

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

- 1) ~~Apparatus for generating nanobubbles of a gas in a liquid, the apparatus including:
 - a) ~~an outer tube;~~
 - b) ~~a porous inner tube coaxially located within the outer tube that is at least partially occluded so as to define one or more liquid flow paths through the inner tube;~~
 - c) ~~a pair of end assemblies attached to respective first and second ends of the outer tube, each end assembly having an opening in fluid communication with the one or more liquid flow paths so as to allow a flow of liquid in an axial direction through the apparatus; and,~~
 - d) ~~a gas inlet for allowing a flow of gas into a chamber formed between the outer and inner tube, the flow of gas permitted to permeate through the porous inner tube into the one or more liquid flow paths;~~wherein, as the gas permeates through the porous inner tube, nanobubbles of gas are generated which become entrained in the liquid flow.~~
- 2) ~~Apparatus according to claim 1, wherein at least a portion of the nanobubbles are generated at a gas liquid interface proximate an inner surface of the inner tube.~~
- 3) ~~Apparatus according to claim 1 or claim 2, wherein the gas inlet is provided in one of:
 - a) ~~a wall of the outer tube; and,~~
 - b) ~~an end assembly.~~~~
- 4) ~~Apparatus according to any one of claims 1 to 3, wherein the end assemblies are welded to the outer tube.~~
- 5) ~~Apparatus according to claim 4, wherein the inner tube is located relative to the outer tube by sandwiching opposing ends of the inner tube between respective end assemblies.~~
- 6) ~~Apparatus according to claim 4, wherein each end assembly includes a recessed or shoulder portion in which an end of the inner tube is seated.~~
- 7) ~~Apparatus according to any one of claims 1 to 6, wherein the apparatus further includes a solid rod located within the inner tube to thereby at least partially occlude the inner tube, the rod having an outer diameter less than an inner diameter of the inner tube to thereby define an annular passageway between the rod and inner tube which provides a liquid flow path.~~

- ~~8) Apparatus according to claim 7, wherein the solid rod located within the inner tube is coupled to the end assemblies.~~
- ~~9) Apparatus according to claim 8, wherein the rod is coupled to the end assemblies by a mechanical fastener at each end.~~
- ~~10) Apparatus according to claim 9, wherein the mechanical fastener is a pin, stud or all threaded rod.~~
- ~~11) Apparatus according to claim 9 or claim 10, wherein each end assembly includes:
 - ~~a) an outer portion for attachment to the outer tube and including the opening for liquid inflow/outflow;~~
 - ~~b) an inner portion for supporting the inner tube; and,~~
 - ~~c) an intermediate portion sandwiched between the inner and outer portions, the intermediate portion for coupling to the rod.~~~~
- ~~12) Apparatus according to claim 11, wherein the intermediate portion includes a body having a plurality of openings to allow passage of liquid flow between the inner and outer portions.~~
- ~~13) Apparatus according to claim 11 or claim 12, wherein the intermediate portion is welded to the inner and outer portions.~~
- ~~14) Apparatus according to claim 12 or claim 13, wherein the body of the intermediate portion includes:
 - ~~a) a flow directing element extending from a first side of the body into the flow path proximate the opening of the outer portion; and,~~
 - ~~b) a boss element protruding from a second side of the body for receiving the mechanical fastener used to couple the rod to the end assembly.~~~~
- ~~15) Apparatus according to any one of claims 11 to 14, wherein at least one of the inner and outer portions of the end assembly are substantially frusto-conical.~~
- ~~16) Apparatus according to claim 14, wherein the flow directing element is conical.~~
- ~~17) Apparatus according to any one of claims 11 to 16, wherein in use, liquid flows through the opening in the outer portion of the end assembly through the plurality of openings in the intermediate portion to the inner portion of the end assembly whereby it is directed into the annular passageway between the rod and inner tube.~~

- ~~18) Apparatus according to any one of claims 1 to 6, wherein the porous inner tube is a solid tube having a plurality of axially extending through channels formed therein which define the one or more liquid flow paths.~~
- ~~19) Apparatus according to claim 18, wherein each end assembly includes:~~
- ~~a) an outer portion for attachment to the outer tube and including the opening for liquid inflow/outflow; and,~~
 - ~~b) an inner portion for supporting the inner tube and configured to direct liquid flow to or from the one or more liquid flow paths.~~
- ~~20) Apparatus according to claim 19, wherein the inner portion has a body including a plurality of through openings corresponding to the plurality of through channels of the porous inner tube.~~
- ~~21) Apparatus according to claim 20, wherein each end of the inner tube is in abutment with an inner portion of a respective end assembly.~~
- ~~22) Apparatus according to claim 20 or claim 21, wherein the inner and outer portions of the end assembly are welded together.~~
- ~~23) Apparatus according to any one of claims 18 to 22, wherein in use, liquid flows through the opening in the outer portion of the end assembly through the plurality of through openings of the inner portion of the end assembly whereby it is directed into the plurality of through channels that axially extend through the inner tube.~~
- ~~24) Apparatus for generating nanobubbles of a gas in a liquid, the apparatus including:~~
- ~~a) an outer tube;~~
 - ~~b) a porous inner tube coaxially located within the outer tube so as to provide an annular passageway between the tubes, the annular passageway providing a liquid flow path;~~
 - ~~c) a pair of end assemblies attached to respective first and second ends of the outer tube, each end assembly having an opening in fluid communication with the annular passageway so as to allow a flow of liquid in an axial direction through the apparatus;~~
 - ~~d) a gas inlet provided in one of the end assemblies for allowing a flow of gas into the porous inner tube, the flow of gas permitted to permeate through the porous inner tube into the liquid flow path,~~
- ~~wherein, as the gas permeates through the porous inner tube, nanobubbles of gas are generated which become entrained in the liquid flow.~~

- ~~25) Apparatus according to claim 24, wherein the end assemblies are configured to support the inner tube in position relative to the outer tube.~~
- ~~26) Apparatus according to claim 24 or claim 25, further including:~~
- ~~a) a first end cap attached to a first end of the inner tube, the first end cap having a through opening permitting gas flow from the gas inlet into the inner tube; and~~
 - ~~b) a second end cap attached to a second end of the inner tube, the second end cap closed to prevent gas from escaping from the second end of the inner tube.~~
- ~~27) Apparatus according to claim 26, wherein the first and second end caps are in abutment with the respective first and second ends of the inner tube.~~
- ~~28) Apparatus according to claim 27, wherein each end cap is welded to the inner tube.~~
- ~~29) Apparatus according to any one of claims 24 to 28, wherein the end caps are seated in respective recessed or shoulder regions of the end assemblies to thereby locate the inner tube relative to the outer tube.~~
- ~~30) Apparatus according to any one of claims 24 to 29, wherein the end assemblies are welded to the outer tube.~~
- ~~31) Apparatus according to any one of claims 24 to 30, wherein each end assembly includes:~~
- ~~a) an outer portion having the opening for allowing the liquid flow into or out of the apparatus;~~
 - ~~b) an inner portion for attachment to the outer tube; and,~~
 - ~~c) an intermediate portion sandwiched between the inner and outer portions, the intermediate portion for supporting the inner tube.~~
- ~~32) Apparatus according to claim 31, wherein the intermediate portion includes a body having a plurality of openings to allow liquid flow between the outer and inner portions.~~
- ~~33) Apparatus according to claim 31 or claim 32, wherein the intermediate portion is welded to the inner and outer portions.~~
- ~~34) Apparatus according to any one of claims 31 to 33, wherein the body of the intermediate portion includes:~~
- ~~a) a flow directing element extending from a first side of the body into the liquid flow path proximate the opening of the outer portion of the end assembly; and,~~
 - ~~b) a recessed or shoulder portion in which an end cap attached to the inner tube is seated.~~

- ~~35) Apparatus according to any one of claims 31 to 34, wherein at least one of the inner and outer portions of the end assembly are substantially frusto-conical.~~
- ~~36) Apparatus according to claim 34 or claim 35, wherein the flow directing element is conical.~~
- ~~37) Apparatus according to any one of claims 31 to 36, wherein in use, liquid flows through the opening in the outer portion of the end assembly through the plurality of openings in the intermediate portion to the inner portion of the end assembly whereby it is directed into the annular passageway between the inner and outer tubes.~~
- ~~38) Apparatus according to any one of the preceding claims, wherein the porous inner tube has an average pore size of between about 40 to 200nm.~~
- ~~39) Apparatus according to any one of the preceding claims, wherein the porous inner tube is one of:~~
- ~~a) a sintered metallic tube;~~
 - ~~b) a porous ceramic tube; and,~~
 - ~~e) a porous plastic tube.~~
- ~~40) Apparatus according to claim 39, wherein for a sintered metallic tube, the metal is one of:~~
- ~~a) stainless steel;~~
 - ~~b) brass;~~
 - ~~e) bronze;~~
 - ~~d) aluminium; and,~~
 - ~~e) titanium.~~
- ~~41) Apparatus according to claim 39, wherein for a porous ceramic tube, the ceramic material is one of:~~
- ~~a) silicon carbide;~~
 - ~~b) alumina; and,~~
 - ~~e) titania.~~
- ~~42) Apparatus according to any one of the preceding claims, wherein the outer tube is stainless steel.~~
- ~~43) Apparatus according to any one of claims 7 to 17, wherein the solid rod is stainless steel.~~
- ~~44) Apparatus according to any one of the preceding claims, wherein liquid flow through the apparatus is bi-directional.~~

- 45) ~~Apparatus according to any one of the preceding claims, wherein liquid flows through the apparatus without a substantial change in direction.~~
- 46) ~~Apparatus according to any one of the preceding claims, wherein the openings of the end assemblies are axially aligned with the outer and inner tubes.~~
- 47) ~~Apparatus according to any one of the preceding claims, wherein a surface area to volume ratio of the one or more liquid flow paths is substantially higher than the surface area to volume flow ratio of the inner or outer tube.~~
- 48) ~~Apparatus according to any one of the preceding claims, wherein the liquid is water.~~
- 49) ~~Apparatus according to any one of the preceding claims, wherein the gas is at least one of:~~
- ~~a) ozone;~~
 - ~~b) oxygen;~~
 - ~~c) nitrogen;~~
 - ~~d) hydrogen; and,~~
 - ~~e) carbon dioxide.~~
- 50) ~~Apparatus for generating nanobubbles of a gas in a liquid, the apparatus including:~~
- ~~a) an outer tube;~~
 - ~~b) an internal sub-assembly housed within the outer tube and arranged to extend axially therein, the sub-assembly including:~~
 - ~~i) a porous tube;~~
 - ~~ii) a centre rod coaxially located within the porous tube so as to define an annular liquid flow path through the porous tube;~~
 - ~~iii) a supporting element at each end of the porous tube, each supporting element configured to receive an end of the porous tube and configured for mounting to an end plate;~~
 - ~~e) a pair of end plates disposed proximate opposing ends of the outer tube, the end plates mounted to the supporting elements of the sub-assembly, each end plate having one or more openings aligned with the liquid flow path through the porous tube;~~
 - ~~d) a pair of end fittings attached to the respective ends of the outer tube so as to cover the end plates and internal sub-assembly, each end fitting having an opening in fluid communication with the liquid flow path through the porous tube via the one or more~~

- openings in a respective end plate so as to allow a flow of liquid in an axial direction through the apparatus; and,
- e) a gas inlet for allowing a flow of gas into a chamber formed between the outer tube and the porous tube, the flow of gas permitted to permeate through a wall of the porous tube into the liquid flow path,
- wherein, as the gas permeates through the wall of the porous tube, nanobubbles of gas are generated which become entrained in the liquid flow.
- 51) The apparatus according to claim 50, wherein the end plates are coupled to the centre rod by mechanical fasteners which act to support the centre rod coaxially within the porous tube.
- 52) The apparatus according to claim 51, wherein the supporting elements include a flange and a ring projecting from the flange in which the end of the porous tube is located in abutment with an internal shoulder portion of the flange, the flange having a centre opening to allow passage of liquid to and from the liquid flow path of the porous tube.
- 53) The apparatus according to claim 52, wherein the supporting element is a gas seal washer.
- 54) The apparatus according to claim 52 or claim 53, wherein a seal ring is sleeved over the ring of the supporting element in abutment with the flange of the supporting element.
- 55) The apparatus according to any one of claims 52 to 54, wherein the one or more openings in each end plate are annular.
- 56) The apparatus according to claim 55, wherein the one or more openings in each end plate are discontinuous.
- 57) The apparatus according to any one of claims 50 to 56 wherein the end fittings are conical reducers.
- 58) Apparatus for generating nanobubbles of a gas in a liquid, the apparatus including:
- a) an outer tube;
 - b) a plurality of internal sub-assemblies housed within the outer tube and arranged to extend axially therein, each sub-assembly including:
 - i) a porous tube;
 - ii) a centre rod coaxially located within the porous tube so as to define an annular liquid flow path through the porous tube;

- ~~iii) a supporting element at each end of the porous tube, each supporting element configured to receive an end of the porous tube and configured for mounting to an end plate;~~
- ~~e) a pair of end plates disposed proximate opposing ends of the outer tube, the end plates mounted to the respective supporting elements of each sub-assembly and each end plate having openings that in use allow passage of liquid to and from the respective liquid flow paths of the porous tubes of each sub-assembly;~~
- ~~d) a pair of end fittings attached to the respective ends of the outer tube so as to cover the end plates and sub-assemblies, each end fitting having an opening in fluid communication with the liquid flow paths of each sub-assembly via the openings in a respective end plate so as to allow a flow of liquid in an axial direction through the apparatus; and,~~
- ~~e) a gas inlet for allowing a flow of gas into a chamber formed between the outer tube and plurality of sub-assemblies, the flow of gas permitted to permeate through walls of the porous tube of each sub-assembly into the liquid flow paths,~~
~~wherein, as the gas permeates through the walls of each porous tube, nanobubbles of gas are generated which become entrained in the liquid flow.~~
- ~~59) The apparatus according to claim 58, wherein the end plates are coupled to the centre rods of each sub-assembly by mechanical fasteners which act to support the centre rods co-axially within the porous tubes.~~
- ~~60) The apparatus according to claim 59, wherein the supporting elements include a flange and a ring projecting from the flange in which the end of the porous tube is located in abutment with an internal shoulder portion of the flange, the flange having a centre opening to allow passage of liquid from the liquid flow path of the porous tube.~~
- ~~61) The apparatus according to claim 60, wherein the supporting element is a gas seal washer.~~
- ~~62) The apparatus according to claim 59 or claim 60, wherein a seal ring is sleeved over the ring of the supporting element in abutment with the flange of the supporting element.~~
- ~~63) The apparatus according to any one of claims 58 to 62, wherein the openings in the end plates are annular.~~
- ~~64) The apparatus according to claim 63, wherein the openings in the end plates associated with each porous tube are discontinuous.~~

~~65) The apparatus according to any one of claims 58 to 64, wherein the end fittings are conical reducers.~~

1) Apparatus for generating nanobubbles of a gas in a liquid, the apparatus including:

- a) an outer tube;
- b) a plurality of internal sub-assemblies housed within the outer tube and arranged to extend axially therein, each sub-assembly including:
 - i) a porous tube;
 - ii) a centre rod coaxially located within the porous tube so as to define an annular liquid flow path through the porous tube;
 - iii) a supporting element at each end of the porous tube, each supporting element configured to receive an end of the porous tube;
- c) a pair of end plates disposed proximate opposing ends of the outer tube, the end plates mounted to the respective supporting elements of each sub-assembly and each end plate having openings that in use allow passage of liquid to and from the respective liquid flow paths of the porous tubes of each sub-assembly;
- d) a pair of end fittings attached to the respective ends of the outer tube so as to cover the end plates and sub-assemblies, each end fitting having an opening in fluid communication with the liquid flow paths of each sub-assembly via the openings in a respective end plate so as to allow a flow of liquid in an axial direction through the apparatus; and,
- e) a gas inlet for allowing a flow of gas into a chamber formed between the outer tube and plurality of sub-assemblies, the flow of gas permitted to permeate through walls of the porous tube of each sub-assembly into the liquid flow paths,
wherein, as the flow of gas permeates through the walls of each porous tube, nanobubbles of gas are generated which become entrained in the flow of liquid.

2) The apparatus according to claim 1, wherein the end plates are coupled to the centre rods of each sub-assembly by mechanical fasteners which act to support the centre rods coaxially within the porous tubes.

3) The apparatus according to claim 2, wherein the supporting elements include a flange and a ring projecting from the flange in which the end of the porous tube is located in

- abutment with an internal shoulder portion of the flange, the flange having a centre opening to allow passage of liquid from the liquid flow path of the porous tube.
- 4) The apparatus according to claim 3, wherein the supporting element is a gas seal washer.
 - 5) The apparatus according to claim 3, wherein a seal ring is sleeved over the ring of the supporting element in abutment with the flange of the supporting element.
 - 6) The apparatus according to any one of claims 1 to 5, wherein the openings in the end plates are annular.
 - 7) The apparatus according to claim 6, wherein the openings in the end plates associated with each porous tube are discontinuous.
 - 8) The apparatus according to any one of claims 1 to 7, wherein the end fittings are conical reducers.
 - 9) Apparatus according to any one of claims 1 to 8, wherein at least a portion of the nanobubbles of gas are generated at a gas-liquid interface proximate an inner surface of each porous tube.
 - 10) Apparatus according to any one of claims 1 to 9, wherein the gas inlet is provided in a wall of the outer tube.
 - 11) Apparatus according to any one of claims 1 to 10, wherein each porous tube has an average pore size of between about 40 to 200nm.
 - 12) Apparatus according to any one of claims 1 to 11, wherein each porous tube is one of:
 - a) a sintered metallic tube;
 - b) a porous ceramic tube; and,
 - c) a porous plastic tube.
 - 13) Apparatus according to claim 12, wherein each porous tube is the sintered metallic tube, the sintered metallic tube being formed from a metal, the metal being one of:
 - a) stainless steel;
 - b) brass;
 - c) bronze;
 - d) aluminium; and,
 - e) titanium.

14) Apparatus according to claim 12, wherein each porous tube is the porous ceramic tube, the porous ceramic tube being formed from a ceramic material, the ceramic material being one of:

- a) silicon carbide;
- b) alumina; and,
- c) titania.

15) Apparatus according to any one of claims 1 to 14, wherein the outer tube is stainless steel.

16) Apparatus according to any one of claims 1 to 15, wherein each centre rod is stainless steel.

17) Apparatus according to any one of claims 1 to 16, wherein liquid flow through the apparatus is bi-directional.

18) Apparatus according to any one of claims 1 to 17, wherein liquid flows through the apparatus without a substantial change in direction.

19) Apparatus according to any one of claims 1 to 18, wherein the flow of liquid is a flow of water.

20) Apparatus according to any one of claims 1 to 19, wherein the flow of gas is a flow of at least one of:

- a) ozone;
- b) oxygen;
- c) nitrogen;
- d) hydrogen; and,
- e) carbon dioxide.