 70')  
hælder i forhold til hinanden med en vinkel på ikke mere end  $10^\circ$  i forhold til længdeplanet af  
den ydre kanalvæg (5). Hvert af de mindst to statiske blandelementer skal bestå af nøjagtigt to  
næsten koplanære pladelignende segmenter (70, 70') og må ikke indeholde yderligere  
segmenter udover disse.
- 10 hvor et i det væsentlige langsgående mellemrum (80) er dannet mellem segmenterne (70, 70'),  
  
hvor hvert segment (70, 70') er fastgjort til kanalvæggen (5) og omfatter mindst to frie kanter  
(72, 72'),  
  
hvor den ene frie kant (72) er den forreste kant (74) og den anden frie kant (72') støder op til  
det langsgående mellemrum (80),
- 15 **hvor**  
  
de to segmenter (70, 70') er skråtstillede i forhold til kanalaksen (2), således at deres forkant  
(74) er orienteret opstrøms i kanalen (1) og i det væsentlige vinkelret på retningen af en  
hovedvæskestrøm (30).
- 20 2. Blandingsrør (1) ifølge krav 1, hvor mindst et segment (70), fortrinsvis de to segmenter (70,  
70'), yderligere omfatter en tredje fri kant (72").
3. Blandingsrør (1) ifølge krav 1, hvor ingen af de to segmenter (70, 70') yderligere omfatter  
mindst en tredje fri kant (72").
- 25 4. Blandingsrør (1) ifølge et hvilket som helst af de foregående krav, hvor blandingsrøret (1)  
yderligere omfatter mindst et yderligere sideindløb (100) placeret opstrøms for det statiske  
blandeelement (50), der er udformet til tilsætning af et tilsætningsstof (120).

5. Blandingsrør (1) ifølge krav 4, hvor et afbøjningsskjold (200) har en bredde (W), hvor afbøjningsskjoldet (200) er placeret i det væsentlige parallelt med sideindløbsaksen (102) og i det væsentlige vinkelret på kanalens akse (2), hvor bredden (W) er mindst lige så stor som sideindløbsdiameteren (104). Afbøjningsskjoldet (200) er placeret opstrøms fra sideindløbet (100), og det er udformet til ikke at blokere kanalindgangen (106) til sideindløbet (100). Samtidig tillader afbøjningsskjoldet (200) tilsætningsstoffet (120) at forplante sig ind i det centrale område (40) af blandingsrøret (1) uden at blive omdirigeret af hovedvæskestrømmen via blandingsrøret (1).
6. Blandingsrør ifølge enten krav 4 eller 5, hvor en stænkplade (300) er placeret i det centrale område (40) af blandingsrøret (1), hvor stænkpladen (300) er orienteret i det væsentlige parallelt med kanalaksen (2) ) for ikke at øge modstanden af hovedvæskestrømmen via blandingsrøret (1), og hvor stænkpladen (300) samtidigt er placeret i det væsentlige vinkelret på sideindløbsaksen (102) og stænkpladens tværsnit ( 305) overlapper sideindløbstværsnittet (105), når det ses langs sideindløbsaksen (102).
7. Blandingsrør (1) ifølge et hvilket som helst af kravene 1 til 4, hvor blandingsrøret (1) omfatter et injektionsrør til tilsætningsstof (400) med mindst ét injektionsrørudløb (402), hvor injektionsrøret til tilsætningsstoffet (400) er udformet til at indsprøjte et tilsætningsstof i blandingsrøret (1) opstrøms for det statiske blandeelement (50) i et område, der støder op til mindst én forkant (74), hvori det mindst ene injektionsrørudløb (402) er udformet således som at dirigere tilsætningsstoffet til den ene (74) eller begge forkanter (74, 74').
8. Blandingsrør (1) ifølge et hvilket som helst af kravene 1 til 7, hvor blandingsrøret (1) indeholder yderligere statiske blandelementer (50'), hvor de statiske blandelementer (50 og 50') gradvist roteres med mellem ca. 110 grader i forhold til hinanden omkring kanalaksen (2), der fortsætter i en nedstrøms retning.
9. Blandingsrør (1) ifølge et hvilket som helst af kravene 1 til 8, hvor indløbet til blandingsrøret (10) har en væskeforbindelse med en kilde til en væske- eller gasstrøm; af væske- og/eller gasopvarmning eller afkøling, en væske og et eller flere additiver, råolie og/eller råoliekvaliteter og/eller andre petrokemikalier, vand.

10. Blandingsrør (1) ifølge et hvilket som helst af kravene 1 til 7, hvor blandingsrøret (1) er i form af en åben kanal (1"), og den åbne kanal (1") indeholder yderligere statiske blandeelementer (50)'), hvor de statiske blandelementer (50 og 50') ikke er roteret i forhold til hinanden, således at deres tværsnit overlapper, når de ses langs den åbne kanalakse (2").

5

11. Blandingsrør (1) ifølge krav 9, hvor blandingsrøret (1) er i form af en åben kanal (1") med en adskillelsesvæg (420), hvor additivinjektionsrøret (400) har mindst et andet indsprøjtningrørudløbet (402') og den åbne kanal (1") har mindst et andet statisk blandeelement (50') placeret ved siden af det statiske blandeelement (50).

10

12. Blandingsrør (1) ifølge et hvilket som helst af kravene 9 eller 10, hvor indløbet til blandingsrøret (10) har en væskeforbindelse med en kilde til en væske- eller gasstrøm.

13. Et kemisk anlæg, petrokemisk anlæg, raffinaderi eller vandbehandlingsanlæg omfattende blandekanal (1) og kilden til krav.

15

14. Et vandbehandlingsanlæg omfattende blandekanal (1) og kilden ifølge krav 12.

15. En fremgangsmåde til at blande en hovedvæske (20) i blandekanal (1) ifølge et hvilket som helst af kravene 1 til 3 for at homogenisere en karakteristik af hovedvæsken (20), hvor processen omfatter trinene:

20

- tilførsel af hovedvæsken (20), der skal homogeniseres, til blandingsrørets indløb (10),

fjernelse af en homogeniseret væske (20') fra blandingsrøret (1) ved hjælp af blandingsrørets udløb (15).

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16. Fremgangsmåden ifølge krav 15, hvor homogeniseringen af en karakteristik af hovedvæsken (20) omfatter blanding af hovedvæsken (20) og et tilsætningsstof (120) i blandingsrøret (1) for at homogenisere sammensætningen af hovedvæsken (20) og tilsætningsstoffet (120), hvor processen yderligere omfatter trinene:

30 - tilførsel af tilsætningsstoffet (120) til blandingsrøret (1) ved hjælp af et sideindløb (100) eller et injektionsrør til tilsætningsstoffer (400),

- blanding af tilsætningsstoffet (120) i hovedvæsken (20) i blandingsrøret (1),
- fjernelse af en homogeniseret sammensætning omfattende hovedvæsken (20) og tilsætningsstoffet (120) fra blandingsrøret (1) ved hjælp af blandingsrørets udløb (15).

# DRAWINGS

Drawing

Figure 1 (a):

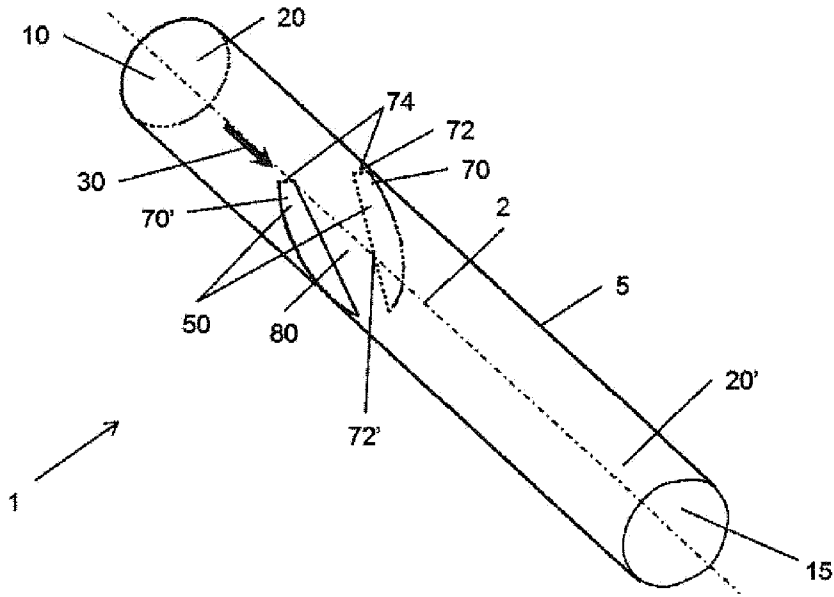


Figure 1 (b):

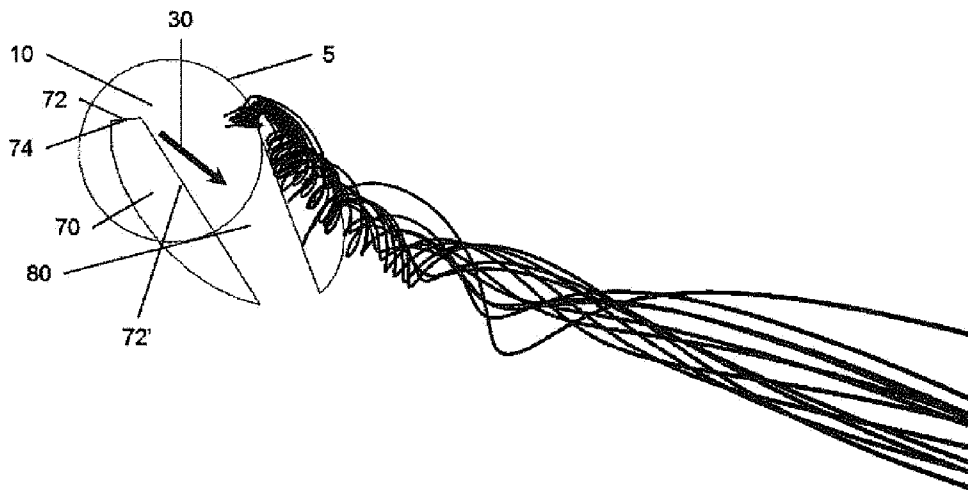


Figure 2:

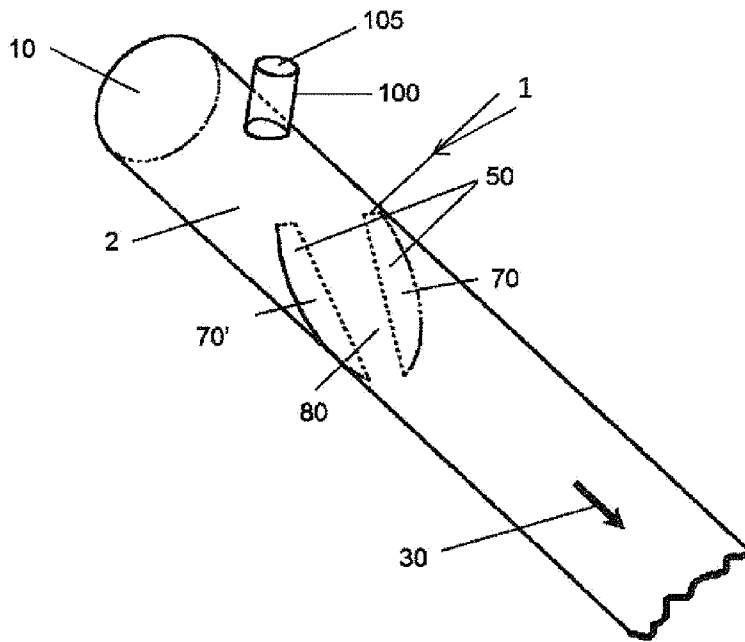


Figure 3:

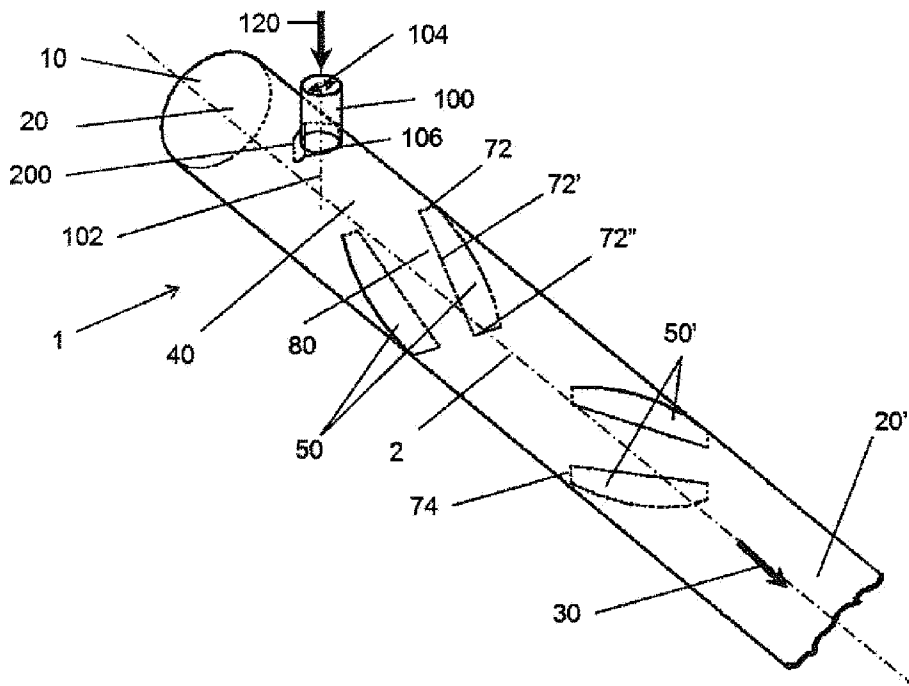


Figure 4 (a):

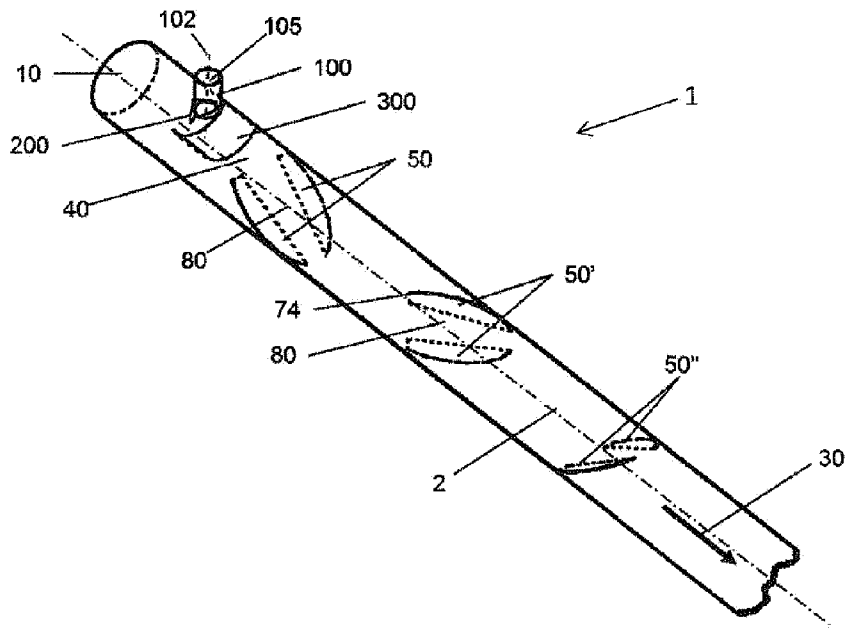


Figure 4 (b):

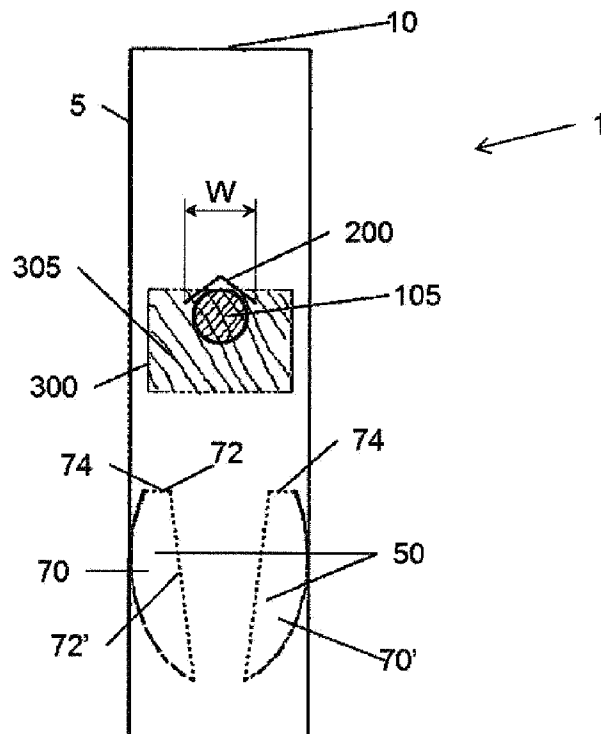




Figure 5 (c):

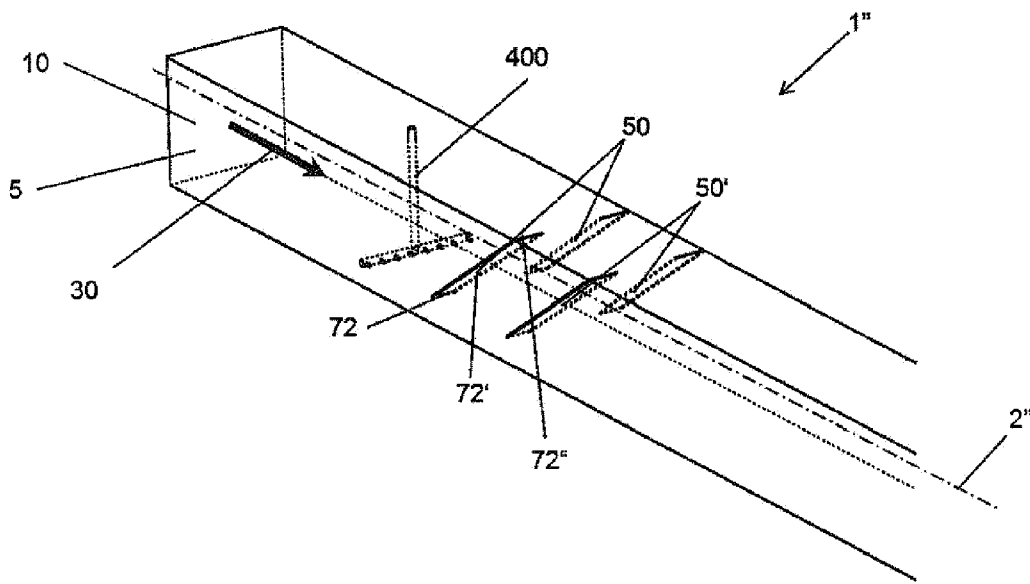


Figure 5 (d):

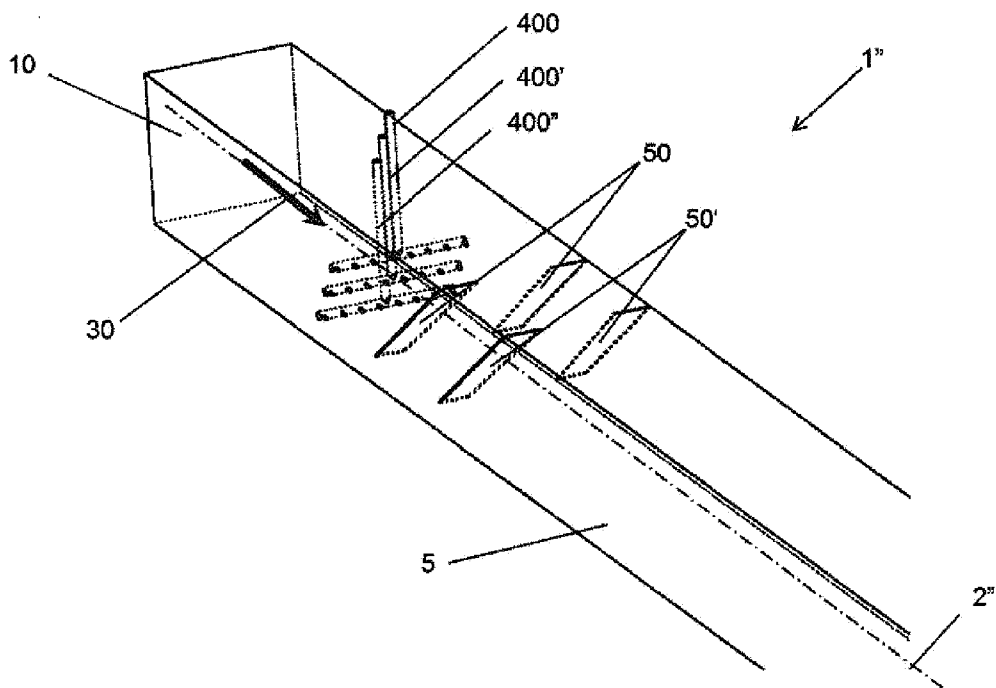


Figure 6:

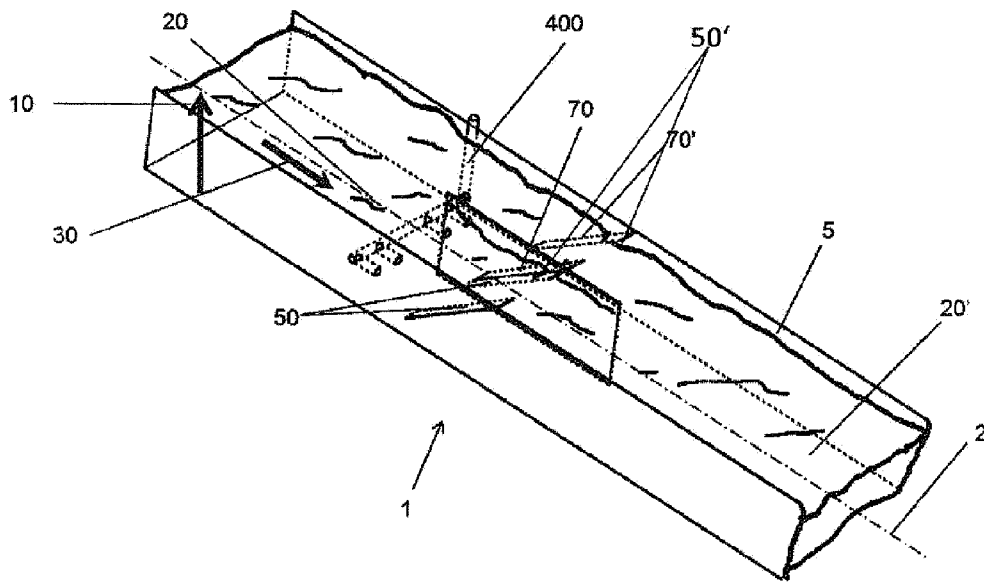


Figure 7:

