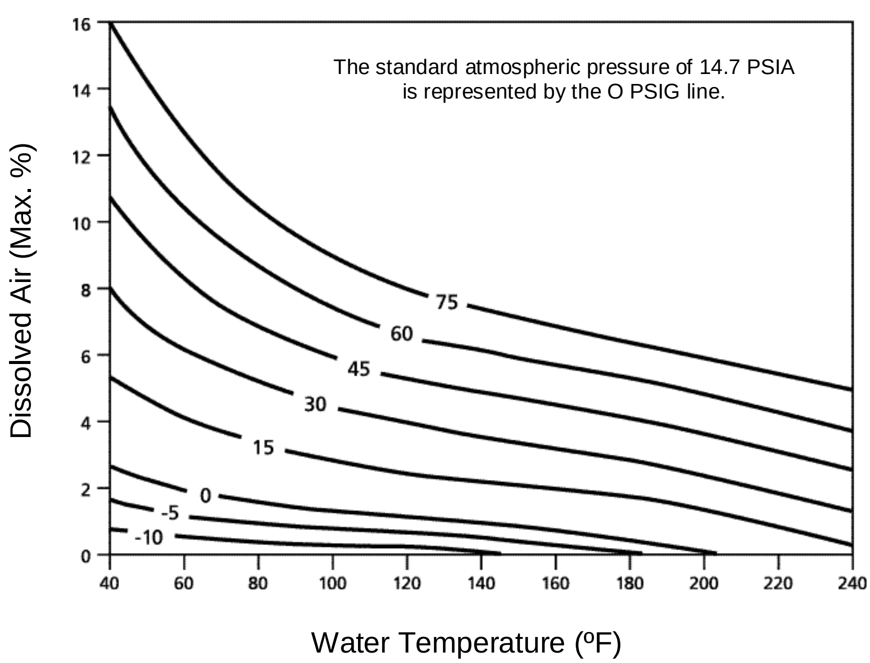
Gasses in Hydronic Systems

Air is present in system fluid in a variety of forms. The large visible air bubbles, or free air, that cannot escape from the system collect and create problems in curved piping, dead end risers, controlled zones, radiators, and radiant floor areas. Entrained air is present as tiny microbubbles that travel at the same speed as the water and are transported by the flow of the liquid. They can remain in the system as microbubbles or combine and become larger. Dissolved or absorbed air is always present in water to some degree, because water (H_2O) is part oxygen.

The solubility of gas in liquid depends on temperature and pressure. Figure B-1 shows the amount of air the water will absorb as a function of pressure and temperature. Note that as the water temperature increases, the percentage of dissolved air by volume decreases. For example, at atmospheric pressure (14.7 PSI) and 50°F, water will contain 2.3% air by volume under standard conditions. Once the water is heated to 195°F (without a change in pressure), however, it can only hold 0.3% air by volume. This means that during a temperature increase of 145°F, 100 gallons of water (comparable to a fresh-filled installation that is heated for the first time) will release 2 gallons of absorbed air.

Figure B-1

Solubility of Air in Water
As a function of temperature and pressure



The percentage of dissolved air by volume will also decrease along with a decrease in system pressure. For example, at 75 PSIG (comparable to the static pressure of a 170 foot high building) and a temperature of 50°F, water contains

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14% air. When the water drops to atmospheric pressure (14.7 PSI), the percentage of air drops to 2.3%. That means that 100 gallons of water under the same conditions would release 11.7 gallons of dissolved air.

The composition and the origin of absorbed gasses vary widely. System water can contain carbon dioxide and atmospheric gasses such as nitrogen and oxygen. Hydrogen and methane can be present as a result of microbiological growth, electrolysis and chemical reactions.

Corrosion is the result of the chemical reaction between iron and oxygen as shown below:

$$Fe + 2H_2O > Fe(OH)_2 + H_2$$

$$3Fe(OH)_2 > Fe_3O_4 + H_2 + 2H_2O$$

As a result, the magnetite FE_3O_4 is formed. This magnetite, with the lasting presence of oxygen, will then be transformed to hematite, $FE_2O_{3,}$ as described in the next equation.

$$Fe_3O_4 + O_2 > 6Fe_2O_3$$

Chemical reactions between system water and system metal, and electrolysis between dissimilar metals are not the only sources of absorbed gasses.

More common sources of air and system gasses include:

- Air diffusion through non-metallic tubing
- Undersized expansion tanks (which cause relief valves to pop and feed valves to feed)
- System fills or refills after repairs
- Seasonal draining of old style steel compression tanks
- Low or negative system pressure at top floors
- Bad plumbing joints and improper seals
- Improperly installed circulators

No hydronic system is completely airtight. Even a manually vented system cannot eliminate dissolved air. As the system operates, water constantly evaporates through valve stem packing, gaskets, mechanical seals, tiny fissures in the pipes and fittings, and dozens of other places. These leaks may go undetected, however, the build-up of mineral deposits on valve stems and gaskets proves that leaks are present. That white crust is evidence left behind by evaporating system water. During maintenance or repair, system water is unavoidably lost. And when water leaves a hydronic system, it must be made up with fresh feed water. Fresh water means more air, and more air means more problems. It is an endless cycle.

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The symptoms of air in the system are easily recognizable:

Annoying noises	The free and entrained gasses in the system cause annoying “pinging” and “waterfall” sounds. Noises can also be caused by falling water in terminal units filled with air pockets.
Reduced pump head, water flow & heat transfer	The water/air mixture in the circulator becomes a compressible fluid with a lower specific density, causing pump head to drop dramatically. This, in turn, decreases the flow rate and disturbs the proper flow distribution over the zones. The lower flow rate causes heat sinks and reduced heat transfer in the heat source.
“Insufficient heat” callbacks	Reduced heat-transfer capabilities result in “insufficient heat” callbacks and labor-intensive manual bleeding to remove air.
Boiler corrosion damage	Caused by the presence of oxygen in air, which is dissolved in water. It may come from water intake, electrolysis, or diffusion and could lead to eventual failure.
Circulator cavitation	Considered one of the most deteriorating forces to circulators and pumps. Vapor-filled bubbles develop when local water pressure is brought below the prevailing vapor pressure.
Premature pump, heat exchanger and component failure	Large pockets of air, condensation and erosion in the system water destroy pump components and cause pump and heat exchanger failure.
Increased maintenance costs	Service calls, manual bleeding, replacement costs of parts, pumps and heat exchangers all contribute to increased maintenance costs.

Elimination of Air

Henry’s Law analyzes the amount of gas that can be absorbed by a liquid, illustrated by the following formula:

$$C = k(T) \times p$$

Where: C = the maximum amount of a specific gas that can be absorbed
k(T) = the absorption coefficient dependent on temperature
p = the partial pressure of the gas

The absorption coefficient depends on the fluid/gas combination. Water keeps a certain amount of gas in solution given a certain temperature and pressure. If the temperature or pressure changes, the maximum absorbed amount of gas, the saturation degree, will adapt to the change. Water loses its ability to hold gasses in solution when the temperature increases and/or the pressure drops.

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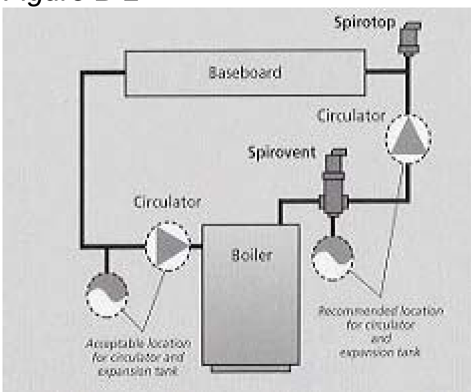
When the temperature decreases and/or the pressure rises, the reverse takes place and water is capable once again of absorbing gasses.

Figure B-2



Hot-Water Installation

In a hydronic heating installation, the highest water temperature is found at the walls of the heat source. Here absorbed gasses are freed in the form of microbubbles when the hot water meets the much cooler adjacent fluid, evidenced by a singing, grumbling or "boiling water" sound. A portion of these new microbubbles will become entrained in the flow and taken into the supply circulation, and the rest will stay behind as stationary or free air bubbles in the boiler, piping, terminal units, and circulator.

A properly placed Spirovent® air eliminator installed at the point of lowest solubility (see Figure B-2); that being directly after the boiler (highest temperature) and before the circulator (lowest pressure), will eliminate air most effectively based on the principles of Henry's Law. However, in instances where high static pressure is present in the system, as is the case with high-rise buildings, directly after the boiler near ground level may not be the optimum location for any air separator.

With the aid of Henry's Law, it is understood that dissolved air will stay dissolved in high static pressure situations despite a temperature increase in the boiler. As water leaves the boiler and begins its upward flow into the building, it will contain dissolved air that is incapable of being separated because of the high static pressure. As it flows upward, however, the static pressure gradually diminishes while the temperature remains unchanged. Thus, the water becomes less absorptive and changes from under-saturated to over-saturated. Now the air can no longer be held in solution and will appear in the form of microbubbles. The microbubbles grow in number as well as size until the highest floor is reached, where the piping subsequently branches to all remaining circuits. In the terminal units, the water exchanges its energy, resulting in a lower water temperature. It is here where all bubbles are ready to be re-absorbed again, intensified by the increasing pressure build-up during the return of the flow down to the boiler. This is the point of lowest solubility, and thus, the ideal location for the air separator in this type of application.

Air elimination is as important in a chilled-water system as it is in a hot–water system. A quick look at the solubility chart (Figure B-1) will illustrate that cold water holds more air than hot. Add system pressure, and the percentage increases. Without an air separator, the constant air/water mixture being pumped can decrease heat transfer capabilities dramatically because air inhibits heat transfer. Pump couplers can snap from the accelerating and braking forces of system air and water. Air can rush into a chilled-water pump and cause it to

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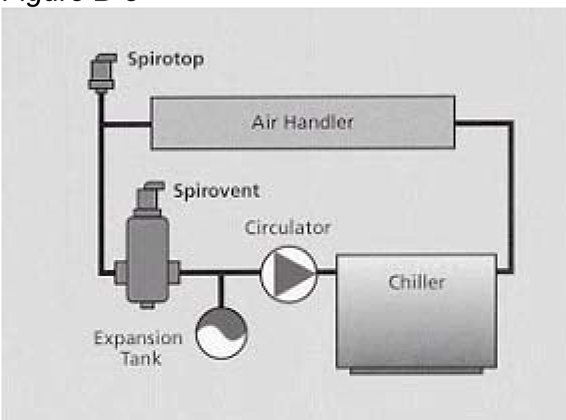
speed up. Water follows the air and creates a breaking force that can seriously damage a pump and its components.

In systems using glycol, released system air and the difference in viscosity create a foam that reduces heat transfer and cuts efficiency dramatically while increasing costs. A Spirovent coalescing separator will eliminate the air that creates the foam. In a chilled water system, however, the Spirovent should be mounted in the main return piping before the chiller on the inlet side of the circulator (refer to Figure B-3).

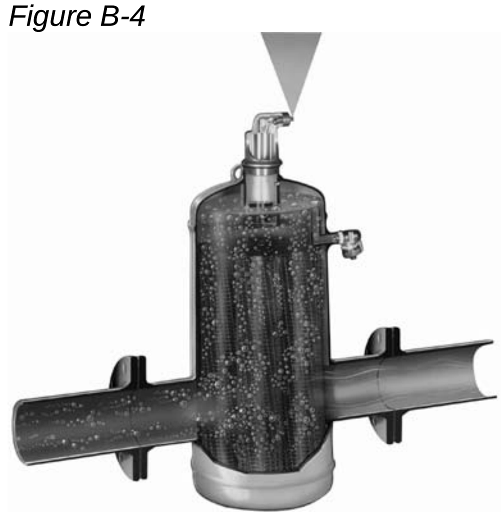
Figure B-3



Chilled-Water Installation

In a standard hydronic heating installation, the Spirovent works as follows. During heat or high temperature demands, system water leaves the boiler and enters the Spirovent. The Spirovent's enlarged straight in-line flow passage has been engineered to create a momentary drop in water velocity. The drop in velocity promotes the release of microbubbles from the system fluid, while the patented coalescing medium inside the Spirovent gives the bubbles something to collide into and adhere to. The trapped bubbles quickly rise and are vented from the system via a full-port integral automatic valve while the air-free water flows out of the other side of the Spirovent (see Figure B-4). This process continues on each pass, resulting in unparalleled efficiency.

Figure B-4



Spirovent Coalescing-type Air Eliminator

During the off-cycle or low temperature demand, the circulating water will begin to absorb gasses again as it cools down. As the water becomes more absorptive, the sizes of the trapped air pockets are reduced as the water dissolves the trapped air. This absorption process continues until the water reaches its saturation point for the present temperature and pressure.

As soon as heat is in demand again and the temperature of the system water rises, the saturated water releases the microbubbles that had originated from the trapped air pockets. Once released, these microbubbles are caught and eliminated from the system by the Spirovent air eliminator. This process continues until all of the gasses have been released and free gasses have disappeared.

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The process of absorption and release never ends. It is the reason why many "scoop" and centrifugal-type separators cannot achieve the efficiency of the Spirovent coalescing separator. Their designs do not allow them to separate microbubbles from the water flow. Furthermore, many of these types of air separators have been improperly selected and installed at "line size," which is too small for effective air separation and only decreases their efficiency. Air separation products should be selected based on GPM flow and peak efficiency.

Figure B-5

Centrifugal Air Separator

A "scoop"-type air separator, most common in the residential market, is capable of removing the larger free air bubbles that float along the top of the pipes. The fluid enters the air scoop via the straight in-line passage and encounters a velocity change and slight pressure drop caused by the dome-shaped chamber on the top of the unit. The free air bubbles follow the dome up to the vent and are released from the system.

A centrifugal air separator is an empty tank that relies on centrifugal force to separate and release air bubbles from the system fluid. The air-saturated fluid enters the upper portion of the tank and whirls around the inside wall until it finds its way out of the tank via the lower offset discharge pipe. The larger free air bubbles are released to a low-pressure vortex in the center and expected to rise to the top. Because of the higher entering water velocity, the insufficient length of time in the air separator, and the lack of a coalescing medium into which the bubbles can collide and adhere, most entrained microbubbles and any absorbed air have no way to escape (see Figure B-5).

The Spirovent Air Eliminator

In 1990, a new type of air eliminator was introduced into the North American market. Having been developed and sold in Europe for well over twenty-five years, this new product combines best-practice selection criteria with new and unique features. Unlike the air scoops and centrifugal separators that only remove larger moving air bubbles and pockets, the Spirovent eliminates 100% of the free air, 100% of the entrained air and up to 99.6% of the dissolved air.

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Entrained air, the tiny microbubbles that travel at the same speed as the fluid, is difficult to eliminate because it must be separated from the flow before it can be accumulated and vented. Larger and smaller air bubbles, and specifically the microbubbles, will only migrate if the water velocity is significantly reduced, the turbulence suppressed, and a high rate of collision and adhesion is reached. The Spirovent air eliminator with its enlarged straight in-line flow passage and patented coalescing medium is the only air eliminator that provides these optimum conditions without substantial pressure loss.

The velocity at which a gas bubble will migrate depends on the bubble size, the difference in density of gas bubble and fluid, the gravitational force, and the viscosity of the fluid.

$$\text{Bubble migration velocity} \approx D^2 \times \Delta p \times g / V$$

The above formula stresses the importance of the bubble diameter. Of all factors, the velocity is most strongly influenced by the square of the diameter of the bubble. This phenomena can best be demonstrated by looking at a tall glass filled with a carbonated drink. At the bottom of the glass, small microbubbles develop and start to rise. As they rise, their diameter increases due to further carbon dioxide diffusion and decreasing local pressure from the water column. As their diameter increases, their speed rapidly accelerates.

The speed of migration is also extremely dependent upon the viscosity of the fluid. At decreasing temperatures, the viscosity increases dramatically. At 50ºF, water has a 3.8 times higher viscosity than water at 190ºF. Viscosity is particularly important in regards to heating or cooling systems that contain anti-freeze, which can contain viscosity values up to 50 times that of plain water.

The enlargement of the Spirovent's flow passage and the patented coalescing process ensure a turbulent-free zone with a widespread contact surface to achieve effective elimination of air from water. The Spirotubes® will separate even the tiniest microbubbles. Once separated, the microbubbles are able to rise upwards and accumulate because of the suppressed water turbulence. The float mechanism and patented venting valve in the air chamber will complete the air elimination process by venting separated air to the outside until the system is air-free.

Trapped or stationary air most often found in terminal units, down-curved piping and dead-end risers is another common form of air that is even more difficult to eliminate than entrained air. These trapped air pockets must be dissolved through absorption and then transformed into entrained microbubbles before they can be eliminated. This occurs when saturated water is heated or its pressure is lowered, and where a properly installed Spirovent will, at this point of lowest solubility, first separate and then eliminate the air through the integral venting mechanism.

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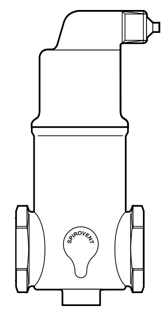
Spirovent Junior

The Spirovent Junior (Figure B-6) is a cast brass air eliminator consisting of a float and valve mechanism and the patented Spirotube coalescing medium. It is manufactured specifically for the venting and separation of air in residential and light commercial installations.

Figure B-6



Spirovent Junior

The Spirotube is a copper core tube with rectangular and spiral-shaped copper wire woven around it. Its design allows an extremely low resistance to the water flow and forces entrained air to turn partially upwards. Because the water flow resistance upward along the core tube is considerable, water turbulence in the upper part of the unit is completely suppressed, allowing the separated microbubbles to rise to the top.

Once the airspace between the water surface and float mechanism is filled with microbubbles, the water level drops and forces the float to open the venting valve. The amount the venting valve opens is dependent upon the amount of air separated at that time. Once the air is vented, the water can rise to its former level. The combination float-valve assembly maintains a constant air space above the water's surface to prevent any dirt from touching the vent. The vent is guaranteed not to leak and cannot be closed off, assuring uninterrupted operation. The Spirovent Junior is available in ¾" through 1-1/2" NPT and includes a ½" connection on the bottom of the valve for a diaphragm-type expansion tank (except for ¾" model).

Spirovent Senior

The Spirovent Senior (Figure B-7) is a steel air eliminator manufactured for larger commercial and industrial applications. With flanged pipe sizes from 2" through 36" (male NPT available on 2" through 4" units only), its operation is identical and just as effective as that of the Spirovent Junior. Other features of the Spirovent Senior are as follows:

- The housing contains multiple Spirotube coalescing tubes for maximum air separation.
- The venting mechanism is mounted in a chamber inside the tank to protect it from system debris.

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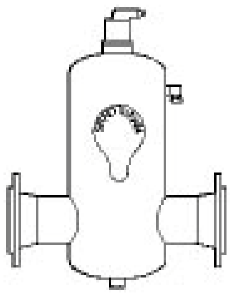
Figure B-7



Spirovent Senior

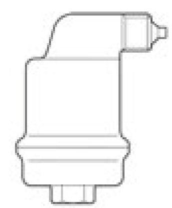
- A side tap valve used to release large amounts of air during filling or for skimming off floating dirt.
- A drain plug located on the bottom of the unit suitable for connecting a valve or temperature sensor.
- Suitable for flows exceeding 30,000 GPM.
- Designed for a maximum working pressure of 150 psig and working temperature of 270ºF.

The Spirovent Senior is also available in custom dimensions and constructions and can be specially designed for space limitations.

Spirotop®

The Spirotop (Figure B-8) is a brass automatic air release valve that is used to vent high points, eliminate air locks, and for quick filling and draining of residential, commercial, and institutional systems. It eliminates the need to manually bleed hard-to-reach areas such as the tops of risers, tanks, heaters, and high-mounted lines with terminal units near the ceiling.

Figure B-8



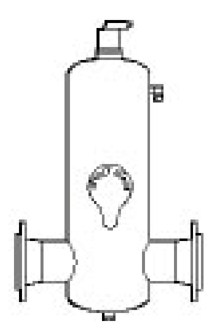
Spirotop

The Spirotop has the same patented valve mechanism and specially constructed air chamber as the Spirovent air eliminator, so the valve is protected from system debris during sudden pressure fluctuations, and it's guaranteed not to leak. It is designed for a maximum working pressure of 150 psig and working temperature of 270ºF.

The Spirotop has one port and is installed outside the flow to gather and release those free air bubbles that are large enough to rise from the flow on their own. During the start-up process all of the air that is able to rise is removed. When draining, the Spirotop acts as a vacuum breaker, opening as the water drains so the system can empty quickly. When used in conjunction with the Spirovent air eliminator, no other air bleeders are necessary.

Spirovent HV (High Velocity) Air Eliminator

Figure B-9



Spirovent HV

The Spirovent HV air eliminator (Figure B-9) has been developed especially for high volume fluid systems where higher velocities are found. It allows a maximum entering water velocity of up to ten (10) feet per second, and offers all of the unique benefits of the standard Spirovent air eliminator. The extended shell and longer Spirotube coalescing medium provide for the greater velocity and higher efficiency of the HV series. Because they are designed to handle higher velocities than the standard series, the HV series often match pipe size.

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In 1976, the Delft Hydronic Laboratory in Europe conducted a comprehensive series of tests analyzing the performance of the Spirovent. The results of these tests concluded the following:

- The absorbed air content dropped to half of its value in less than six (6) hours.
- The absorbed air content dropped to nearly 0.4% (0.08% oxygen).
- Trapped air (pockets) outside the circulation disappeared via absorption.
- The circulation speed determines the speed of air elimination. Lower velocity means increased air elimination efficiency.
- The speed of air elimination is also influenced by the amount of microscopic dust particles that enhance the growth of microbubbles.

These conclusions are included in the American patent #4,456,172 issued by the U.S. patent office, as shown on the following page.

The first marked text block of the patent describes how stationary air is absorbed during the operation of the Spirovent. Only through the process of absorption and release can trapped air pockets be removed from a system.

The second marked block of text reiterates the important conclusion that the Spirovent reduces the content of dissolved air to 0.4%. As 20% of air consists of oxygen, it was concluded that a corresponding 0.08% concentration of oxygen is too low to cause any corrosion damage.

The third and last marked text block describes the release and elimination of microbubbles and the extraordinary air removal efficiency rate of 100% of the free air, 100% of the entrained air and 99.6% of the dissolved air.

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US Patent #4,456,172

…However in circulation systems which do not have a heat source it is necessary to provide closely in front of the air separator the special heating device and, if necessary, a cooling device behind the air separator.

The drawing schematically illustrates an embodiment of the apparatus which is suited to carry out the method which forms the subject matter of the invention.

In its simplest form, this apparatus consists of a self-contained circulation line 1, an air separator 2 extending upwardly from a horizontally extending part of the line, a heating device 4 and a cooling device 5. The housing of the air separator 2 which is open toward the top forms an inwardly extending branch of the circulation line 1. Its inside cross-section is four times as large as the one of the circulation line. The circulation line 1 is completely filled with water and the air separator housing 2 is filled with water up to an upper space which is connected to the outside air. Accordingly, this space forms a collection chamber for the air which has reached the separator housing from the circulation line and has risen in the housing, while the remaining portion of the separator housing corresponds to the expansion tank which is conventionally used in heating systems with open circulation. The heating device 4 arranged on one side of the air separator 2 and the cooling device 5 arranged on the other side ensure that in the circulation line 1 continuous flow in the direction of arrow 3 is generated and that the water flowing through the air separator is heated to 70ºC. from otherwise 35ºC. Opposite the air separator 2, a transparent, completely enclosed control vessel 6 is arranged in the circulation line 1. This control vessel 6 forms a branch of the circulation line 1 which extends upwardly. The control vessel is connected through a check valve 7 to a line 8 through which the apparatus is filled with water, but through which also a small amount of air can be blown into the vessel 6, the air forming a visible bubble 9 in the vessel 6.

When the apparatus is operated at the above-stated temperatures it can clearly be seen that an air bubble which is present in the control vessel becomes increasingly smaller and flatter, at first quickly and then slower and slower, until it finally disappears completely. This process takes place significantly faster when the water circulation is accelerated by means of a pump 10 which is arranged, as seen in flow direction, closely behind the air separator and which is indicated by broken lines and, in addition, when the negative pressure generated in the water by the pump favors the release of dissolved air.

In the apparatus constructed for control purposes, the cooling device is only provided because it must be expected due to the length of the circulation line of only a few meters that the heated water is not sufficiently cooled during one circulation.

Moreover, tests performed by scientific institutes have confirmed that the means provided by the invention make it possible to lower, in open as well as in closed circulation systems of heating systems which are operated with excess pressure, the saturation value of the operating water to such an extent that the water no longer releases any harmful amounts of dissolved air at the points of highest operating temperature and lowest operating pressure, but that the water completely absorbs any air which might be present in its circulation path

During the operation of the illustrated apparatus, the air content of 4 l water was reduced within about five hours from 15 to 5 ml/l and, a little later, to 4 ml/l. This corresponds to an oxygen content of approximately 0.08%. This is a concentration which cannot cause any corrosion damage.

I claim:

1. Heating system including deaeration of dissolved extremely small gas bubbles from a circulating liquid comprising a closed loop for circulating a liquid heat carrier, said closed loop having an upper horizontally extending part, means in said closed loop for circulating the liquid heat carrier, means in said closed loop for heating the liquid heat carrier, a branch line connected to and extending upwardly from said horizontally extending part of said closed loop immediately adjacent to and downstream from said means for heating the liquid heat carrier for containing a body of the liquid heat carrier therein in the at-rest condition with the lower end of said branch line and said horizontally extending part of said closed loop forming an interface between the liquid in said closed loop and the liquid in said branch line so that the liquid in said closed loop continues to flow past the interface at a temporarily reduced rate of flow velocity whereby extremely small gas bubbles can be released from the circulating liquid at the interface into said branch line, an air separator connected to said branch line upwardly from the interface with said closed loop and forming a continuation of said branch line for containing the body of liquid heat carrier in the at-rest condition, said circulating means comprising a pump located in said closed loop adjacent to and downstream from said branch line containing said air separator so that the liquid flowing in said closed loop past said air separator enters the suction side of said pump, said air separator having an enclosed air collecting chamber, and a float-controlled valve connected to said aid collecting chamber for regulating flow of air of gas from the collecting chamber to the ambient air.

2. Method of deaerating dissolved extremely small gas bubbles from a circulation system including a closed circulation line containing a constant amount of liquid, comprising the steps of generating a force for circulating the liquid through the circulation line by one of heating the circulating liquid and generating a negative pressure in the circulating liquid, positioning the force generation at a determined location in the circulation line, providing an upwardly extending branch line off a generally horizontally extending part of the circulation line immediately adjacent to the determined location of the circulating force, providing an air collecting chamber in the branch line spaced upwardly from the circulation line, connecting the collection chamber to the ambient air, filling the branch line from the circulation line into the air collection chamber with the liquid flowing in the circulation line so that the upwardly extending column of liquid is at-rest within the branch line and air collecting chamber and providing an interface between the liquid flowing through the circulation line and the liquid in the at-rest condition within the branch line, releasing gases dissolved in the circulating liquid in the form of extremely small gas bubbles invisible to the naked eye by the force generating step, effecting temporarily reduced flow velocity of the liquid in the horizontally extending part of the circulation line directly underneath the interface with the upwardly extending column of liquid at-rest and, while the liquid continues circulating in the circulation line, removing the extremely small gas bubbles of the released gases at the interface from the circulation line into the branch line…

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Notes: