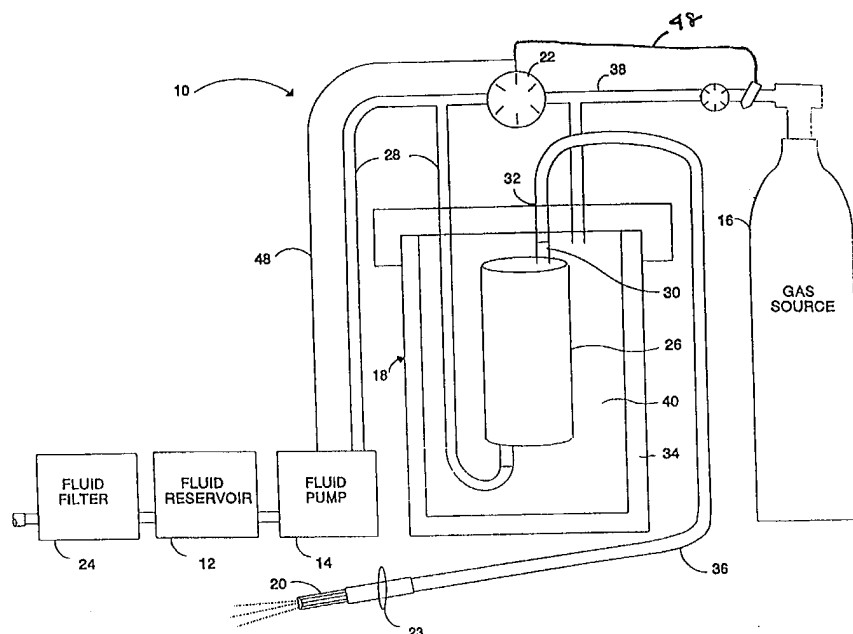




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<b>(21) International Application Number:</b> PCT/US98/07671 <b>(22) International Filing Date:</b> 16 April 1998 (16.04.98)  <b>(30) Priority Data:</b> 08/840,908      16 April 1997 (16.04.97)      US  <b>(71) Applicant:</b> WAYNE STATE UNIVERSITY [US/US]; 656 West Kirby Street, Detroit, MI 48202 (US).  <b>(72) Inventors:</b> SPEARS, J., Richard; 615 Bridle Path Court, Bloomfield Hills, MI 48304 (US). CRILLY, Richard, J.; 935 Bartlet Street, Windsor, Ontario N9G 1V3 (CA).  <b>(74) Agents:</b> STARK, Jon, R. et al.; Pennie & Edmonds LLP, 1155 Avenue of the Americas, New York, NY 10036 (US).		<b>(81) Designated States:</b> AU, CA, JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.          Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

**(54) Title:** SYSTEM AND METHOD FOR DELIVERY OF GAS-SUPERSATURATED FLUIDS

**(57) Abstract**

A system and method for delivering a gas-supersaturated fluid comprising a fluid reservoir (12), a fluid pump (14), a gas source (16), a high pressure gas exchanger (18), and one or more arrays of capillary channels (20) is disclosed. Suitable controls such as differential pressure gauge (22) and valves are provided to maintain a near constant hydrostatic pressure of the fluid within the semi-permeable membrane gas-fluid interface (26) of the gas exchanger at approximately 1 % to 20 % higher than the gas partial pressure of the fluid within the gas exchanger. Gas-supersaturated fluid output from the gas exchanger via the capillary channels is at a flow velocity of greater than 0.05 m/sec, thereby facilitating delivery of large flow rates of gas-supersaturated fluids without cavitation inception.

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SYSTEM AND METHOD FOR DELIVERY OF GAS-SUPERSATURATED FLUIDSCross-Reference to Related Applications

This application is a continuation-in-part of co-  
5 pending application Serial No. 08/453,660, filed May 30,  
1995, which is a divisional of Serial No. 273,652, filed July  
12, 1994 (now U.S. Patent No. 5,569,180), which is a  
continuation-in-part of application Serial No. 152,589, filed  
November 15, 1993 (now U.S. Patent No. 5,407,426. Each of  
10 these disclosures is incorporated by reference herein.

FIELD OF THE INVENTION

The present invention generally relates to a system  
and method for delivering gas-supersaturated fluids. More  
15 specifically, the present invention relates to a system and  
method for delivering gas-supersaturated fluids to a gas-  
depleted site without the premature formation of bubbles.

BACKGROUND OF THE INVENTION

20 In many industrial and clinical environments, it is  
desirable to deliver a gas-enriched fluid to a site of  
interest, and/or increase the gas concentration of a fluid  
without a significant increase in the fluid volume.

For example, a fire may be extinguished by  
25 delivering an inflammable or an inert gas, such as carbon  
dioxide or nitrogen, rapidly to the fire via a fluid  
transporting medium. Environmental problems presented by  
toxic site cleanups may be ameliorated by delivering a high  
concentration of a neutralizing or cleansing gaseous agent to  
30 the toxic site. The oxygenation level of ponds used in fish  
farms, and the oxygenation level of waste streams (prior to  
their release into the environment) may also be increased by  
delivery of oxygen-enriched fluids to the ponds or streams.

One method of obtaining an increase in the gas  
35 concentration level without significant increase in fluid  
volume is by directly pumping a desired gas into a fluid site  
of interest. However, such direct pumping is not always

efficient and may thereby result in an insufficient increase in gas concentration. Where a noxious gas is used, direct pumping also poses waste engineering problems and/or health hazard due to the presence of any unabsorbed noxious gas.

5           Another method of obtaining an increase in the gas concentration level without significant increase in fluid volume is by infusing a gas-enriched fluid, such as a gas-supersaturated fluid, into the site of interest. To create a gas-supersaturated fluid, high pressure compression of a gas-  
10 liquid mixture can be performed, for example, with the use of a high pressure gas exchanger. Prior art systems for producing gas-supersaturated fluids typically require the use of a high pressure vessel to provide dwell time for dissolving gas nuclei in the fluid outputted from the high  
15 pressure gas exchanger. Two such prior art systems are U.S. Pat. No. 5,407,426, "Method and Apparatus For Delivering Oxygen Into Blood" to Spears and U.S. Pat. No. 5,569,180, "Method For Delivering A Gas-Supersaturated Fluid To A Gas-Depleted Site And Use Thereof" to Spears.

20           In addition, gas nuclei may be present in the fluid prior to supersaturating the fluid with gas. For example, gas nuclei may be dust particles suspended in the fluid or crevices in the container wall in which gas is trapped or absorbed. The presence of gas nuclei facilitates cavitation  
25 inception (or, bubble formation), resulting in release of gas from the liquid and thereby decreasing the gas concentration of the fluid.

          Furthermore, some prior art systems also require a high pressure (> 70 bar) fluid pump to deliver the gas-  
30 supersaturated fluid. Particularly in industrial applications (where it may be necessary to deliver large volumes of a gas-enriched fluid to a site of interest), such prior art systems may prove impractical because of the overall complexity, cost, and time associated with operating  
35 them.

          Another problem associated some of the prior art devices in infusing gas-supersaturated fluid from a high

pressure vessel into a site of interest is that cavitation inception at or near the exit ports often results. Cavitation inception may occur because ejection of the fluid into an atmospheric environment results in a decrease in the hydrostatic pressure of the fluid below the gas partial pressure. Disturbances at or near the exit ports may further facilitate cavitation inception. When cavitation takes place, gas is released from the fluid, decreasing its gas concentration. Furthermore, the presence of bubbles in the fluid generates turbulence and impedes the flow of the fluid beyond the exit ports.

Accordingly, there remains a need in the art for a simple, efficient and cost-effective system and method for producing and delivering gas-supersaturated fluid to a site of interest which does not require a high pressure vessel to provide dwell time and which does not require a high pressure fluid pump for delivery of the gas-supersaturated fluid. There remains a further need for a system and method for producing and delivering gas-supersaturated fluid to a site of interest without cavitation inception in the fluid during ejection, particularly at or near the exit ports.

#### SUMMARY OF THE INVENTION

Preferred embodiments of the present invention meet the foregoing needs by providing a system and method for delivering gas-enriched fluid to a site of interest. Such a system includes a fluid reservoir, a fluid pump, a gas source, a high pressure gas exchanger, and one or more arrays of capillary channels for delivery of gas-supersaturated fluid. Differential pressure gauges and other suitable controls may be provided to maintain a near constant hydrostatic pressure of the fluid throughout the delivery system that is approximately 1% to 20% higher than the gas pressure within the housing of the high pressure gas exchanger. The delivery system may also include a fluid filter for filtering the fluid before it enters the fluid reservoir.

The system and method of the present invention requires relatively low hydrostatic pressures and eliminates the need for a high pressure vessel for providing a dwell time for dissolving gas nuclei in the fluid. The system and  
5 method of the present invention also eliminates the need for a high pressure fluid pump for high output delivery of the gas-supersaturated fluid. Furthermore, the system and method of the present invention reduces or eliminates gas nuclei on the inner surface of the exit ports through which the gas-  
10 supersaturated fluid exits, in part by providing exit ports with a relatively small diameter.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a system for delivery of gas-  
15 supersaturated fluids according to a preferred embodiment.

FIG. 2 shows a system for delivery of gas-supersaturated fluids according to an alternative embodiment.

#### DETAILED DESCRIPTION OF THE INVENTION

20 The structure and function of the preferred embodiments can best be understood by reference to the drawings. The reader will note that the same reference numerals appear in multiple figures. Where this is the case, the numerals refer to the same or corresponding structure in those figures.

As shown in FIG. 1, delivery system 10 includes fluid reservoir 12, fluid pump 14, gas source 16, high pressure gas exchanger 18, delivery tube 36, and one or more  
30 arrays of capillary channels 20. High pressure gas exchanger 18 preferably includes an outer gas tight housing surrounding semi-permeable membrane gas-fluid interface 26, such as an oxygenator, which comprises a gas permeable and at least substantially fluid impervious container. Differential  
35 pressure gauge 22 is provided to measure the difference between the gas pressure in interior 40 and the hydrostatic pressure within gas-fluid interface 26. Differential

pressure gauge 22 and other suitable controls are provided to maintain a near constant hydrostatic pressure within gas-fluid interface 26 approximately 1% to 20%, higher than the gas pressure in interior 40 within housing 34 of high pressure gas exchanger 18. The higher hydrostatic pressure within gas-fluid interface 26 facilitates the dissolution of gas in the fluid in interior 40.

Delivery system 10 may also include a fluid filter 24 to filter fluid before it enters fluid reservoir 12. Fluid filter 24 is preferably a standard, commercially available filter such as porous sintered metal filters manufactured by Mott Metallurgical.

Fluid pump 14 pumps fluid from fluid reservoir 12 into gas-fluid interface 26 via input tube 28. As previously described, gas-fluid interface 26 is located within gas exchanger 18 surrounded by gas containing interior space 40. Gas-fluid interface 26 preferably incorporates silicone, such as silicone membranes or silicone tubules, as the gas exchanging media. Hollow microporous polypropylene tubes may also be used as a gas exchanging media. Where gas source 16 contains a corrosive gas such as ozone, gas-fluid interface 26 is made of corrosive resistant materials such as certain plastics, stainless steel, glass, Kevlar, silicone, silicone rubber or platinum, and gold plated soft metal seals may also be utilized.

Output 30 of gas-fluid interface 26 is coupled to output 32 of high pressure gas exchanger 18, which is in turn coupled to output tube 36. Fluid exits output tube 36 via capillary channels 20. Capillary channels 20 are preferably cylindrical, and have a relatively small diameter which helps to stabilize the gas supersaturated fluid upon ejection. Capillary channels 20 may also have slit-like, rectangular, square, triangular, and annular cross-sectional shapes. Where channels 20 have a circular cross-section, the inner diameter of each of capillary channels 20 is preferably within the approximate range of 25 to 300  $\mu\text{m}$ .

Using capillary channels with inner diameters of less than about 25  $\mu\text{m}$  is possible, but may require a large number of such channels to be used to compensate for the higher flow resistance. In addition, the use of capillary channels with  
5 inner diameters of less than about 25  $\mu\text{m}$  may also increase the likelihood that such channels will become blocked with particulates. On the other hand, the use of capillary channels with inner diameters larger than about 300  $\mu\text{m}$  may not effectively stabilize fluids supersaturated gases, such  
10 as oxygen, at high partial pressures.

Capillary channels 20 are preferably non-hydrophobic with a smooth inner surface. Although plastic channels (such as polyimide channels), and metal channels (such as stainless steel channels), can be used, glass or  
15 silica channels generally provide a smoother inner surface, are less expensive to obtain commercially, and large arrays of parallel glass or silica channels can be easily fabricated. Moreover, large numbers of parallel channels within glass plates may also be easily obtained commercially.  
20 Glass and silica provide the additional benefit of being chemically inert in many environments, and thus are less likely to react with the gas-supersaturated fluid. Glass and silica channels can also be cleaned with harsh solvents with little or no damage.

25 In operation, gas is delivered from gas source 16 to interior 40 of high pressure gas exchanger 18 via gas input tube 38. Preferably, gas within interior 40 of high pressure gas exchanger 18 is maintained at a pressure of approximately 8 to 50 bar. Differential pressure gauge 22  
30 and other suitable controls are provided to maintain a near constant hydrostatic pressure within gas-fluid interface 26 approximately 1% to 20% higher than gas pressure within interior 40 of high pressure gas exchanger 18. More preferably, the near constant hydrostatic pressure within  
35 gas-fluid interface 26 is approximately 9 to 51 bar, which is slightly higher than the gas pressure within interior 40 of high pressure gas exchanger 18.



One example of a suitable control is to adjust the rate of the fluid flow from fluid pump 14 into gas-fluid interface 26. Pressure differential gauge 22 may provide electrical signals to fluid pump 14 and/or to gas source 16 via electrical signals carrier 48. Thus, in response to the electrical signals, fluid flow rate from fluid pump 14 would be adjusted accordingly so as to achieve and maintain proper hydrostatic pressures within gas-fluid interface 26 and proper pressure differences between the hydrostatic pressure and the gas pressure within interior 40. Another example of a suitable control is to adjust the rate of the fluid flow from gas exchanger 18 to the site of interest by adjusting fluid valve 23 so as to achieve and maintain proper hydrostatic pressures within gas-fluid interface 26 and proper pressure differences between the hydrostatic pressure and the gas pressure within interior 40. Where a variable fluid flow rate from gas exchanger 18 to the site of interest is desired, differential pressure gauge 22 regulates the gas flow rate from gas source 16 and regulates a gas release valve (not shown) for selective release of gas from within gas exchanger 18 in order to vary the fluid flow rate from gas exchanger 18.

Because the peak hydrostatic pressure required for the fluid in delivery system 10 (i.e. fluid in input tube 28, gas-fluid interface 26, and delivery tube 36) is approximately 1% to 20% higher than the gas partial pressure, overt gas pockets in the gas-supersaturated fluid do not create active, bubble generating gas nuclei at the tube-liquid interface. Because the pressure differential prevents generation of active, bubble generating gas nuclei, the need for a dwell time for dissolving gas nuclei in the fluid and the corresponding need for a high pressure vessel to provide the dwell time are eliminated. Once fluid valve 23 is opened and a constant supply of fluid from fluid reservoir 12 is established, stabilized flow of gas-supersaturated liquid into a gas-depleted site of interest via output tube 36 and

capillary channels 20 can proceed continuously with minimum supervision.

Referring now to FIG. 2, delivery system 10 may be configured such that gas-deficient fluid pumped by fluid pump 5 14 can bypass high pressure gas exchanger 18 via bypass tube 42 and be delivered to capillary channels 20 via output tube 36, for initial flushing of capillary channels 20. Delivery system 10 may further provide valves 44, 46 which may be in an initial bypass position or an operational position.

10 During the initial flushing, valves 44, 46 are in the initial bypass position which allow fluid to flow from input tube 28 directly to output tube 36 via bypass tube 42 and prevent fluid from entering high pressure gas exchanger 18. After the initial flushing procedure, valves 44, 46 are in the

15 operational position which allow fluid to flow from input tube 28 to output tube 36 via high pressure gas exchanger 18 and prevent fluid from entering bypass tube 42.

This procedure of flushing capillary channels 20 facilitates elimination of surface nuclei within capillary

20 channels 20 because the surface gas nuclei can be relatively easily absorbed by the gas-deficient fluid and because the velocity of the fluid flow through channels 20 may result in flushing out the surface gas nuclei from channels 20. Thus, the initial flushing procedure may be used to facilitate high

25 volume delivery of gas-supersaturated fluid to the site of interest without cavitation inception despite a relatively low hydrostatic pressure of approximately 9 to 51 bar.

Delivery of gas-supersaturated fluid through capillary channels 20 at a high velocity provides an

30 additional mechanism for reducing or eliminating gas nuclei at the interface between the inner surface of capillary channels 20 and the gas-supersaturated fluid. Specifically, high velocity flow may reduce or eliminate gas nuclei at the channel-fluid interface due to a possible Venturi effect at

35 the channel-fluid interface. The high velocity flow and possible associated Venturi effect acts to flush gas nuclei from the inner surface of capillary channels 20 before the

gas nuclei can grow large enough to become active and cause trains of bubbles to form.

High velocity flow further inhibits bubble formation because there is insufficient time for nucleation and bubble growth in the fluid within capillary channels 20, before the fluid exits the capillary channels. After the gas-supersaturated fluid exits capillary channels 20, subcritical bubble nuclei, i.e. a bubble nuclei of size insufficient for bubble formation, are reabsorbed into the fluid and relatively rapid mixing of the fluid with liquids in the external environment occurs under ambient atmospheric pressure.

The velocity of fluid exiting capillary channels 20 is preferably greater than 0.05 m/sec, and more preferably in the range of 0.5 m/sec to 10 m/sec. As an example, a parallel array of 55 fused silica capillary channels 20 each having an inner diameter of about 150  $\mu$ m and a length of about 10 cm can be used to deliver 800 ml/min of water containing oxygen dissolved at a partial pressure of 20.5 bar, at a hydrostatic pressure of 22.5 bar. The mean flow velocity of the oxygen-supersaturated water through each channel 20 would be approximately 13 m/sec.

Applications for preferred embodiments include many different gas-liquid combinations, which may be a mixture of a plurality of gases and/or liquids.

For example, system 10 may be used for relatively quick and inexpensive large scale delivery of oxygen-supersaturated water into fluid requiring aeration, such as potable water, municipal water, wastewater, water in bioreactors, fisheries, ponds, lakes, streams, wells, swimming pools, baths and hot tubs. Oxygenation of such bodies of water using oxygen supersaturated liquid generated by system 10 would be more rapid than aeration by directly pumping gas into the site of interest, and allows precise control of the final oxygen concentration in the site of interest.

In addition, relatively high oxygen concentrations, for example, 10 mg/L or greater, can be achieved in the external environment because the preferred embodiments provide a gas transfer efficiency of nearly 100%; thus, almost all of the dissolved gas delivered is absorbed by the oxygen-deficient body of water. As a result, a relatively smaller volume of oxygen-supersaturated water is required to adequately aerate an oxygen-deficient body of water. For example, the volume of water super-saturated with oxygen at 21 bar partial pressure necessary to adequately aerate wastewater would be a small fraction of the volume of the wastewater, depending on the B.O.D. (biologic oxygen demand) level. Furthermore, for treatment of many types of large bodies of gas-deficient fluids, a small portion of the fluid, after filtration, can be used as the fluid source for preparation of the gas-supersaturated fluid to be recycled back into the large body of fluid. Thus, by utilizing gas-deficient fluid from the body of fluid to be aerated as a fluid source, the volume of body of fluid is not increased.

Hyperbaric gas concentration levels are achievable in the external body of fluid to be aerated. If the mean velocity of the effluent is relatively low, for example less than 5 m/sec, and the volume of fluid in the external body of fluid is small relative to the effluent volume flow rate per minute, for example ratios of 10:1, resulting in a turnover of gas-supersaturated water approximately every 10 minutes, a hyperbaric gas level can be achieved and maintained in the external body of fluid.

When such an approach is utilized to deliver an oxygen-supersaturated effluent to an external body of fluid, an oxygen bath is thereby provided where the  $pO_2$  in the external body of fluid is in the range of at least approximately 5-10 bar. Such an oxygen bath may be utilized for neonates and infants with respiratory insufficiency to increase the oxygen levels in the general circulation. Both the higher permeability of human neonatal skin relative to that of adults and the relatively high ratio of the neonatal

body surface area to the neonatal body volume facilitate the transport of oxygen from the oxygen bath across the skin into the general circulation. For older individuals, the high oxygen level in an oxygen bath may also be utilized to  
5 enhance healing of superficial wounds, such as burns, and to enhance collagen synthesis of otherwise normal, but relatively oxygen-poor skin.

Another application of preferred embodiments is the infusion of ozone-supersaturated fluid into various types of  
10 fluids. The ozone may be generated, for example, within gas source 16 or within housing 34 of high pressure gas exchanger 18 by utilizing high voltage arcs. Ozone-supersaturated fluid infusion can be used for disinfection, flocculation, oxidation of dissolved metals, odor control, and oxidation of  
15 organic material.

For example, when system 10 is used for the delivery of an effluent supersaturated with a non-toxic gas into, for example, wastewater, microorganisms and other organic matters may grow and accumulate on gas-fluid  
20 interface 26 over time, thereby reducing its gas transfer efficiency. To alleviate or eliminate such growth and accumulation, system 10 may also be used for the periodic and temporary delivery of ozone-enriched or ozone-supersaturated fluid. The ozone would kill the microorganisms and oxidize  
25 the organic materials, which would then be more easily flushed from gas-fluid interface 26. In addition or alternatively, a suitable solvent such as alcohol, acetone, or a strong acid or base may be flushed through gas exchanger 18 to clean gas-fluid interface 26 of microorganisms and  
30 organic matter. Thus, the periodic and temporary delivery of effluent containing ozone and/or a suitable solvent would sterilize and disinfect system 10 of organic elements as well as to flush out any accumulated debris. Furthermore, because of the relatively high solubility of ozone in water, a high  
35 ozone concentration can be achieved at partial pressures of only approximately 3 to 10 bar.

A concern with infusing ozone-supersaturated fluid into a site of interest is that the half-life of ozone in ordinary tapwater is generally in the range of 10 to 20 minutes. Thus, because of the half-life of ozone, rapid  
5 delivery of ozone-supersaturated fluid is desirable. By using system 10, ozone-supersaturated water from high pressure gas exchanger 18 can be delivered at high velocities via capillary channels 20 within a few seconds, resulting in very little loss of activity of the dissolved ozone. And  
10 because the ozone delivered remains dissolved (that is, it does not bubble out of fluid) there is less concern that ozone will enter the atmosphere. As a result, the ozone-supersaturated water can be used to treat open bodies of water, such as reservoirs, lakes, ponds, streams, rivers,  
15 swimming pools, as well as groundwater, well water, and water within closed chambers.

Bioreactors often use carbon monoxide as a carbon source for synthesis of organic compounds by anaerobic bacteria. Because carbon monoxide has a low solubility in  
20 water and consumption of the gas by the anaerobic bacteria can be relatively high, it may be difficult to maintain a sufficient carbon monoxide supply in a bioreactor. An infusion of carbon monoxide-supersaturated water generated by system 10 could be used to provide an efficient and  
25 controlled means for increasing the level of carbon monoxide in a bioreactor. Other gases, such as nitrogen sources, may be useful for the growth of other types of organisms.

To extinguish a fire, it may be desirable to deliver a fluid supersaturated with an inert gas, such as  
30 nitrogen or carbon dioxide, rapidly to the fire without premature liberation of the inert gas from its dissolved state in the fluid. Upon high velocity delivery of fluid supersaturated with an inert gas, a fire can be extinguished with greater efficiency than with the use of water alone  
35 because of the displacement of oxygen in the air with the inert gas, cooling of the fluid during gas expansion, and the dispersion of the fluid upon gas expansion.

Liquids other than water may also be used in system 10 to deliver a high concentration of a gas or a mixture gases to a site of interest. For example, many liquid fuels, such as diesel fuel, gasoline, kerosene and alcohols, may 5 burn more efficiently with a high oxygen concentration. System 10 may be utilized to eject the fluid into a combustion chamber, such as the cylinders of an engine. The high solubility of oxygen in most fuels, such as gasoline and diesel fuel, results in a high oxygen concentration at 10 relatively low partial pressures. In addition to greater combustion efficiency provided by a high concentration of oxygen, the improved oxidation of the fuel could reduce some toxic gaseous byproducts associated with incomplete combustion.

15 Another application of the system of the present invention is snow making by ejecting water supersaturated with air into air having an ambient temperature slightly higher than 0°C. When the air-supersaturated water exits capillary channels 20 into the atmospheric environment, there is a drop in hydrostatic pressure of the water which results in a rapid expansion of the gas. Because the rapid expansion of the gas lowers the temperature of the fluid, freezing of water droplets can occur despite an air temperature higher than 0°C.

25 In contrast, typical prior art snowmaking equipment uses large fans to propel water from a hose into air that is at or below 0°C. With the prior art equipment, small water droplets and ice crystals form and are propelled into the air by the force of the fans. However, because an intact stream 30 of water can relatively easily be propelled further than water droplets and ice crystals can be propelled with the force of the fans, the prior art snowmaking equipment does not achieve as great a maximum distance as the system of the present invention. With the system of the present invention, 35 the air-supersaturated water fluid can remain as an intact stream for sufficiently long periods because of the high flow velocity of the fluid. Due to gas bubbles nucleating from

the fluid and normal hydrodynamic forces, such as Rayleigh instability, the fluid fragments in the air and form water droplets, fragments, and/or bubbles. The associated drop in temperature from expansion of the dissolved gas then freezes  
5 the water to produce artificial snow.

The present invention has been described in terms of preferred embodiments. The invention, however, is not limited to the embodiment depicted and described. Rather, the scope of the invention is defined by the appended claims.  
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What is claimed is:

1. A system for delivering gas-enriched fluid, comprising:
  - a source of gas under pressure;
  - 5 a source of fluid under pressure;
  - a gas exchanger in gaseous communication with the gas source and in fluid communication with the fluid source;
  - a pressure control for controlling pressures within the gas exchanger such that hydrostatic pressure of the fluid
  - 10 within the gas exchanger is 1% to 20% greater than gas partial pressure of the fluid within the gas exchanger; and
  - one or more channels in fluid communication with the gas exchanger capable of delivering gas-enriched fluid from the gas exchanger without cavitation inception.
- 15 2. The system according to claim 1, further comprising a fluid pump for delivering the fluid from the fluid source to the gas exchanger.
- 20 3. The system according to claim 1, further comprising a fluid filter for filtering fluid prior to the fluid entering the gas exchanger.
4. The system according to claim 1, wherein said
- 25 source of gas comprises a metastable gas generator.
5. The system according to claim 4 wherein said metastable gas generator generates ozone.
- 30 6. The system according to claim 1, wherein the gas exchanger comprises a gas-fluid interface for containing fluid and a housing enclosing the gas-fluid interface and gas inside the gas exchanger.
- 35 7. The system according to claim 6, wherein the gas-fluid interface is at least partially made of silicone.

8. The system according to claim 6 wherein the gas-fluid interface is made of corrosion resistant materials.

9. The system according to claim 1, wherein the pressure control comprises one or more pressure differential gauges wherein at least one pressure differential gauge is in fluid and gaseous communication with the gas exchanger.

10. The system according to claim 9, further comprising a fluid pump for delivering the fluid from the fluid source to the gas exchanger, wherein the pressure differential gauge provides a first electrical signal to the fluid pump and wherein the fluid pump delivers the fluid at a fluid delivery rate in response to said first electrical signal.

11. The system according to claim 9, wherein the pressure differential gauge provides a second electrical signal to the gas source and wherein the gas source delivers the gas at a delivery rate in response to said second electrical signal.

12. The system according to claim 9, wherein the pressure control further comprises one or more valves in fluid communication with the one or more channels.

13. The system according to claim 9, the gas exchanger containing gas-enriched fluid at a hydrostatic pressure 1% to 20% greater than the gas partial of said fluid in said exchanger.

14. The system according to claim 13, wherein inner diameters of the output channels are in the range of 25 to 300  $\mu\text{m}$ .

15. The system according to claim 1, wherein one or more of the channels is made of a material selected from a

group consisting of silica, glass, metal, polymer and ceramic.

16. The system according to claim 1, wherein the  
5 fluid source is in fluid communication with the one or more channels such that fluid may flow from the fluid source to the one or more channels.

17. The system according to claim 1, wherein the  
10 gas-enriched fluid flow rate through the channels from the gas exchanger is greater than 0.05 m/sec.

18. The system according to claim 1, wherein the  
pressure control is capable of controlling the pressures  
15 within the gas exchanger such that the hydrostatic pressure of the fluid within the gas exchanger is 5% to 10% greater than gas partial pressure of the fluid within the gas exchanger

20 19. A system for delivering gas-enriched fluid to a delivery site, comprising:

a gas-enriched fluid generator comprising a gas port, a fluid inlet port, and a fluid outlet port; and

a fluid transport for transporting fluid from the  
25 generator to the delivery site, comprising a first end and a second end, wherein the first end is connected to the fluid outlet port and the second end is disposed at the delivery site,

wherein the fluid transport comprises a plurality  
30 of channels at the second end, wherein the fluid flows through said channels at a flow rate greater than 0.05 m/sec, and wherein the fluid transport is capable of delivering the gas-enriched fluid from said generator to the delivery site without cavitation inception.

35

20. The system according to claim 19, wherein the gas port of the gas-enriched fluid generator is in gaseous communication with a pressurized gas source.

5           21. The system according to claim 19 wherein said source of gas comprises a metastable gas generator.

22. The system according to claim 19, wherein the fluid inlet port of the gas-enriched fluid generator is in  
10 fluid communication with a pressurized fluid source.

23. The system according to claim 22, wherein the fluid transport is in fluid communication with the fluid source such that fluid may flow from the fluid source to the  
15 fluid transport.

24. The system according to claim 19, wherein the gas-enriched fluid generator further comprises pressure control for controlling pressures within the gas exchanger  
20 such that pressure of the fluid within the gas exchanger is 1% to 20% greater than gas partial pressure of the fluid within the gas exchanger.

25. The system according to claim 24, wherein the  
25 pressure control comprises one or more pressure differential gauges wherein at least one pressure differential gauge is in fluid and gaseous communication with the gas-enriched fluid generator.

30           26. The system according to claim 24, wherein the pressure control comprises one or more valves in fluid communication with the fluid transport.

27. A method for delivering gas-enriched fluid to  
35 an environment, comprising the steps of:

delivering fluid under pressure from a fluid source to a gas exchanger at a fluid flow rate;

delivering gas under pressure from a gas source to the gas exchanger at a gas flow rate;

controlling pressures of the fluid and gas inside the gas exchanger such that hydrostatic pressure of the fluid  
5 within the gas exchanger is 1% to 20% greater than pressure of the gas within the gas exchanger; and

delivering gas-enriched fluid from the gas exchanger through one or more channels in fluid communication with the gas exchanger without cavitation inception.

10

28. The method according to claim 27, further comprising the step of filtering the fluid prior to the step of delivering the fluid to the gas exchanger.

15

29. The method according to claim 27, wherein the step of delivering fluid under pressure comprises the step of providing a fluid pump for delivering the fluid from the fluid source to the gas exchanger.

20

30. The method according to claim 29, wherein the controlling step comprises the steps of:

providing one or more pressure differential gauges in fluid and gaseous communication with the gas exchanger;

providing an electrical signal from the pressure  
25 differential gauges to the fluid pump; and

adjusting the fluid flow rate from the fluid pump to the gas exchanger in response to said electrical signal so as to achieve and maintain hydrostatic pressures within the gas exchanger at 1% to 20% greater than pressure of the gas  
30 within the gas exchanger.

31. The method according to claim 29, wherein the controlling step comprises the steps of:

providing one or more pressure differential gauges  
35 in fluid and gaseous communication with the gas exchanger;

providing an electrical signal from the pressure differential gauges to the gas source; and

adjusting the gas flow rate from the gas source to the gas exchanger in response to said electrical signal so as to achieve and maintain hydrostatic pressures within the gas exchanger at 1% to 20% greater than pressure of the gas  
5 within the gas exchanger.

32. The method according to claim 27, wherein said channels are cylindrical with inner diameters in the range of 25 to 300  $\mu\text{m}$ .

10

33. The method according to claim 27, further comprising the step of delivering fluid from the fluid source through the channels prior to delivering the gas-enriched fluid from the gas exchanger.

15

34. The method according to claim 27, wherein the step of delivering gas-enriched fluid from the gas exchanger through the channels is at a fluid flow velocity of greater than 0.05 m/sec.

20

35. The method according to claim 27, wherein the gas is an inert gas.

36. The method according to claim 27, wherein the  
25 gas is selected from a group consisting of ozone, oxygen, air, chlorine, nitrogen, carbon dioxide and carbon monoxide.

37. The method according to claim 27, wherein the environment is selected from a group consisting of fire,  
30 potable water, bioreactor, wastewater, fishery, lake, pond, stream, well, swimming pool, bath, hot tub or municipal water.

38. The method according to claim 27, wherein the  
35 environment is ambient air at a temperature near 0°C and wherein the step of delivery gas-enriched fluid from the gas exchanger through the channels produces snow and/or ice.

39. A system for delivery gas-enriched fluid,  
comprising:

a gas source;  
a fluid source;  
5 a gas exchanger communicating with said  
sources in which the gas and fluid are combined under  
pressure to provide a gas-enriched fluid having a desired gas  
partial pressure, said gas exchanger containing said gas-  
enriched fluid at a hydrostatic pressure between about 1% to  
10 20% greater than said gas partial pressure.

40. The system according to claim 39, wherein:  
said gas exchanger comprises,

gas tight housing defining interior space;  
15 gas permeable and at least substantially fluid  
impervious container disposed within said housing;  
fluid inlet passage leading through said  
interior space to provide fluid into said container;  
gas inlet passage leading into said interior  
20 space to provide gas under pressure in said space and  
surrounding said container;  
gas-enriched fluid outlet leading from said  
container and out of said housing for delivering gas-enriched  
fluid; and  
25 said system further comprising pressure  
detecting and control means communicating with said fluid  
inlet and said gas inlet to maintain said hydrostatic  
pressure.

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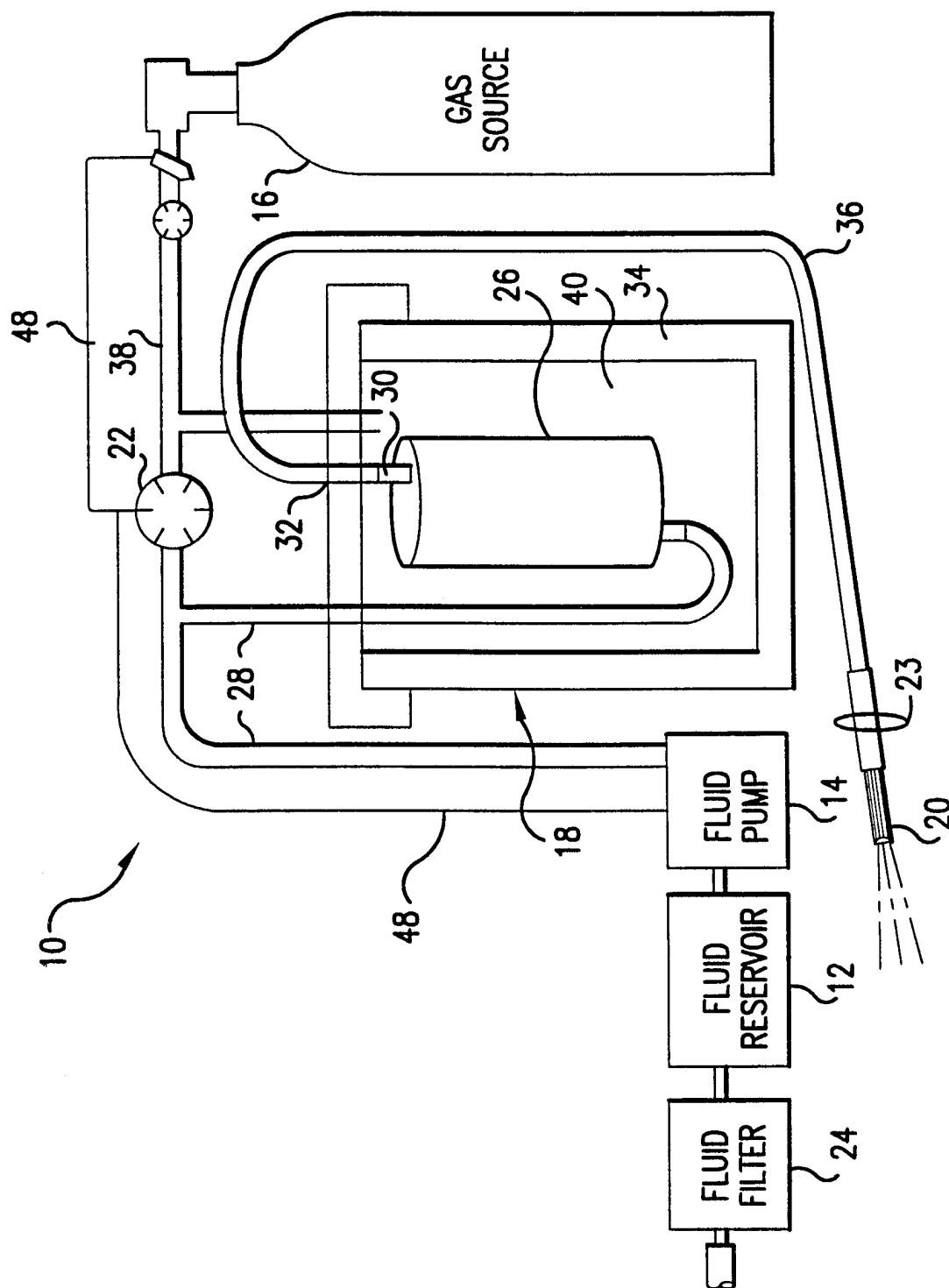
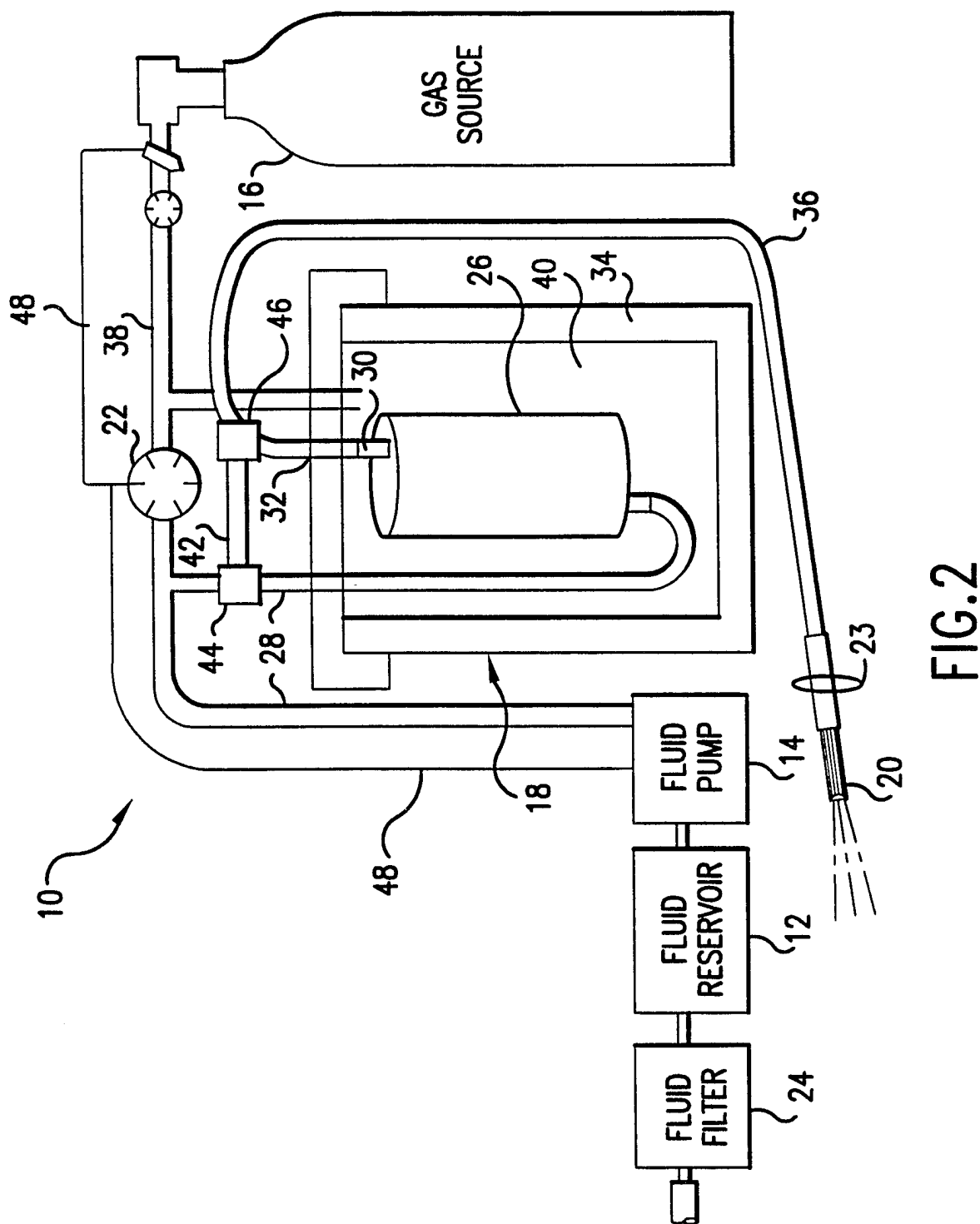


FIG.1







# INTERNATIONAL SEARCH REPORT

Inter. Patent Application No

PCT/US 98/07671

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 442 843 A (RASOR JULIA S ET AL) 17 April 1984 ----	1-40
A	US 5 599 296 A (SPEARS JAMES R) 4 February 1997 ----	1-40
A	US 4 681 119 A (RASOR JULIA S ET AL) 21 July 1987 ----	1-40
A	US 4 657 756 A (RASOR JULIA S ET AL) 14 April 1987 ----	1-40
P,A, L	US 5 693 017 A (SPEARS JAMES RICHARD ET AL) 2 December 1997 -----	1-40

# INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No

PCT/US 98/07671

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5569180 A	29-10-1996	US 5407426 A	18-04-1995
		US 5261875 A	16-11-1993
		US 5086620 A	11-02-1992
		AU 685651 B	22-01-1998
		AU 2948695 A	09-02-1996
		CA 2194961 A	25-01-1996
		EP 0767632 A	16-04-1997
		JP 10507400 T	21-07-1998
		WO 9601593 A	25-01-1996
		US 5599296 A	04-02-1997
		US 5735934 A	07-04-1998
		US 5797874 A	25-08-1998
		US 5693017 A	02-12-1997
		AU 1090595 A	06-06-1995
		CA 2176601 A	26-05-1995
		EP 0729369 A	04-09-1996
		JP 9509072 T	16-09-1997
		WO 9513843 A	26-05-1995
		US 5730935 A	24-03-1998
		AU 1416192 A	15-09-1992
		WO 9214404 A	03-09-1992
		AU 1368192 A	15-09-1992
		DE 69119610 D	20-06-1996
		DE 69119610 T	19-09-1996
		EP 0571513 A	01-12-1993
		JP 6509016 T	13-10-1994
		WO 9214976 A	03-09-1992
US 5407426 A	18-04-1995	US 5261875 A	16-11-1993
		US 5086620 A	11-02-1992
		AU 1090595 A	06-06-1995
		CA 2176601 A	26-05-1995
		EP 0729369 A	04-09-1996
		JP 9509072 T	16-09-1997
		WO 9513843 A	26-05-1995
		US 5569180 A	29-10-1996
		US 5599296 A	04-02-1997
		US 5735934 A	07-04-1998
		US 5797874 A	25-08-1998
		US 5693017 A	02-12-1997

# INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No

PCT/US 98/07671

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5407426 A		US 5730935 A AU 1416192 A WO 9214404 A AU 1368192 A DE 69119610 D DE 69119610 T EP 0571513 A JP 6509016 T WO 9214976 A	24-03-1998 15-09-1992 03-09-1992 15-09-1992 20-06-1996 19-09-1996 01-12-1993 13-10-1994 03-09-1992
DE 4105726 C	17-09-1992	NONE	
FR 2320908 A	11-03-1977	DE 2535837 A AT 348952 B AT 596076 A BE 845103 A CH 616393 A GB 1531810 A JP 52022369 A NL 7608888 A SE 420826 B SE 7608981 A US 4071443 A	17-02-1977 12-03-1979 15-07-1978 14-02-1977 31-03-1980 08-11-1978 19-02-1977 15-02-1977 02-11-1981 13-02-1977 31-01-1978
US 4664680 A	12-05-1987	CA 1299778 A DK 174487 A, B, EP 0244954 A JP 62277130 A	28-04-1992 08-10-1987 11-11-1987 02-12-1987
US 4442843 A	17-04-1984	AU 565842 B AU 4127485 A AU 545866 B AU 7931382 A CA 1170569 A EP 0052575 A WO 8201642 A US 4657756 A US 4681119 A	01-10-1987 19-09-1985 01-08-1985 07-06-1982 10-07-1984 26-05-1982 27-05-1982 14-04-1987 21-07-1987
US 5599296 A	04-02-1997	US 5569180 A	29-10-1996

# INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No

PCT/US 98/07671

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5599296 A		US 5407426 A	18-04-1995
		US 5261875 A	16-11-1993
		US 5086620 A	11-02-1992
		AU 4418196 A	26-06-1996
		CA 2207410 A	13-06-1996
		WO 9617565 A	13-06-1996
		US 5797874 A	25-08-1998
		US 5693017 A	02-12-1997
		US 5730935 A	24-03-1998
		AU 685651 B	22-01-1998
		AU 2948695 A	09-02-1996
		CA 2194961 A	25-01-1996
		EP 0767632 A	16-04-1997
		JP 10507400 T	21-07-1998
		WO 9601593 A	25-01-1996
		US 5735934 A	07-04-1998
		AU 1090595 A	06-06-1995
		CA 2176601 A	26-05-1995
		EP 0729369 A	04-09-1996
		JP 9509072 T	16-09-1997
		WO 9513843 A	26-05-1995
		AU 1416192 A	15-09-1992
		WO 9214404 A	03-09-1992
		AU 1368192 A	15-09-1992
		DE 69119610 D	20-06-1996
		DE 69119610 T	19-09-1996
		EP 0571513 A	01-12-1993
		JP 6509016 T	13-10-1994
		WO 9214976 A	03-09-1992
US 4681119 A	21-07-1987	AU 565842 B	01-10-1987
		AU 4127485 A	19-09-1985
		AU 545866 B	01-08-1985
		AU 7931382 A	07-06-1982
		CA 1170569 A	10-07-1984
		EP 0052575 A	26-05-1982
		WO 8201642 A	27-05-1982
		US 4442843 A	17-04-1984
		US 4657756 A	14-04-1987

# INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No

PCT/US 98/07671

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4657756 A	14-04-1987	AU 565842 B	01-10-1987
		AU 4127485 A	19-09-1985
		AU 545866 B	01-08-1985
		AU 7931382 A	07-06-1982
		CA 1170569 A	10-07-1984
		EP 0052575 A	26-05-1982
		WO 8201642 A	27-05-1982
		US 4442843 A	17-04-1984
		US 4681119 A	21-07-1987
US 5693017 A	02-12-1997	US 5599296 A	04-02-1997
		US 5569180 A	29-10-1996
		US 5407426 A	18-04-1995
		US 5261875 A	16-11-1993
		US 5086620 A	11-02-1992
		AU 6027096 A	30-12-1996
		EP 0836495 A	22-04-1998
		WO 9640334 A	19-12-1996
		AU 4418196 A	26-06-1996
		CA 2207410 A	13-06-1996
		WO 9617565 A	13-06-1996
		US 5797874 A	25-08-1998
		US 5730935 A	24-03-1998
		AU 685651 B	22-01-1998
		AU 2948695 A	09-02-1996
		CA 2194961 A	25-01-1996
		EP 0767632 A	16-04-1997
		JP 10507400 T	21-07-1998
		WO 9601593 A	25-01-1996
		US 5735934 A	07-04-1998
		AU 1090595 A	06-06-1995
		CA 2176601 A	26-05-1995
		EP 0729369 A	04-09-1996
		JP 9509072 T	16-09-1997
		WO 9513843 A	26-05-1995
		AU 1416192 A	15-09-1992
		WO 9214404 A	03-09-1992
		AU 1368192 A	15-09-1992
		DE 69119610 D	20-06-1996
		DE 69119610 T	19-09-1996

## INTERNATIONAL SEARCH REPORT

**information on patent family members**

International Application No.

PCT/US 98/07671

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5693017 A		EP 0571513 A	01-12-1993
		JP 6509016 T	13-10-1994
		WO 9214976 A	03-09-1992
<hr/>			