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(54) **Method and apparatus for relieving stress in a pipeline**

(57) A method of treating a pipeline (4) (or other welded structure under tensile stress) to increase resistance to stress corrosion cracking, the method comprising heating the outside surface of a weld of a pipeline (4), and cooling the inside surface (12) of the weld of the pipeline (4) with a cryogenic coolant during and/or after the heating step to provide a tensile stress-relieved layer on the inside of the pipeline.

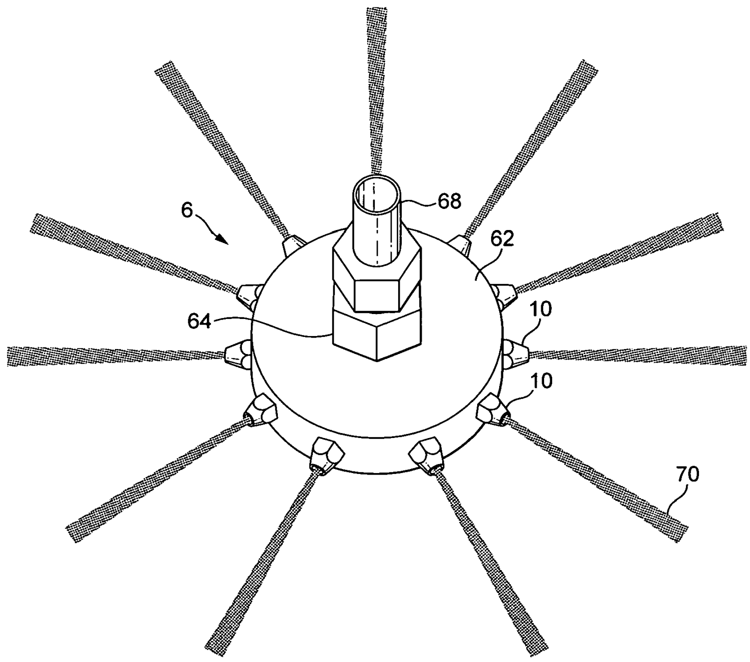

FIG. 4

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Description

[0001] The present invention relates to a method and an apparatus for treating a pipeline for other welded structure under tensile stress to increase resistance to stress corrosion cracking.

[0002] Stress corrosion cracking can occur in stainless steel or high nickel process piping during operational service, particularly in nuclear, chemical, oil and gas operational environments. There are three factors which predominantly control the stress corrosion cracking (SCC) mechanism: tensile residual stress fields in the material, high temperature, and high chloride ion concentrations. High tensile residual stress fields arise across welds due to the heat cycle and shrinkage stress associated with welding. The SCC mechanism therefore predominantly occurs in the weld and heat affected zones.

[0003] In a first aspect, the present invention provides a method of treating a pipeline (or other welded structure under tensile stress) to increase resistance to stress corrosion cracking, the method comprising heating the outside surface of a weld of the pipeline, and cooling the inside surface of the weld of the pipeline with a cryogenic coolant during and/or after the heating step to provide a tensile stress-relieved layer on the inside of the pipeline

[0004] In a further aspect, the present invention provides an apparatus for treating a pipeline (or other welded structure under tensile s tress) to increase resistance to stress corrosion cracking (SCC), comprising at least one heat source arranged to be adjacent to the outside surface of a weld of a pipeline; and at least one nozzle dimensioned to be received within the pipeline and to be located adjacent to the inside surface of a weld, in which the at least one nozzle is adapted to provide a cryogenic coolant to the inside surface of the weld of a pipeline.

[0005] "Cryogenic coolant" is herein defined as a coolant having a temperature of less than -50°C. A "pipeline" is herein defined as at least two pipe sections having at least one welded joint there between. The "weld" may include both the weld (or fusion) zone and the heat affected zone.

[0006] It will be appreciated that the stress-relieved layer comprises an area of the pipe in which the tensile residual stress is decreased in comparison to a like pipe section on which the method of the invention has not been applied. Typically the stress-relieved layer starts at the inner surface of the pipe (upon which the cryogenic coolant may have impinged) and extends through the thickness of the pipe towards the outer surface (which has been heated). The stress-relieved layer may extend partially through the thickness of the pipe. The stress-relieved layer preferably includes an innermost region of compressive residual stress.

[0007] The heating and/or cooling is preferably applied for a sufficient duration to provide a tensile stress-relieved layer of a desired depth. The tensile stress relieved layer preferably includes a region of compressive residual stress. The duration of the cryogenic treatment should be sufficient to provide an adequate treatment depth. The stress-relieved layer may cover approximately the innermost third of the thickness of the pipeline, for example if the pipeline has a wall thickness of at least 10 mm, then the depth of the tensile stress-relieved layer should be at least 3 mm. Thinner layers will suffice for thinner pipelines.

[0008] All weld zones have tensile stress fields and are therefore susceptible to SCC. It has been found that super-cooling the inside surface of the weld zone on a pipeline with a cryogenic coolant results in a modification of the tensile residual stress field to a compressive residual stress field. The compressive residual stress field has the benefit of resisting SCC as SCC only occurs in tensile stress fields. By modifying the stress field the resistance to SCC is dramatically improved in piping, such as for example in austenitic stainless alloys, including austentic stainless steel piping, and high nickel piping, such as for example alloy 625, alloy 725, alloy C276, alloy C22, monel, alloy 905L, alloy 304L, alloy 316L.

[0009] The cryogenic coolant is preferably selected from one or more of solid carbon dioxide particles, liquid nitrogen, liquid air and liquid argon, or a mixture thereof.

[0010] The cryogenic coolant is preferably applied from at least one cooling nozzle. For example cooling the inside surface of the weld zone of the pipeline with a cryogenic coolant may comprises expanding a liquid coolant through a nozzle proximal to the inside surface. The expansion of the coolant may advantageously result in a change of state of the coolant from liquid to solid.

[0011] Preferably the coolant is applied around the full internal circumferential surface of the pipeline. For example the cooling nozzle can be a 360° radial cooling nozzle, for example a spray ring. The spray ring may be positioned within the pipeline to effect the cooling. The cooling nozzle may for example comprise a circumferentially distributed array of nozzles, for example the cooling nozzle may comprise at least 12 nozzles.

[0012] The weld is preferably heated to a temperature of between about 600°C and about 700°C using a suitable heat source, such as for example induction heating or oxy fuel heating burners.

[0013] It has been found that the method of the invention can extend plant life by delaying or eliminating stress corrosion cracking in existing pipelines, for example in situ process plant pipelines. This method can be used on existing process pipelines, such as for example pipelines in nuclear, chemical, oil and gas operational environments. Accordingly, a further aspect of the invention provides a method of improving the life of a pipeline comprising treating welds in the pipeline to increase resistance to stress corrosion cracking, the method comprising heating the outside surface of a weld of a pipeline, and cooling the inside surface of the weld of the pipeline with a cryogenic coolant during and/or after the heating step to provide a tensile stress-relieved layer on the inside of the pipeline.

[0014] The method and apparatus may be suitable for use either on an existing weld zone or during the formation of a new weld zone. Accordingly, a further aspect of the invention provides a method of assembling a pipeline comprising forming a root weld between adjacent pipe sections; and treating the weld to increase resistance to stress corrosion cracking, the method comprising heating the outside surface of a weld of a pipeline, and cooling the inside surface of the weld of the pipeline with a cryogenic coolant during and/or after the heating step to provide a tensile stress-relieved layer on the inside of the pipeline. The step of treating the weld may be performed while simultaneously forming a capping weld. The capping weld may be a high heat input weld, for example the capping weld may be a Last Pass Heat Sink Weld.

[0015] The pipeline/pipe is preferably composed of austenitic stainless steel or high nickel alloys, such as for example alloy 625, alloy 725, alloy C276, alloy C22, monel, alloy 905L, alloy 316L.

[0016] Although illustrative embodiments of the invention are described in detail herein with reference to the accompanying drawings, it is to be understood that the invention is not limited to these precise embodiments. As such, many modifications and variations will be apparent to practitioners skilled in the art. Furthermore, it is contemplated that a particular feature described either individually or as part of an embodiment can be combined with other individually described features, or parts of other embodiments, even if the other features and embodiments make no mention of the particular feature. Thus, the invention extends to such specific combinations not already described.

[0017] The invention may be performed in various ways, and by way of example only embodiments thereof will now be described, reference being made to the accompanying figures in which:

Figure 1 is a schematic cross-sectional view of a pipeline comprising an apparatus according to one embodiment of the invention;

Figure 2 is a schematic cross-sectional view of a pipeline comprising an apparatus according to a further embodiment of the invention;

Figure 3 is an image of the cooling apparatus according to an embodiment of the invention; and

Figure 4 is an image of the cooling apparatus of figure 3 in use.

[0018] As seen in figures 1 and 2, an austenitic stainless steel pipeline 4 comprises first and second pipe sections 4a and 4b joined by a weld 3. A heat source 5 is arranged around the outside surface 2 of the pipeline 4. A cooling apparatus 6 is provided within the pipeline 4 for delivering cryogenic coolant to the inside surface 12 of the weld 3 of the pipeline 4. The cooling apparatus 6 is inserted into the pipeline 4 at a free end or via an access opening (not shown) and moved into alignment with the weld 3 prior to use. For long pipelines, such as in situ pipelines in processing plants, the cooling apparatus may be attached to a pipe pig (not shown) for positioning within the pipeline (such pipe pigs are well known in the art and commercially available and are not, therefore, described herein).

[0019] The cooling apparatus 6 comprises an inlet 8 for delivering coolant, which in the preferred embodiment is provided as liquid carbon dioxide, along the pipeline 4. The cooling apparatus is provided with multiple radial passageways 7 to distribute the coolant around the inner circumference of the pipeline 4. Each passageway terminates at a nozzle 10 arranged to eject coolant towards the inside surface 12 of the pipeline 4. By providing a plurality of nozzles 10 at circumferentially distributed locations around the pipeline the cooling apparatus 6 enables coolant to be delivered to the entire internal circumference of the pipeline simultaneously.

[0020] In use, the heat sources 5 in the form of an array of induction heaters 5 are arranged adjacent to the outside surface 2 of the pipeline 4 so as to heat the weld 3 to be treated. The cooling apparatus 6 is inserted inside pipeline 4 and moved along the pipeline 4 until the nozzles 10 are adjacent to the inside surface 12 of the weld 3.

[0021] The heat sources 5 raise the temperature of the outside surface to between approximately 600°C and 700°C. Simultaneously or immediately after heating, liquid carbon dioxide is pumped into the cooling apparatus 6 through inlet 8. The liquid carbon dioxide is pumped out of the nozzles 10 under high pressure. The liquid carbon dioxide turns into solid carbon dioxide snow, having a temperature of approximately -70°C, as it expands out of nozzles 10. The carbon dioxide snow 14 sublimes immediately on contact with the inside surface 12 of the hot weld 3. Advantageously, such sublimation means that spent coolant does not accumulate in the area of the weld 3. at high pressure to transform the liquid carbon dioxide to solid snow and gas.

[0022] This rapid cooling of the inside surface 12 of the hot weld 3 results in a modification of the tensile residual stress field to a compressive residual stress field. The compressive residual stress field is able to resist SCC.

[0023] Figure 2 shows an alternative embodiment of the invention. This embodiment is identical to the embodiment of Figure 1 but uses an alternate heat source 5' in the form of an array of oxy fuel gas burners 50 arranged along the outer surface 2 of the pipeline 4.

[0024] As seen in figure 3, the cooling apparatus 6 can comprise a body portion 62 having twelve radially extending nozzles 10. The nozzles 10 are evenly distributed about the circumference of the body 62. The cooling apparatus 6 comprises an inlet 64 which has a threaded connector 66 for receiving a pipe to provide a source of cryogenic coolant (not shown).

[0025] As seen in figure 4, in use the inlet 64 of the cooling apparatus 6 is connected to a source of liquid carbon dioxide 68. The liquid carbon dioxide is pumped out of the twelve radially extending nozzles 10 under high pressure. Due to the even distribution of the nozzles around the entire circumference of the body 62 the cooling apparatus ensures that coolant is delivered simultaneously and evenly to the entire internal circumferential surface of the weld 3. As the liquid carbon dioxide expands under pressure through the nozzles 10 it transforms into solid carbon dioxide snow 70.

[0026] The method is performed for a duration which is sufficient to transform the weld zone such that there is an adequate treatment depth. By way of example pipeline having a 10mm wall thickness may be treated such that the tensile stress relieved layer is at least 3mm thick.

[0027] In experimental pipeline sections to verify the effectiveness of embodiments of the invention it was found that the residual tensile stress on the outer surface of a pipeline could be reduced from 67 microstrain to 17 microstrain by application of the treatment of the invention.

[0028] The skilled person will appreciate that other cryogenic coolants are available with significantly lower temperatures that carbon dioxide snow. However, carbon dioxide has been found to have the highest heat transfer characteristics due to the immediate sublimation of the carbon dioxide snow upon contact with the hot weld surface. In contrast, other coolants may vaporise without contacting the weld surface.

Claims

1. A method of treating a pipeline (or other welded structure under tensile stress) to increase resistance to stress corrosion cracking, the method comprising heating the outside surface of the weld of a pipeline, and cooling the inside surface of the weld of the pipeline with a cryogenic coolant during and/or after the heating step to provide a tensile stress-relieved layer on the inside of the pipeline.

2. A method as claimed in claim 1, in which the heating and/or cooling is applied for a sufficient duration to provide a tensile stress-relieved layer of a desired depth.

3. A method as claimed in claim 2, in which the stress-relieved layer includes a region of compressive residual stress.

4. A method as claimed in any preceding claim, in which the cryogenic coolant is selected from one or more of solid carbon dioxide particles, liquid nitrogen, liquid air and liquid argon.

5. A method as claimed in claim 4, in which the cryogenic coolant is solid carbon dioxide snow.

6. A method as claimed in any preceding claim, in which the outside surface of the weld of the pipeline is heated to a temperature between approximately 600 and 700°C.

7. A method as claimed in any preceding claim, in which the heating is carried out using oxy-fuel heating burners.

8. A method as claimed in any preceding claim, in which the pipeline is composed of austenitic stainless steel or high nickel alloys.

9. A method as claimed any preceding, in which the heating step is carried out on an existing weld.

10. A method as claimed in any one of claims 1 to 8, in which the method is carried out on existing pipelines.

11. A method as claimed in any preceding claim, in which the cooling is applied to the full internal circumferential surface of the weld of the pipeline.

12. A method of improving the life of a pipeline comprising treating welds in the pipeline according to the method of any of claims 1 to 11.

13. A method of assembling a pipeline comprising:

    a. forming a root weld between adjacent pipe sections; and
    b. treating the weld according to the method of any of claims 1 to 11.

14. A method as claimed in claim 14, in which the step of treating the weld further comprises simultaneously forming a capping weld.

15. An apparatus for treating a pipeline (or other welded structure under tensile stress) to increase resistance to stress corrosion cracking, comprising at least one heat source arranged to be adjacent to the outside surface of a weld of a pipeline; and at least one nozzle dimensioned to be received within the pipeline and to be located adjacent to the inside surface of a weld, in which the at least one nozzle is adapted to provide a cryogenic coolant to the inside surface of the weld of a pipeline.

16. An apparatus as claimed in claim 11, in which the at least one nozzle is a 360° radial cooling nozzle.

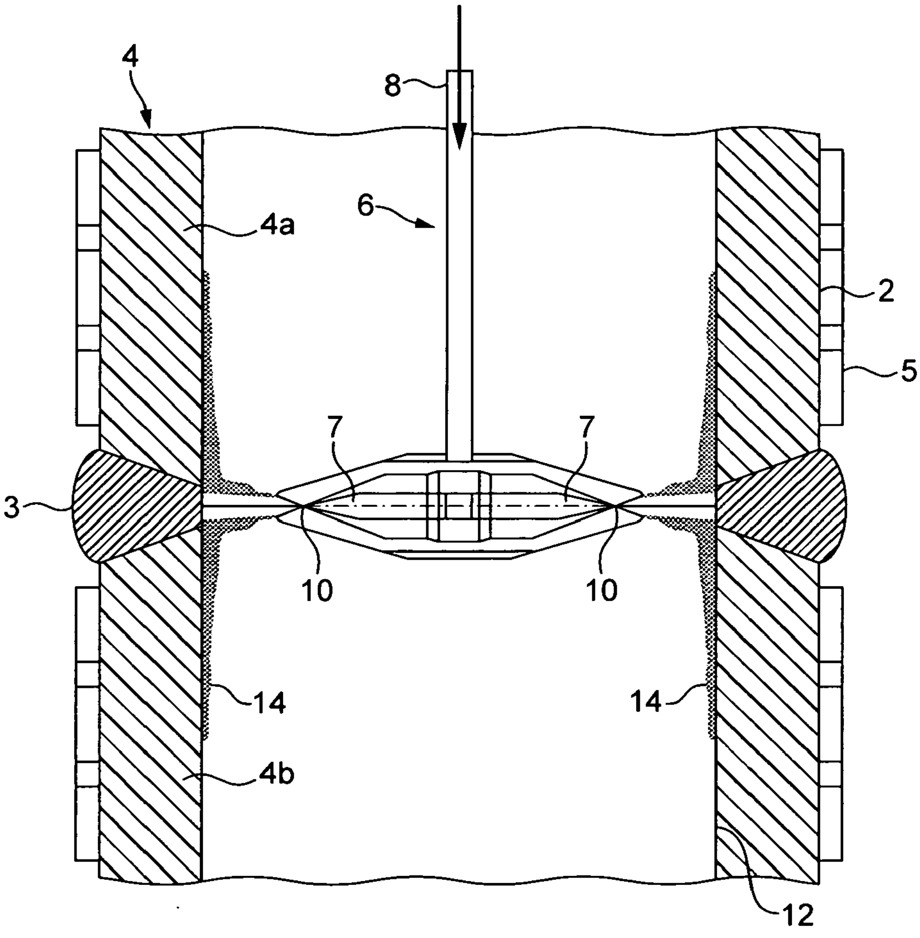

FIG. 1

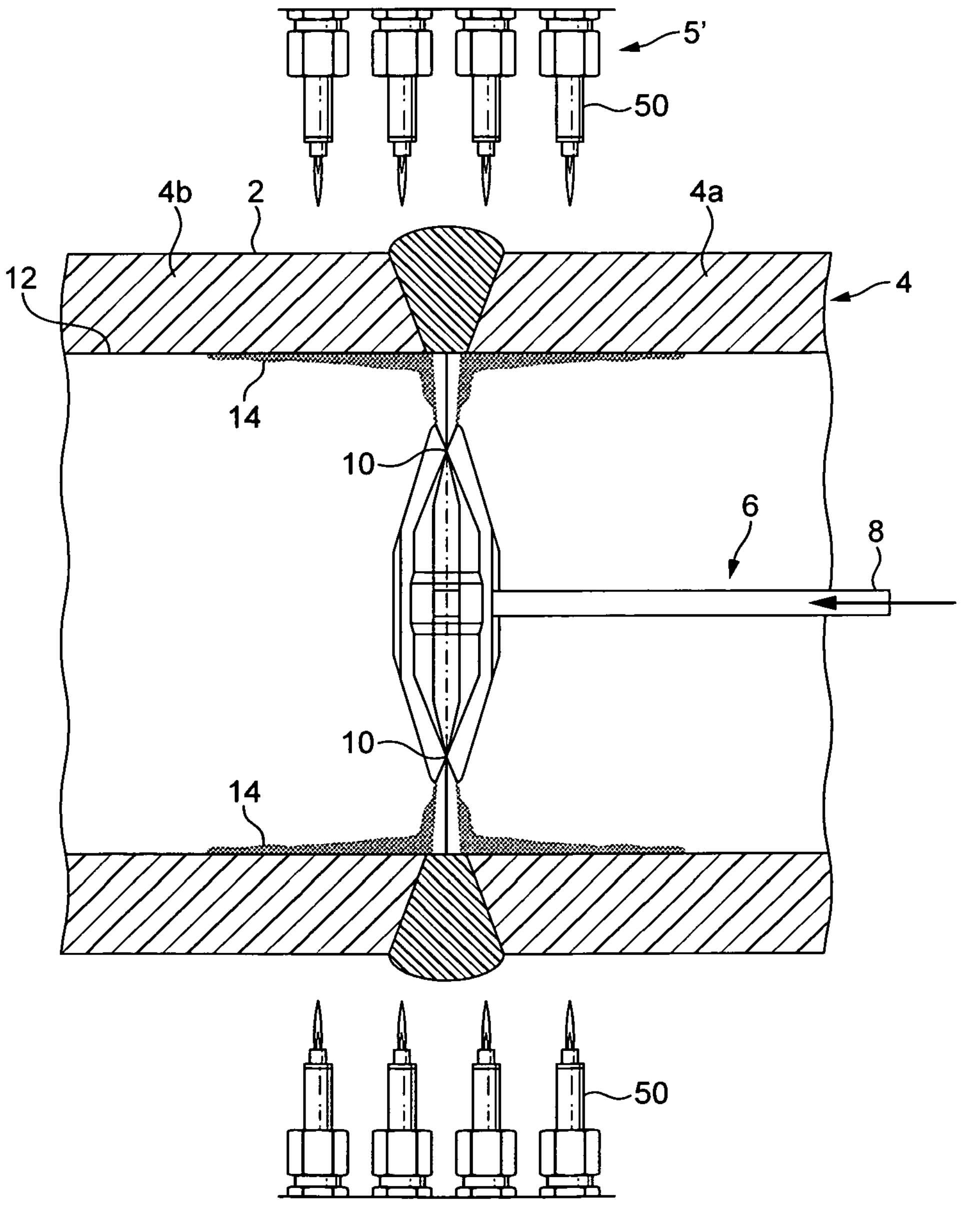

FIG. 2

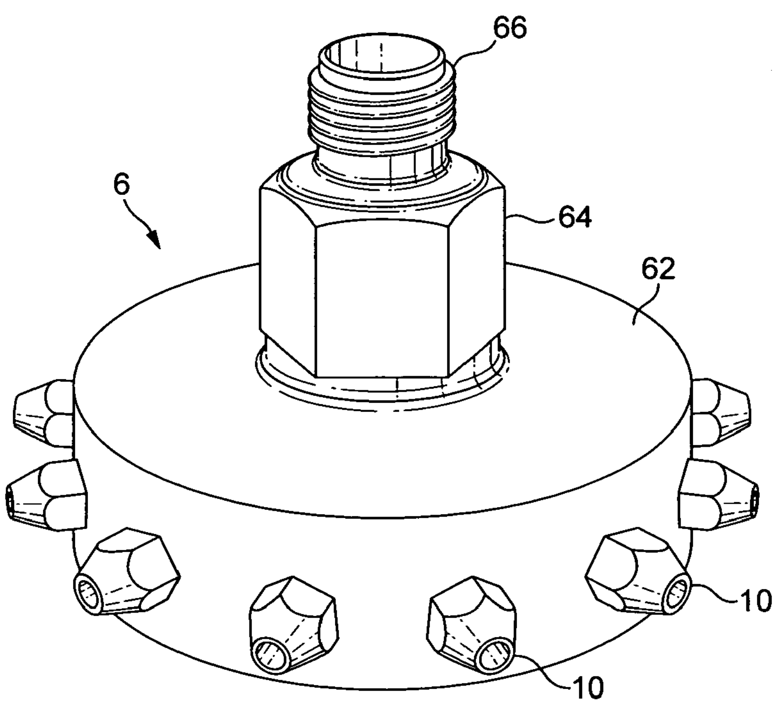

FIG. 3

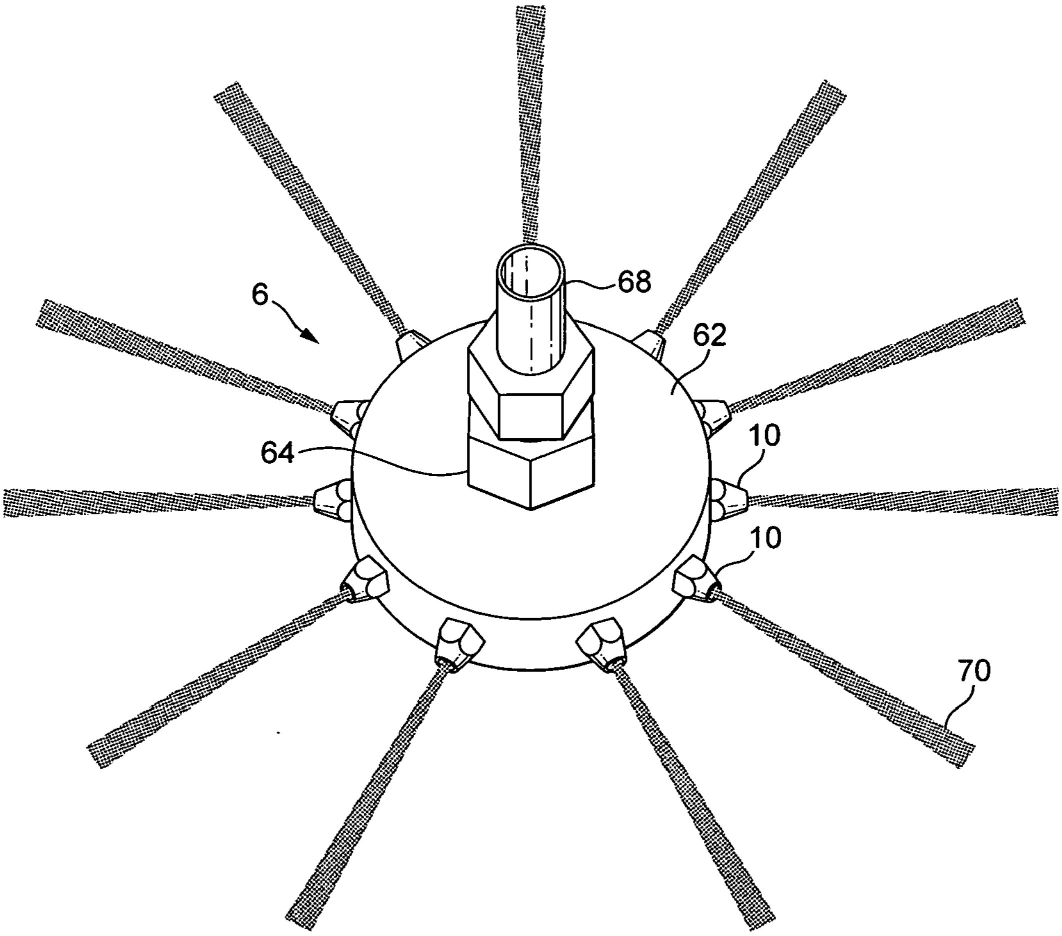

FIG. 4