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(54) **APPARATUS AND METHOD TO CONVEY A FLUID**

(75) Inventors: **Thomas J. Simpson**, Ottawa (CA); **Jim Hagerman**, Ottawa (CA)

Correspondence Address:
VIKSNINS HARRIS & PADYS PLLP
P.O. BOX 111098
ST. PAUL, MN 55111-1098 (US)

(73) Assignee: **MDS (Canada) Inc.**, Ottawa (CA)

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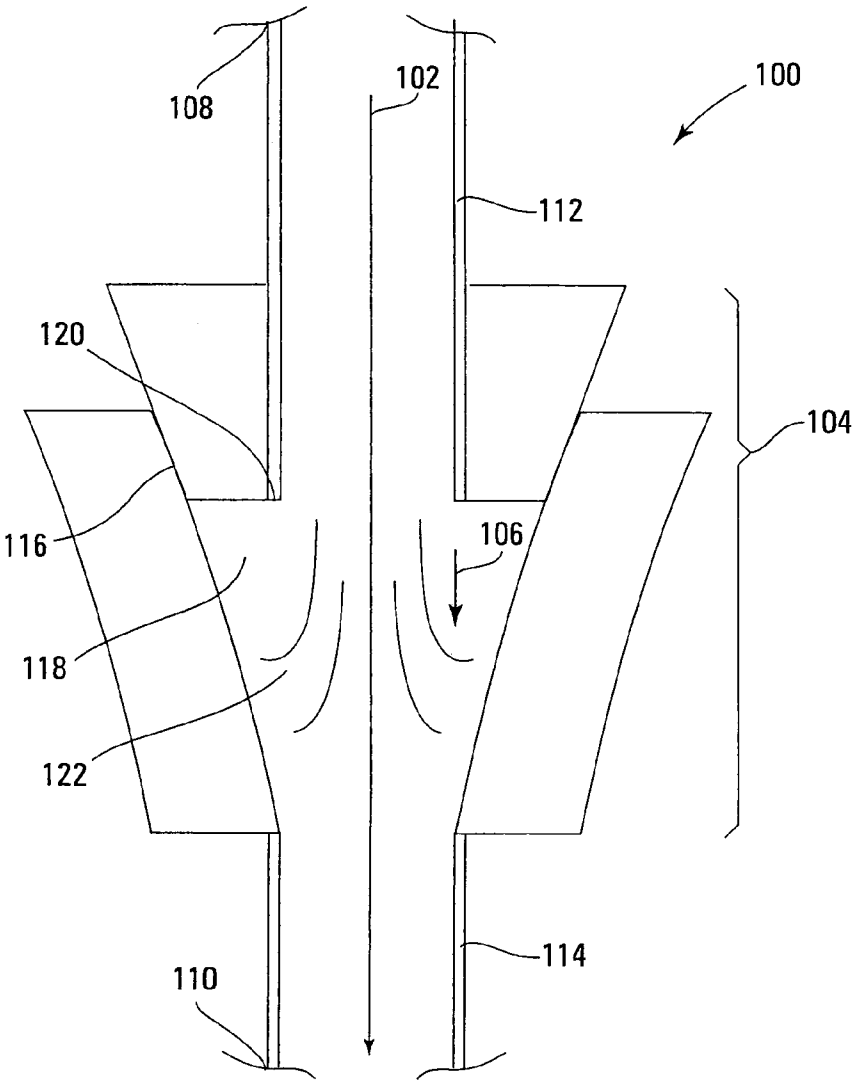
(52) **U.S. Cl.** **600/420**; 604/537

(57) **ABSTRACT**

An apparatus includes a fluid path, a coupling, and a nozzle. The fluid path is to carry a fluid including one or more microparticles. The coupling is located in the fluid path. The nozzle is located in the fluid path to move the fluid through a stagnant region located near the coupling.



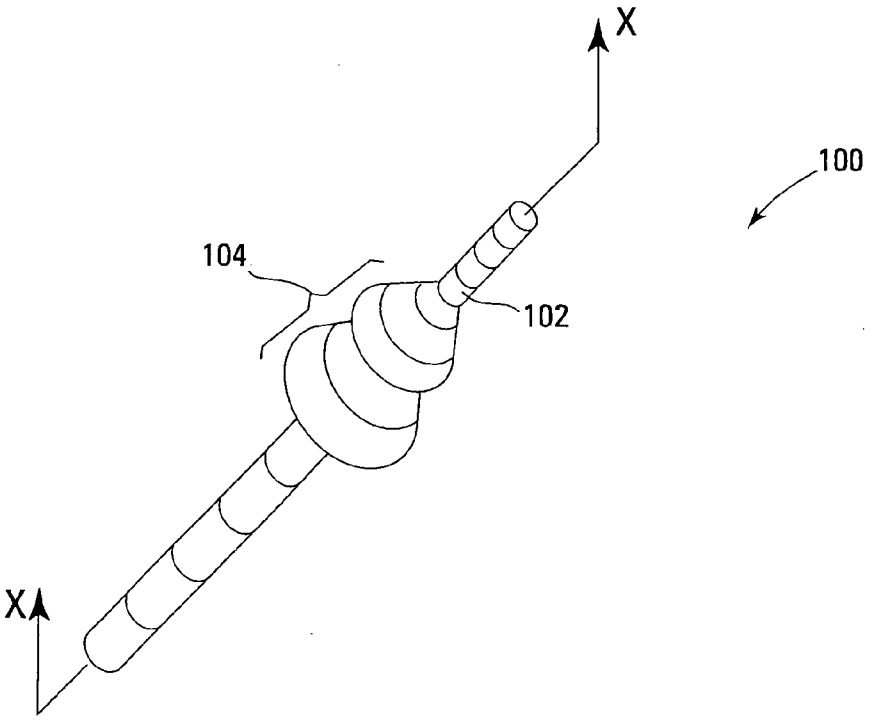


FIG. 1A

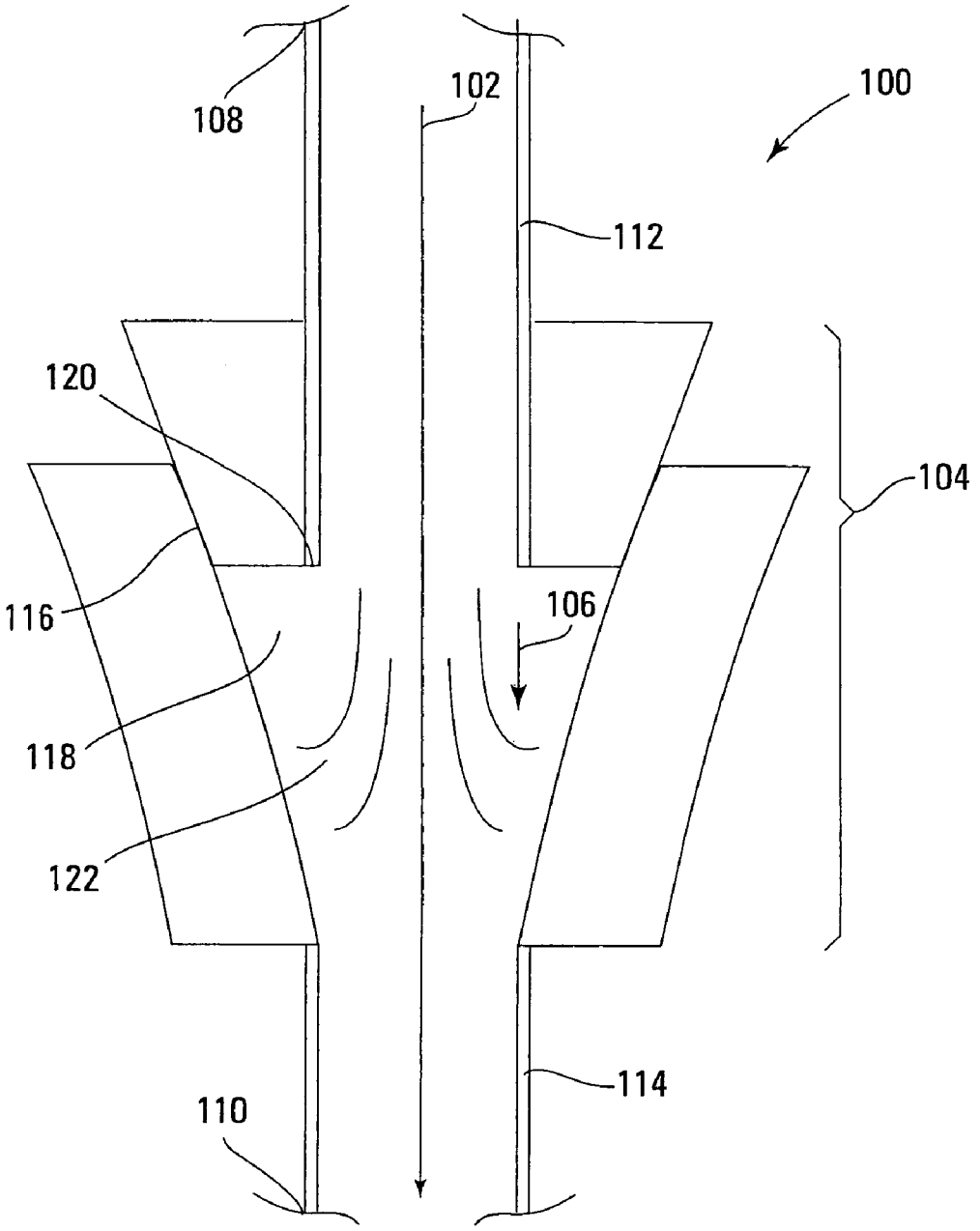


FIG. 1B

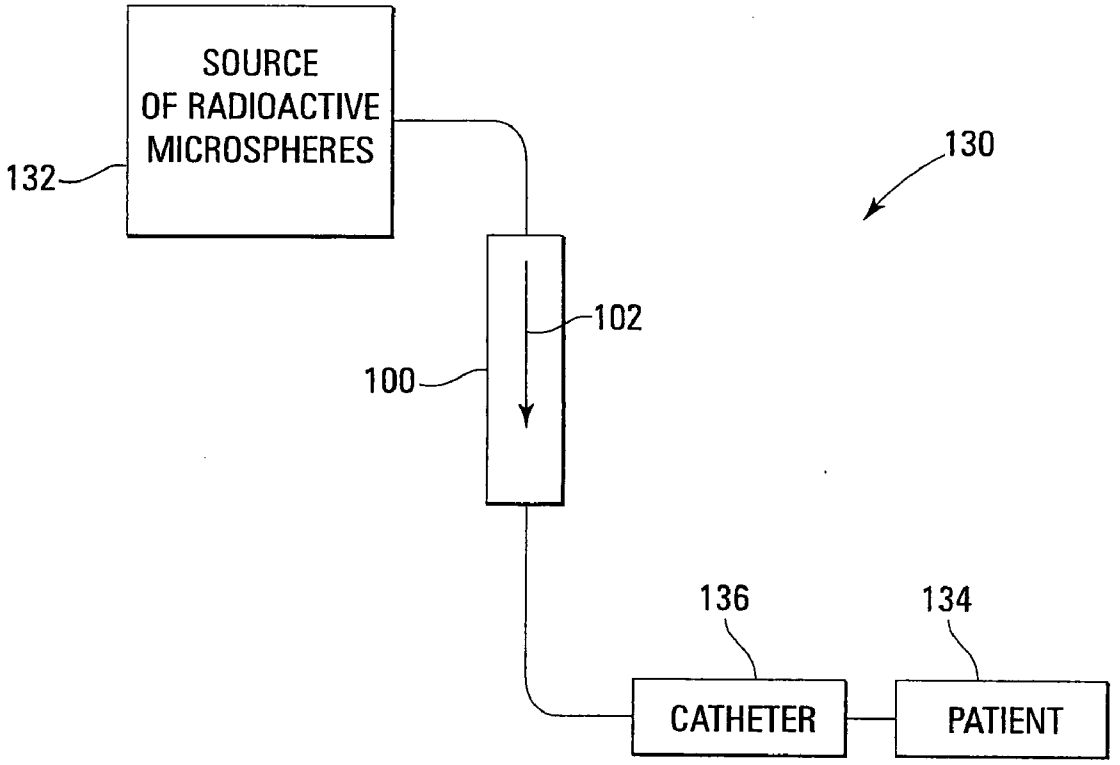

SOURCE OF RADIOACTIVE MICROSPHERES
132
130
102
100
136
134
CATHETER
PATIENT

FIG. 1C

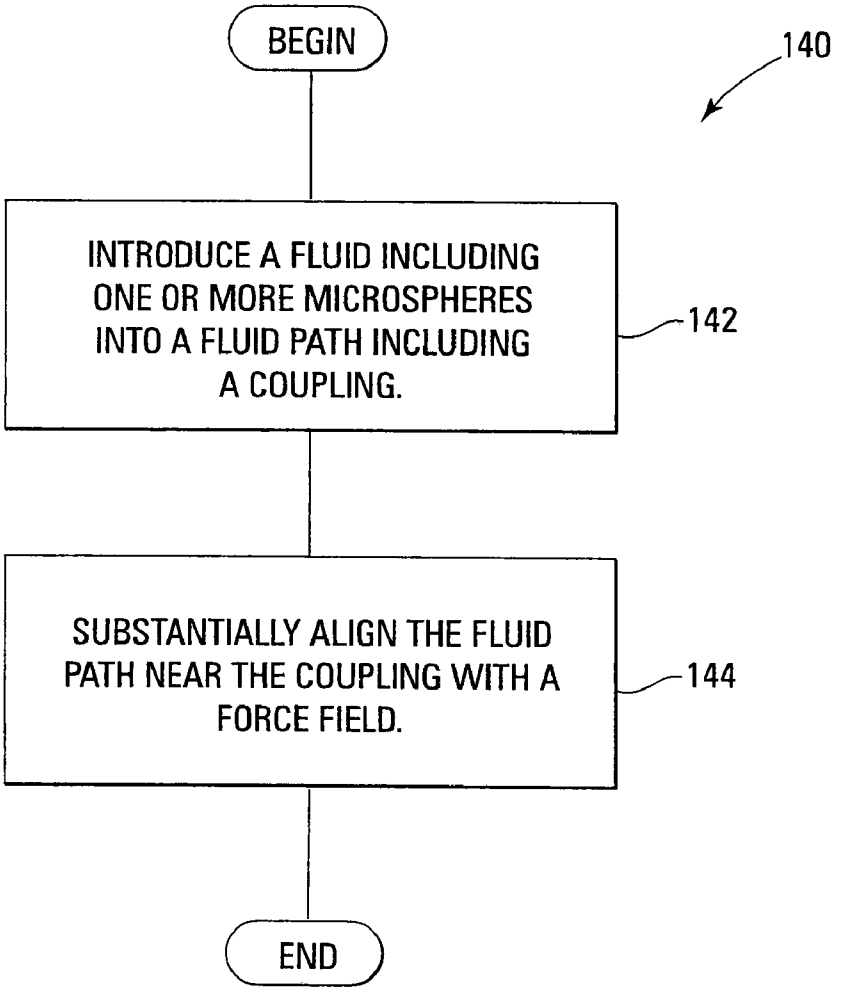

BEGIN
140
INTRODUCE A FLUID INCLUDING ONE OR MORE MICROSPHERES INTO A FLUID PATH INCLUDING A COUPLING.
142
SUBSTANTIALLY ALIGN THE FLUID PATH NEAR THE COUPLING WITH A FORCE FIELD.
144
END

FIG. 1D

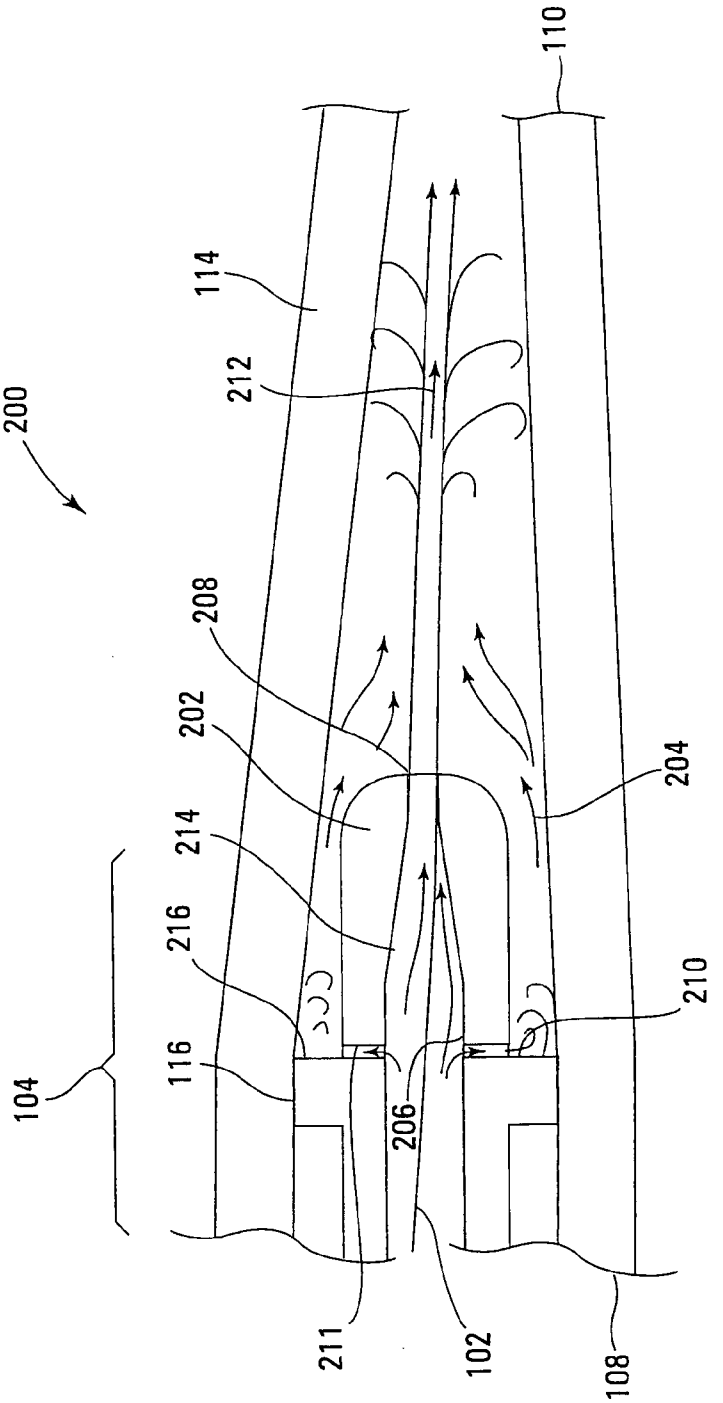


FIG. 2A

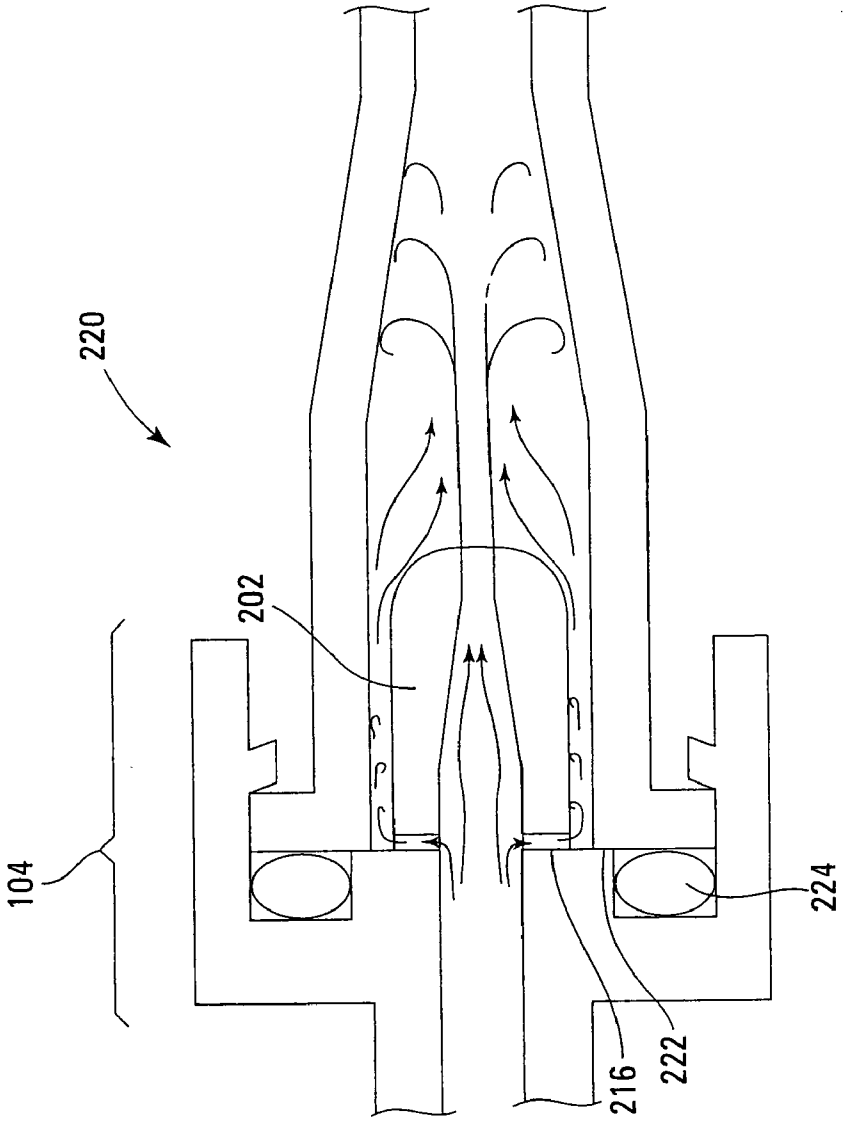


FIG. 2B

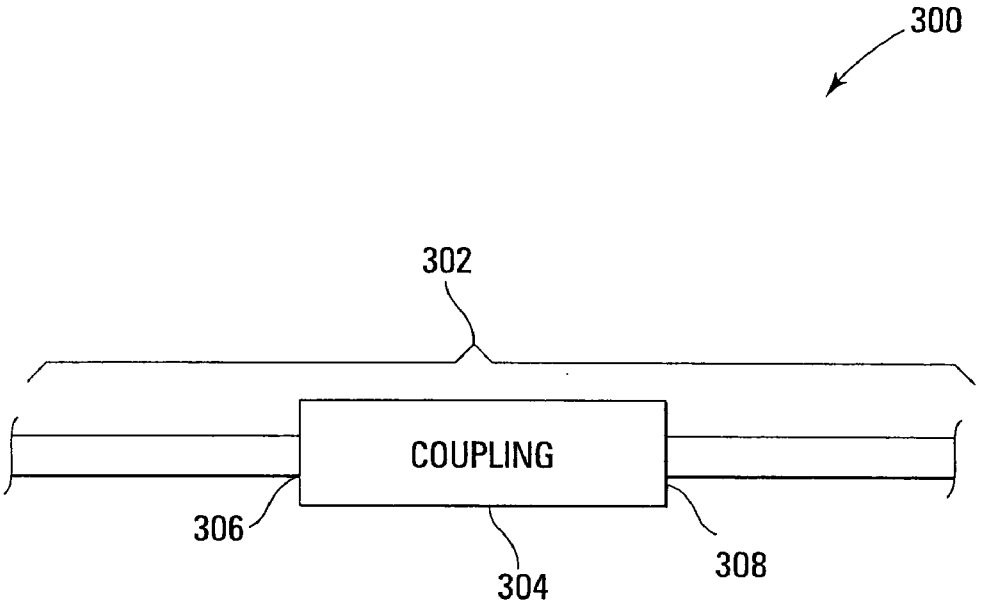


FIG. 3

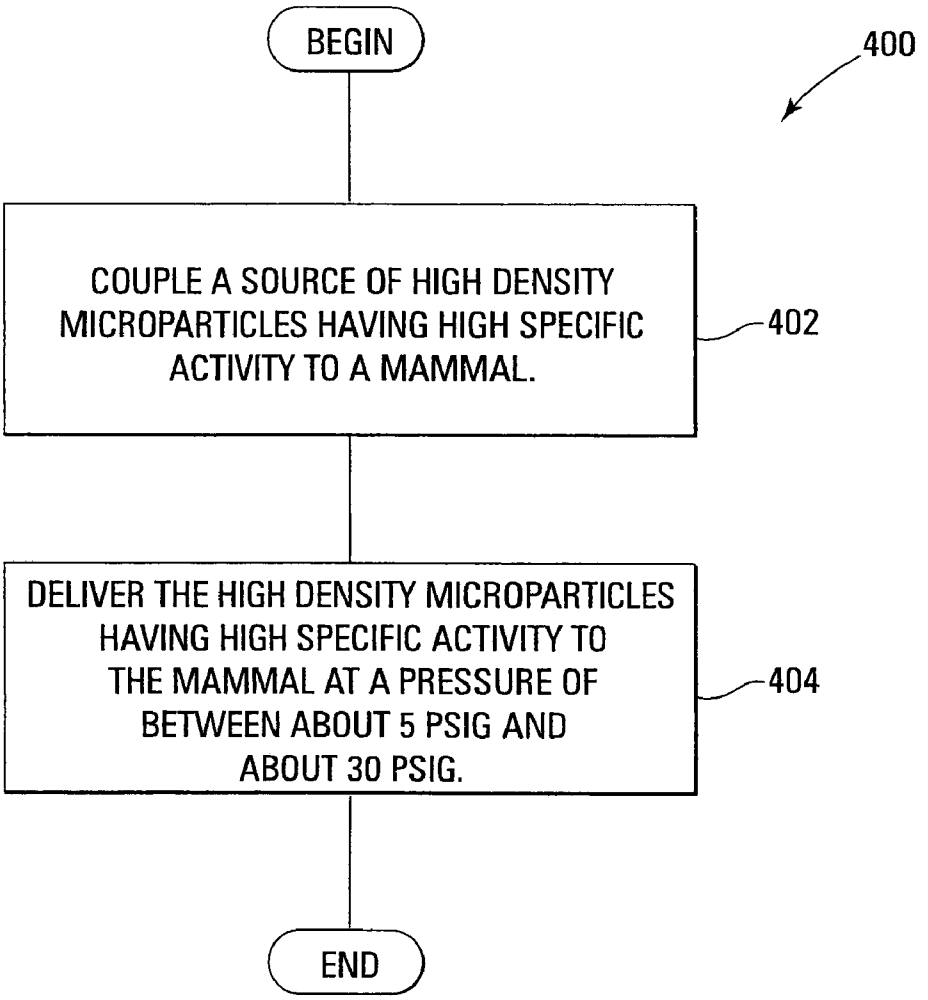

BEGIN
400
COUPLE A SOURCE OF HIGH DENSITY MICROPARTICLES HAVING HIGH SPECIFIC ACTIVITY TO A MAMMAL.
402
DELIVER THE HIGH DENSITY MICROPARTICLES HAVING HIGH SPECIFIC ACTIVITY TO THE MAMMAL AT A PRESSURE OF BETWEEN ABOUT 5 PSIG AND ABOUT 30 PSIG.
404
END

FIG. 4

SUMMARY TABLE

Catheter Size (French)	Pressure Range (psig)	Equivalent Flow Rate (mL/s)	Flush Volume (mL)
3	5-30	0.49±0.44	<60 mL
5	5-30	2.1±0.9	<60 mL

FIG. 5

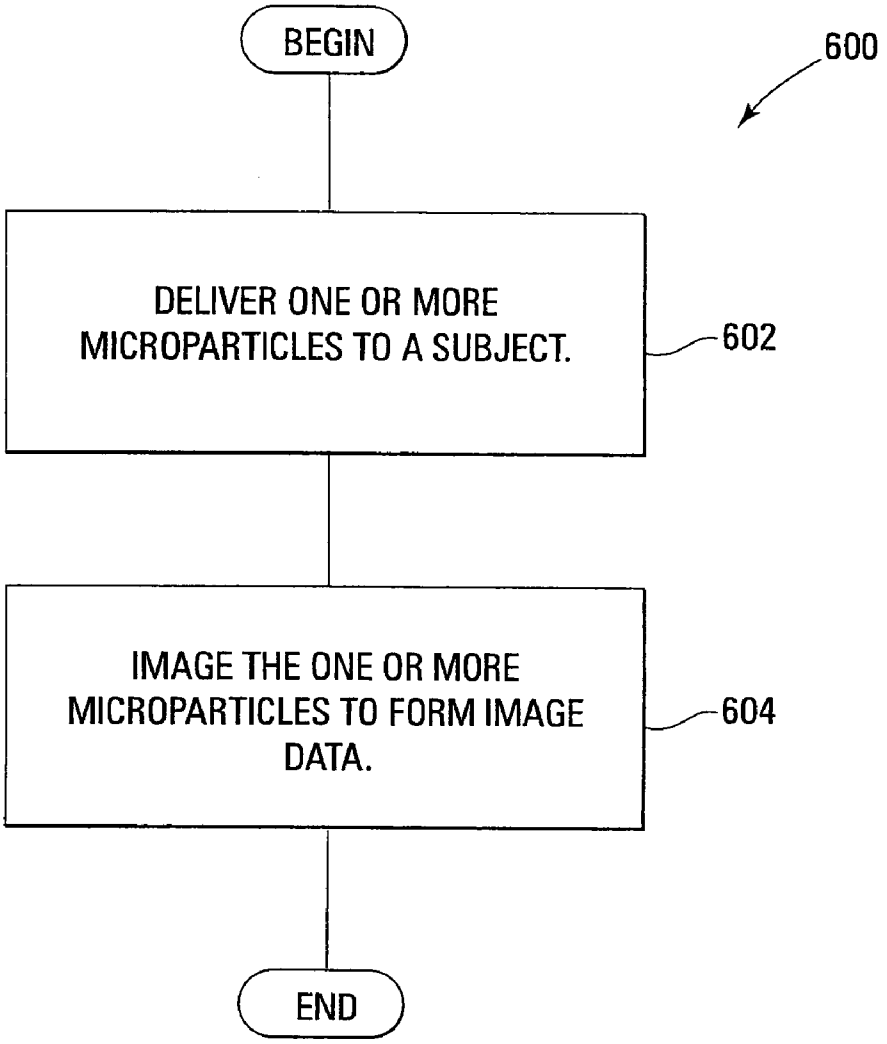

BEGIN
600
DELIVER ONE OR MORE MICROPARTICLES TO A SUBJECT.
602
IMAGE THE ONE OR MORE MICROPARTICLES TO FORM IMAGE DATA.
604
END

FIG. 6

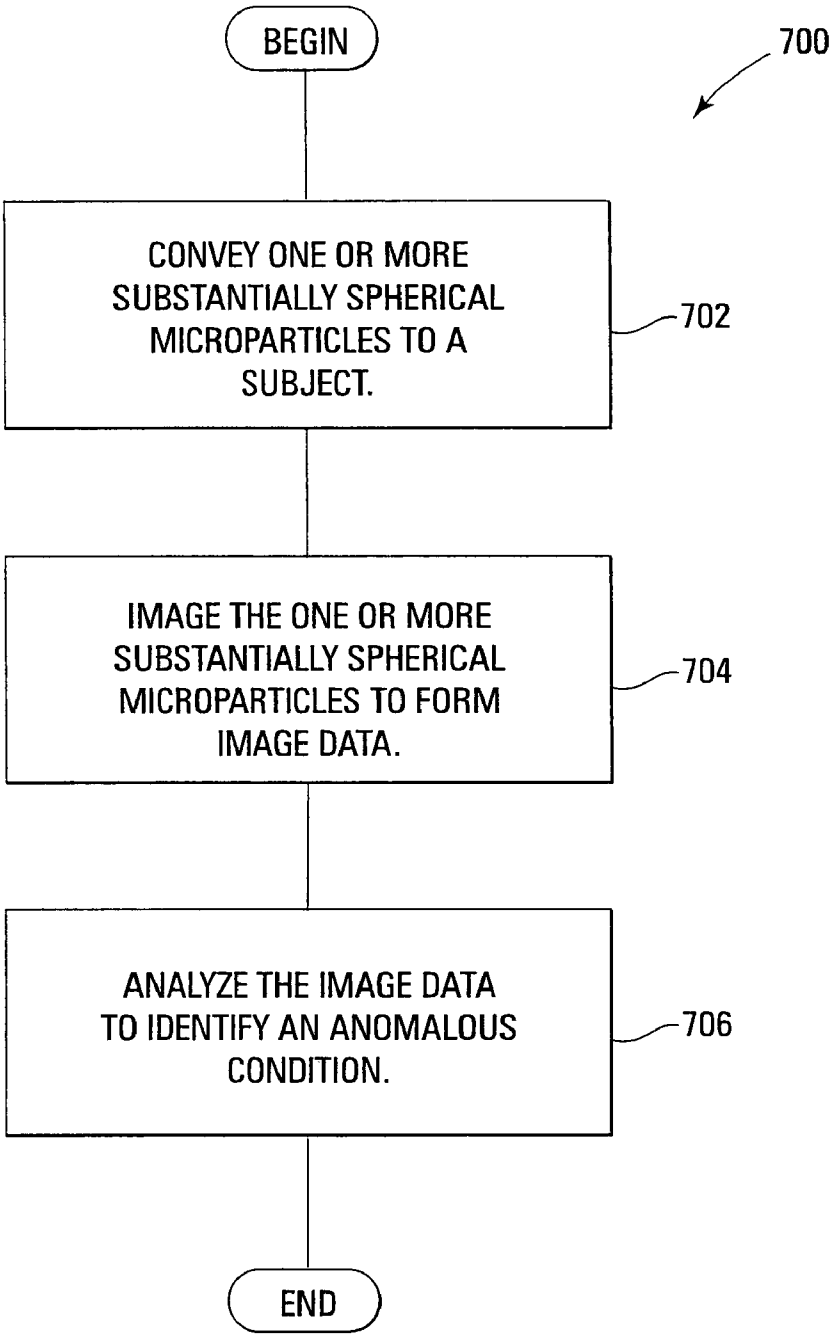

BEGIN
700
CONVEY ONE OR MORE SUBSTANTIALLY SPHERICAL MICROPARTICLES TO A SUBJECT.
702
IMAGE THE ONE OR MORE SUBSTANTIALLY SPHERICAL MICROPARTICLES TO FORM IMAGE DATA.
704
ANALYZE THE IMAGE DATA TO IDENTIFY AN ANOMALOUS CONDITION.
706
END

FIG. 7

APPARATUS AND METHOD TO CONVEY A FLUID

FIELD

[0001] The present invention relates to conveying a fluid, and more particularly, to conveying a fluid that includes microparticles.

BACKGROUND

[0002] In some systems, such as therapeutic systems employed in the treatment of disease, a fluid is conveyed or delivered to a target, such as a cancerous tumor, through a conduit that includes a coupling. For a fluid that includes microparticles, such as radioactive microparticles or radioactive microspheres, the microparticles can become trapped at the coupling.

[0003] Some microparticles are trapped in gaps that result from mechanically mismatched components in the coupling. Other microparticles are trapped in regions of stagnant fluid flow, such as regions in which the fluid velocity is less than the saltation velocity. Corners and discontinuities in the coupling can create regions of fluid expansion in which the fluid velocity is less than the saltation velocity. A force field, such as gravity, can also contribute to the trapping of microparticles. In some systems, more than fifty percent of the microparticles in the flow become trapped. The trapped microparticles are not delivered to the target. For systems that attempt to solve this problem by conveying the fluid at high pressures, the risk of system leakage increases.

[0004] In a therapeutic system, to achieve effective treatment, substantially all microparticles introduced into the system should be delivered to the target. Failure to deliver substantially all microparticles to the target reduces the effectiveness of the treatment. Similarly, in a diagnostic system, to achieve an accurate diagnosis, substantially all microparticles introduced into the system should be delivered to the target. Further, for microparticles that constitute a medical device, under delivery of the microparticles to the intended target is an incident reportable to regulatory authorities.

SUMMARY

[0005] An apparatus includes a fluid path, a coupling, and a nozzle. The fluid path is to carry a fluid including one or more microparticles. The coupling is located in the fluid path. The nozzle is located in the fluid path to move the fluid through a stagnant region located near the coupling.

[0006] An apparatus includes a fluid path and a coupling. The fluid path is to carry a fluid including one or more microparticles. The coupling is located along the fluid path. The fluid path is substantially aligned with a force field.

[0007] A method includes introducing a fluid including one or more microparticles into a fluid path including a coupling and aligning the fluid path near the coupling with a force field.

[0008] An apparatus includes a coupling including a proximal end and a distal end and a low flow rate fluid path including the coupling to deliver at least about 90% of a source of high density microparticles from the proximal end of the coupling to the distal end of the coupling.

[0009] A method includes coupling a source of high density microparticles having high specific activity to a mammal and delivering the high density microparticles having high specific activity to the mammal at a pressure of between about 5 psig and about 30 psig at the source.

[0010] A method includes delivering one or more microparticles to a subject, and imaging the one or more microparticles to form image data.

[0011] A method includes conveying one or more substantially spherical microparticles to a subject, imaging the one or more substantially spherical microparticles to form image data, and analyzing the image data to identify an anomalous condition.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1**(*a*) is a perspective view of an apparatus to convey a fluid in accordance with some embodiments.

[0013] FIG. **1**(*b*) is an illustration of a cross-sectional view at line x-x of the apparatus shown in FIG. **1**(*a*) and including a fluid path and a coupling located in the fluid path and substantially aligned along the field lines of a force field in accordance with some embodiments.

[0014] FIG. **1**(*c*) is block diagram of an apparatus including the apparatus shown FIG. **1**(*a*) and coupled to a source of radioactive microparticles and a patient for use in connection with therapies, such as cancer therapies, in accordance with some embodiments.

[0015] FIG. **1**(*d*) is a flow diagram of a method including introducing a fluid including one or more microparticles into a fluid path including a coupling and substantially aligning the fluid path near the coupling with a force field.

[0016] FIG. **2**(*a*) is an illustration of a cross-sectional view of an apparatus including the fluid path shown in FIG. **1**(*a*), the coupling shown in FIG. **1**(*a*) and located in the fluid path shown in FIG. **1**(*a*), and a nozzle located in the fluid path to move a fluid through a stagnant region located near the coupling in accordance with some embodiments.

[0017] FIG. **2**(*b*) is a detailed illustration of an apparatus including the coupling shown in FIG. **2**(*a*), the nozzle, shown in FIG. **2**(*a*), and a flat-face seal and an elastomeric seal in accordance with some embodiments.

[0018] FIG. **3** is an illustration of apparatus including a low flow rate fluid path including a coupling in accordance with some embodiments.

[0019] FIG. **4** is a flow diagram of a method including coupling a source of high density microparticles having high specific activity to a mammal, and delivering the high density microparticles having high specific activity to the mammal at a pressure of between about 5 psig and about 30 psig at the source in accordance with some embodiments.

[0020] FIG. **5** is a Summary Table showing catheter size, pressure ranges, equivalent flow rates, and flush volumes for microparticles suitable for use as the source of microparticles in accordance with some embodiments.

[0021] FIG. **6** is a flow diagram of a diagnostic method in accordance with some embodiments.

[0022] FIG. **7** is a flow diagram of a diagnostic method including analysis in accordance with some embodiments.

DESCRIPTION

[0023] FIG. **1**(*a*) is a perspective view of an apparatus **100** to convey a fluid in accordance with some embodiments. The apparatus **100** is suitable for use in connection with systems and devices that convey or deliver a fluid. A fluid is a continuous amorphous substance that is readily reshaped and has a tendency to assume the shape of its container. The apparatus **100** is not limited to use in connection with a particular fluid or a particular application or industry. Exemplary fluids suit-

able for use in connection with the apparatus **100** include liquids and gases. Further embodiments of the apparatus **100** are shown in FIGS. **1**(*b*), **1**(*c*), **2**(*a*), and **2**(*b*) and described below.

[0024] FIG. **1**(*b*) is an illustration of a cross-sectional view at line x-x of the apparatus **100**, shown in FIG. **1**(*a*), including a fluid path **102** and a coupling **104** located in the fluid path **102** and substantially aligned along the field lines of a force field **106** in accordance with some embodiments. The fluid path **102** includes a proximal end **108** and a distal end **110** and provides a path or conduit to convey or deliver a fluid from the proximal end **108** to a distal end **110**. The delivery of a fluid intravenously for therapeutic use in the treatment of disease is one exemplary application of the apparatus **100**. In one illustrative embodiment, the apparatus **100** provides for the delivery of a fluid, such as a fluid including one or more radioactive microparticles, to a human vascular system for the treatment of cancer. Liver cancer is an exemplary disease for which therapies have been developed that can benefit from the use of the apparatus **100**. Cancer and other disease states can be diagnosed using microparticle injections. The microvascular bed of cancer lesions, or other diseases, and surrounding healthy tissue can be characterized to allow treatment planning, including but not limited to the number of therapeutic microspheres and the specific activity of the therapeutic microspheres in a subsequent treatment. Other treatments can be planned from the knowledge of the microvascular bed.

[0025] In some embodiments, the fluid path **102** is formed from a conduit, such as a tube or microtube. A tube is a conduit that has an inside diameter greater than a few thousand microns. A microtube is a tube that has an inside diameter a between about a fraction of a micron and a few thousand microns. The inside diameter of the conduit is not limited to a particular value. For the transport of a fluid that includes one or more microparticles or microspheres along the fluid path **102**, the fluid path **102** is formed from a conduit of sufficient diameter to allow the microparticles to flow unimpeded from the proximal end **108** to the distal end **110**. For example, to transport a fluid that includes five micrometer diameter microparticles, in some embodiments the inside diameter of a conduit that forms the fluid path **102** is between about twenty-five micrometers and about fifty micrometers. The conduit can be flexible or inflexible. Exemplary materials suitable for use in connection with the fabrication of the conduit that forms the fluid path **102** include polystyrene, plastic, and metals, such as stainless steel.

[0026] The coupling **104** included in the fluid path **102** provides a mechanical connection or link between two or more objects, such as two or more pieces of conduit **112** and **114** or between a conduit and a catheter. A coupling can be formed separately from the objects to be connected or the coupling can be integrated with the objects. The coupling **104** is not limited to a particular type of coupling. Various couplings, connectors, and fittings are suitable for use in forming the coupling **104** in the fluid path **102** of the apparatus **100**.

[0027] A Luer connector is one type of coupling used as an interconnection component in vascular fluid delivery systems. A Luer connector includes a tapered barrel and a conical male part that fits into the barrel without a seal. In some embodiments, the taper is about six percent. For use in a vascular fluid delivery system, in some embodiments, the apparatus **100** includes a Luer connector for the coupling **104** in the fluid path **102**. The coupling material is selected to be compatible with the fluid and the environment and operating conditions, such as temperature and pressure, of the fluid path **102**.

[0028] In operation, the apparatus **100** conveys a fluid, such as a fluid including one or more microparticles, along the fluid path **102**. A microparticle may be spherical but it need not be spherical. Solid or hollow glass or glass composite beads can form microparticles suitable for use in connection with the apparatus **100**. In some embodiments, each of the one or more microparticles has a specific gravity of more than about 1.5.

[0029] The term microparticle includes nanoparticles, microparticles, and microspheres. Nanoparticles include particles and nanospheres having a diameter of about fifty nanometers to about 1000 nanometers. Microparticles include particles having a diameter of between about 1 μm to about 1000 μm. Microspheres include substantially spherical elements having a diameter between about 1 μm and about 1000 μm. Exemplary materials suitable for use in forming microparticles include inorganic, organic, polymer, radioactive and magnetic materials. Inorganic materials include metals, silica, alumina, titania, glass, and ceramic. Organic materials include polystyrene, melanin, and polylactide. Polymer materials include polyurethane, lignin, polyamide, silicone, copolymers and trimers. A radioactive material exhibits the spontaneous emission of a stream of particles or electromagnetic rays during nuclear decay. The stream may include atomic or subatomic particles that may be charged positively or negatively. Alpha particles and positrons are exemplary positively charged particles. Beta particles are exemplary negatively charged particles. Radioactive materials include radioactive oxides and radioactive polymers. A magnetic material responds to a magnetic field. Magnetic materials include some metals, such as iron, ferromagnetic, and paramagnetic materials. The surface of a microparticle is not limited to being formed from a particular material.

[0030] Also, in operation, the fluid path **102** near the coupling **104** is substantially aligned with the force field **106**. The fluid path **102** is substantially aligned with the force field **106** when the angle between the direction of travel of microparticles in the fluid path **102** and the direction of the force field **106** is between about thirty-five degrees and about forty-five degrees. The fluid path **102** is very substantially aligned with the force field **106** when the angle between the direction of travel of microparticles in the fluid path **102** and the direction of the force field is less than about thirty-five degrees. When the fluid path **102** is very substantially aligned with the force field **106** fewer of the particles in the fluid path **102** will become trapped than when the fluid path **102** is substantially aligned with the force filed **106**. The force field **106** is not limited to a particular type of force field. Exemplary force fields suitable for use in connection with the apparatus **100** include gravitational force fields, magnetic force fields, centrifugal force fields, and electric force fields. The force field **106** can be static or dynamic. A static force field does not vary with time. A dynamic force field varies with time.

[0031] The substantial alignment of the fluid path **102** near the coupling **104** with the force field **106** reduces the likelihood of the microparticles being trapped in a gap **116** created in mismatched fittings of the coupling **104**. Further, fewer microparticles enter a stagnant fluid region **118** at a re-entrant corner **120**, when the fluid path **102** is substantially aligned with the force field **106**. Finally, microparticles that enter the stagnant fluid region **118** travel in the direction of the force

field **106** into a turbulent region **122** where they are re-entrained or pulled into the fluid flow of the fluid path **102**.

[0032] FIG. **1**(*c*) is block diagram of an apparatus **130** including the apparatus **100**, shown FIG. **1**(*b*), coupled to a source of radioactive microparticles **132** and a patient **134** for use in connection with therapies, such as cancer therapies, in accordance with some embodiments. The source of radioactive microparticles **132** includes a container, such as a vial, to hold a fluid including radioactive microparticles. The container is either shielded or maintained in a shielded case to provide protection from the radiation emitted by the radioactive microparticles **132**. A catheter **136** can provide a coupling from the fluid path **102** of the apparatus **100** to the patient **134**. The catheter **136** is a hollow flexible tube for insertion into a body cavity, duct, or vessel to allow the passage of fluids. In some embodiments, the apparatus **100** is included in the catheter **136**.

[0033] FIG. **1**(*d*) is a flow diagram of a method **140** including introducing a fluid including one or more microparticles into a fluid path including a coupling (block **142**), and substantially aligning the fluid path near the coupling with a force field (block **144**). In some embodiments, aligning the fluid path near the coupling with the force field includes aligning the fluid path near the coupling with a gravitational field. In some embodiments, the method **140** further includes introducing a cancer patient into the fluid path. And in yet other embodiments, introducing the fluid including one or more microparticles into the fluid path including the coupling includes introducing a slurry of radioactive microparticles under pressure into the fluid path. In some embodiments, the method further includes introducing a flushing fluid having a volume of between about twenty millilitres and about eighty millilitres into the fluid path at an operating pressure of about thirty pounds per square inch per square inch gauge.

[0034] FIG. **2**(*a*) is an illustration of a cross-sectional view of an apparatus **200** including the fluid path **102**, shown in FIG. **1**(*a*), the coupling **104**, shown in FIG. **1**(*a*), located in the fluid path **102**, and a nozzle **202** located in the fluid path **102** to move a fluid through a stagnant region **204** located near the coupling **104**. The nozzle **202** includes an input port **206** and an output port **208**. In some embodiments, the nozzle **202** includes a side port **210**. The nozzle **202** is not limited to a particular number of side ports. In some embodiments, the nozzle **202** includes the side port **210** and one or more additional side ports, such as side port **211**.

[0035] The fluid path **102** includes the proximal end **108**, shown in FIG. **1**(*b*), and the distal end **110**, shown in FIG. **1**(*b*), and provides a path or conduit to convey or deliver a fluid from the proximal end **108** to the distal end **110**. The delivery of a fluid intravenously for therapeutic use in the treatment of disease is one exemplary application of the apparatus **200**. In one illustrative embodiment, the apparatus **200** provides for the delivery of a fluid, such as a fluid including one or more radioactive microparticles, to a human vascular system for the treatment of cancer. Liver cancer is an exemplary disease for which therapies have been developed that can benefit from the use of the apparatus **200**.

[0036] In operation, all microparticles that enter the fluid path **102** at the proximal end **108** of the apparatus **200** should enter the nozzle **202** at the input port **206** and should exit the apparatus **200** at the distal end **110**. The stagnant region **204** is an interior area of the coupling **104** in which microparticles entering the coupling **104** at the input port **206** of the nozzle **202** can become trapped. When microparticles become trapped in the stagnant region **204** they do not pass through the coupling **104** to the distal end **110**. In some systems, such as therapeutic systems, it is desirable to keep the number of trapped microparticles low.

[0037] Introduction of the nozzle **202** into the fluid path **102** changes the dynamics of the fluid flow in the coupling **104**. In some embodiments, the input port **206** of the nozzle **202** has an input port cross-sectional area and the output port **208** has an output port cross-sectional area. Making the cross-sectional area of the input port **206** greater than the cross-sectional area of the output port **208** reduces the likelihood that microparticles traveling along the fluid path **102** will become trapped in the stagnant region **204**. In some embodiments, the output port **208** has a diameter of between about 0.2 millimeters and about 1 millimeter. In some embodiments, the output port **208** cross-sectional area is about forty percent of the input port **206** cross-sectional area. In some embodiment, the output port **208** diameter is equal to between about five microparticle and about ten microparticle diameters. In addition, making the cross-sectional area of the input port greater than the cross-sectional area of the output port forces fluid flow through the side port **210** to assist in moving microparticles through the stagnant region **204**.

[0038] The velocity of the fluid at the output port **208** of the nozzle **202** creates a low pressure region to draw fluid and microparticles from the stagnant region **204** into the fluid path **102**. Further, the nozzle **202** occupies a volume in the coupling **104** which increases the flow rate and entrainment of microparticles into the fluid path **102** near the nozzle **202**. In addition, positioning the output port **208** of the nozzle **202** beyond the stagnant region **204** results in delivery of substantially all microparticles in the fluid to a location in the coupling **104** beyond the stagnant region **204**.

[0039] The nozzle **202** includes a nozzle fluid path **212** located between the input port **206** and the output port **208**. In some embodiments, the nozzle fluid path **212** includes a taper **214**. In some embodiments, the slope of the taper **214** is less than about forty-five degrees. The slope of the taper **214** is the largest slope of the curve of the nozzle fluid path **212** between the input port **206** and the output port **208**. For the taper **214** having a slope of less than about forty-five degrees, the likelihood of microparticle bridging along the nozzle fluid path **212** is reduced. Microparticle bridging occurs when a group of microparticles block or partially block the nozzle fluid path **212**.

[0040] In some embodiments, the nozzle **202** includes the side port **210**. The side port **210** is an opening located on a side surface of the nozzle **202**. Introduction of the side port **210** into the nozzle **202** changes the dynamics of the fluid flow in the coupling **104**. The side port **210** provides a fluid path through the stagnant region **204** for a fluid entering the nozzle **202** at the input port **206**. The side port **210** is located near the input port **206** of the nozzle **202**. Further, as described above, making the cross-sectional area of the input port **206** greater than the cross-sectional area of the output port **208** creates a back pressure to force more fluid flow through the side port **210**. The fluid flow at the side port **210** induces turbulence near the nozzle **202** that sweeps microparticles from the stagnant region **204** near the nozzle **202** into the fluid path **102**. The fluid flow provided by the side port **210** to the stagnant region **204** removes substantially all microparticles from the stagnant region **204**.

[0041] The side port **210** is not limited to a particular shape. In some embodiments, the side port **210** is substantially a

cylindrical passage that has a diameter at least as large as the largest microparticle. However, to reduce the likelihood of blockage by bridging, the side port diameter should be at least two or more microparticle diameters. In some embodiments, the side port diameter is about 0.25 millimeters.

[0042] The nozzle **202** is not limited to a particular number of side ports. The side port **210** can be replicated along the perimeter of the nozzle **202**. The replication of the side port **210** is not limited to a particular configuration. In some embodiments, the side port **210** includes two or more side ports spaced a substantially equal distance from each other along the perimeter of the nozzle **202**. In some embodiments, the side port **210** includes four side ports with each of the four side ports spaced a substantially equal distance from each other along the perimeter of the nozzle **202**.

[0043] In some embodiments, the nozzle **202** includes a nozzle flange **216**. The nozzle flange **216** is sized and centered in the coupling **104** to form a seal at the leading edge of the nozzle flange **216**. The purpose of the seal between the nozzle flange **216** and the coupling **104** is to substantially prevent formation of the gap **116**. Preventing formation of the gap **116** reduces the number of potential sites that can trap microparticles in the coupling **104**.

[0044] In operation, a fluid enters the apparatus **200** at the proximal end **108** and flows along the fluid path **102** through the coupling **104** and the nozzle **202** and exits the coupling **104** at the distal end **110**. For a fluid that includes one or more microparticles, the coupling **104** and the nozzle **202** provide a fluid flow that keeps the number of microparticles trapped in regions of the coupling **104**, such as the stagnant region **204**, low.

[0045] FIG. **2**(*b*) is a detailed illustration of an apparatus **220** including the coupling **104**, shown in FIG. **2**(*a*), the nozzle **202**, shown in FIG. **2**(*a*), and a flat-face seal **222** and an elastomeric seal **224** in accordance with some embodiments. In some embodiments, the nozzle **202** includes the nozzle flange **216**. The flat-face seal **222** is formed between in the coupling **104** and the nozzle flange **216**. A flat-face seal includes a surface-to-surface seal between the two components. In some embodiments, the coupling **104** includes the elastomeric seal **224**. The elastomeric seal **224** is formed by a ring of elastomeric material compressed between the two components of the coupling **104**.

[0046] The apparatus **200**, shown in FIG. **2**(*a*) and the apparatus **220** shown in FIG. **2**(*b*) can be included in a fluid delivery system coupled to a patient. In such embodiments, each of the apparatus **200** and **220** enables effective infusions of high density, high potency microparticles at low infusion pressure and flow rates. The low infusion pressure reduces the likelihood of leakage. The low flow rate reduces the possibility of reflux (back flow into a patient's vasculature) which in turn increases the likelihood that the microparticles will be delivered to the target.

[0047] FIG. **3** is an illustration of apparatus **300** including a low flow rate fluid path **302** including a coupling **304** in accordance with some embodiments. The coupling **304** has a proximal end **306** and a distal end **308**. In operation, the low flow rate fluid path **302** including the coupling **304** delivers at least about 90% of a source of high density microparticles from the proximal end **306** to the distal end **308** of the coupling **304**. For example, if a source of high density microparticles includes ten million particles, then in operation the apparatus **300** delivers at least about nine million high density microparticles from the source to the distal end **308** of the coupling **304**. A catheter is an exemplary coupling suitable for use in connection with the apparatus **300**. In some embodiments, in operation, the low flow rate fluid path **302** has a flow rate of between about 0.05 millilitres per second and about 0.93 millilitres per second. A high density microparticle has a specific gravity of greater than about 1.5. A high specific activity radioactive microparticle has a specific activity of greater than about 0.5 Ci/g. For non-radioactive particles, high specific activity refers to the concentration of active ingredient, for example, a therapeutic drug or enhancing drug such as an oxidizing agent. The apparatus **300** improves microparticle delivery to a target and is particularly useful when the volume in the coupling **304** available to trap microparticles exceeds about **5**% of the volume of the microparticles intended for delivery to the target.

[0048] FIG. **4** is a flow diagram of a method **400** including coupling a source of high density microparticles having high specific activity to a mammal (block **402**), and delivering the high density microparticles having high specific activity to the mammal at a pressure of between about 5 psig and about 30 psig at the source (block **404**). In some embodiments, coupling the source of high density microparticles having high specific activity to the mammal includes connecting a catheter between the source and the mammal. In some embodiments, delivering the high density microparticles having high specific activity to the mammal at the pressure of between about 5 psig and about 30 psig at the source includes delivering more than about 90% of the high density microparticles available at the source to the mammal.

[0049] FIG. **5** is a Summary Table showing catheter size, pressure ranges, equivalent flow rates, and flush volumes for microparticles suitable for use as the source of microparticles in accordance with some embodiments. As can be seen in the Summary Table, for a catheter size of 3 French, the pressure range in the fluid path **302**, shown in FIG. **4**, is between about 5 psig and about 30 psgi. The equivalent flow is 0.49±0.44 mL/s and the flush volume is less than about 60 ml. For a catheter size of 5 French, the pressure range in the fluid path **302**, shown in FIG. **4**, is between about 5 psig and about 30 psig. The equivalent flow is 2.1±0.9 and the flush volume is less than about 60 ml. The flow rate variability is based on three standard deviations. Flow rate values for 4 French catheters fall between the 3 and 5 French values. At the pressures and flow rates for the fluid path shown in the Summary Table, a source of high density microparticles can include a seal rated for a lower pressure than for higher pressure fluid paths.

[0050] FIG. **6** is a flow diagram of a diagnostic method **600** in accordance with some embodiments. The method **600** includes delivering one or more microparticles to a subject (block **602**), and imaging the one or more microparticles to form image data (block **604**). The image data can be analyzed by a physician, clinician, or a computing system to generate a diagnosis. The image data is not limited to a particular type of data. Exemplary types of data include digital, such as digital data stored in a computing system, analog, such as photographs or other displayable images, and mixed digital and analog. In some embodiments, delivering the one or more microparticles to the subject includes delivering the one or more microparticles to a microvascular bed. A microvascular bed includes the small vascular structures in organs, such as the human liver. These small vascular structures can trap substantially spherical microparticles. In some embodiments, delivering the one or more microparticles to the subject includes delivering one or more radioactive microparticles to

the subject. In some embodiments, delivering the one or more microparticles to the microvascular bed includes delivering the one or more microparticles to the microvascular bed in a human liver or other human organ. In some embodiments, delivering the one or more microparticles to the microvascular bed includes delivering one or more radioactive microparticles to the microvascular bed in a human liver, breast, brain, or other human organ. The imaging of the microparticles is not limited to a particular method. Any method of imaging capable of detecting microparticles or clusters of microparticles is suitable for use in connection with the method **600**. Exemplary imaging methods include ultrasound, magnetic resonance imaging, and computer aided tomography.

[0051] FIG. **7** is a flow diagram of a diagnostic method **700** including analysis in accordance with some embodiments. The method **700** includes conveying one or more substantially spherical microparticles to a subject (block **702**), imaging the one or more substantially spherical microparticles to form image data (block **704**), and analyzing the image data to identify an anomalous condition (block **706**). Cancer is one example of an anomalous condition that can be detected and analyzed using the method **700**. The method **700** also includes delivering a small numbers of radiocative microparticles a subject, such as an animal, analyzing the location and distribution of the microparticles in the subject, and a generating a treatment regime from the analysis. The treatment regime can include delivering a larger number of substantially spherical microparticles to the subject. In some embodiments, conveying the one or more substantially spherical microparticles to a subject includes conveying one or more radioactive microparticles to the subject. In some embodiments, analyzing the image data to identify the anomalous condition includes comparing the image data against data that identifies known diseases to identify a an animal disease state. In some embodiments, imaging the one or more substantially spherical microparticles to form image data includes imaging using a magnetic resonance imaging system. However, the methods of imaging are not limited to a particular method. Any imaging method capable of detecting microparticles can be used in connection with the described diagnostic methods. Exemplary imaging systems include systems that image using waves, such as electromagnetic or acoustic waves. Exemplary imaging systems that use electromagnetic waves include magnetic resonance imaging and computer aided tomography. Exemplary imaging systems that use acoustic waves include ultrasound imaging systems.

[0052] Although many alterations and modifications of the described embodiments will no doubt become apparent to a person of ordinary skill in the art after having read the foregoing description, it is to be understood that any particular embodiment shown and described by way of illustration is in no way intended to be considered limiting. Therefore, references to details of various embodiments are not intended to limit the scope of the claims.

1.-**32**. (canceled)

33. A method comprising:

delivering one or more microparticles to a subject; and

imaging the one or more microparticles to form image data.

34. The method of claim **33**, wherein delivering the one or more microparticles to the subject comprises:

delivering the one or more microparticles to a microvascular bed.

35. The method of claim **33**, wherein delivering the one or more microparticles to the subject comprises:

delivering one or more radioactive microparticles to the subject.

36. The method of claim **34**, wherein delivering the one or more microparticles to the microvascular bed comprises:

delivering the one or more microparticles to the microvascular bed in a human liver.

37. The method of claim **34**, wherein delivering the one or more microparticles to the microvascular bed comprises:

delivering one or more radioactive microparticles to the microvascular bed in a human liver.

38. A method comprising:

conveying one or more substantially spherical microparticles to a subject;

imaging the one or more substantially spherical microparticles to form image data; and

analyzing the image data to identify an anomalous condition.

39. The method of claim **38**, wherein conveying the one or more substantially spherical microparticles to a subject comprises:

conveying one or more radioactive microparticles to the subject.

40. The method of claim **38**, wherein analyzing the image data to identify the anomalous condition comprises:

comparing the image data against data that identifies known diseases to identify a an animal disease state.

41. The method of claim **38**, wherein imaging the one or more substantially spherical microparticles to form image data comprises:

imaging using a magnetic resonance imaging system.

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