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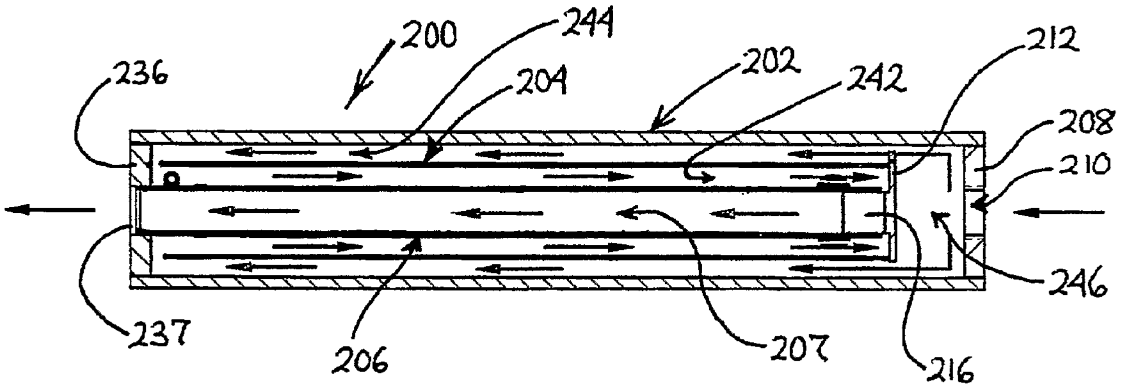
(54) Title: AIR HEATER FOR A GAS CHROMATOGRAPH



(57) Abstract: The invention is directed to an air heater for a gas chromatograph. The air heater has a core disposed inside a housing and includes an electrically resistive heating element. An air passage in the core extends parallel to a central axis of the air heater. A conduit extends parallel to the central axis of the air heater and is disposed farther outward from the central axis of the air heater than the air passage of the core. The conduit is connected between an air flow inlet and the air passage in the core such that when the air flow inlet is connected to an air source, air from the air inlet flows through the conduit to the air passage in the core and thence through an air flow outlet of the air heater. The air flowing through the conduit is cooler than the air flowing through the air passage in the core.

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AIR HEATER FOR A GAS CHROMATOGRAPH

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. provisional patent application No. 60/801,686 filed on May 19, 2006, which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0001] The present invention is directed toward heaters and, more particularly, toward an improved air heater for a gas chromatograph.

[0002] In a gas chromatograph, a sample gas mixture is injected into a carrier gas stream which carries the sample gas mixture through a separation column packed with adsorptive material. The different components of the sample gas mixture are absorbed and de-absorbed by the adsorptive material. The de-absorption (or elution) of the different components occurs at different rates, with the higher molecular weight components being eluted at a slower rate than the lower molecular weight components. As a result of these different rates of elution, the different components of the sample gas mixture exit the separation column at different times, thereby separating the different components in time and space. After exiting the separation column, the carrier gas stream with the separated components is fed to a detector that determines the quantities of the components. Once all of the components of the sample gas mixture have exited the column, the separation column may be back-flushed, and a new sample gas mixture may be injected and carried into the column for separation. The time between the injection of a first sample gas mixture and the injection of a second sample gas mixture is typically referred to as the cycle time.

[0003] The separation of a gas mixture into its constituent components in the separation column is significantly affected by temperature. Accordingly, the separation column is disposed in an oven, where the temperature of the separation column can be closely controlled. The oven may be heated by an electrical resistance heater disposed in the oven and/or by heated air, which is heated by an electrical resistance air heater. Examples of gas chromatographs utilizing air heaters are disclosed in U.S. Patent Nos. 4,461,950; 5,846,293; and 6,427,522, all of which are hereby incorporated by reference. If the components of the sample gas mixture have a relatively narrow molecular weight range, the oven is maintained at a constant temperature. Such control is typically referred to as isothermal gas chromatography. If the components of the sample gas mixture have a wide range of molecular weights, the temperature of the oven is increased, usually as a linear function of time. Such control is typically referred to as programmed-temperature gas chromatography. The increase in temperature in programmed-temperature gas chromatography accelerates the elution rate of the higher molecular weight components that would otherwise take a long time to elute.

[0004] In gas chromatography, especially programmed-temperature gas chromatography, the oven must be heated and cooled rapidly to permit a short cycle time. If an air heater is used in connection with the heating and cooling of the oven, it is desirable for the air heater to quickly heat air to a desired temperature. The ability of a conventional air heater to quickly heat air, however, is limited by safety considerations. Since a gas chromatograph is often used in an explosive atmosphere, it is necessary to keep the surface temperature of the air heater below a rated temperature (T-Rating) in order to avoid igniting the atmosphere. Typically, power to the air heater is limited so as to keep the skin temperature below the rated temperature. This power limitation increases the time it takes to reach the desired temperature and prevents elevated air temperatures from being achieved.

[0005] Based on the foregoing, there exists a need in the art for an air heater that can quickly heat air to a desired temperature, while maintaining a skin temperature below the rated temperature. The present invention is directed to such an air heater.

SUMMARY OF THE INVENTION

[0006] In accordance with the present invention, an air heater is providing having a central axis. The air heater includes a housing, an air flow inlet, a core and an air flow outlet. The housing has first and second ends. The core is disposed in the housing and includes an electrically resistive heating element. The core has an air passage extending parallel to the central axis of the air heater. The air flow outlet is disposed toward the first end of the housing and is connected to the air passage of the core. A conduit extends parallel to the central axis of the air heater and is disposed farther outward from the central axis of the air heater than the air passage of the core. The conduit is connected between the air flow inlet and the air passage in the core such that when the air flow inlet is connected to an air source, air from the air inlet flows through the conduit to the air passage in the core and thence through the air flow outlet. The air flowing through the conduit is cooler than the air flowing through the air passage in the core.

[0007] Also provided in accordance with the present invention is a gas chromatograph having the air heater described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings where:

[0009] Fig. 1 is a front view of a gas chromatograph having an air heater embodied in accordance with the present invention, wherein an oven door and other exterior portions of the gas chromatograph are removed to better show interior portions of the gas chromatograph;

[0010] Fig. 2 is a schematic view of an analytical flow system of the gas chromatograph;

[0011] Fig. 3 is a front view of an oven assembly of another embodiment of the gas chromatograph having two of the air heaters, wherein the oven door is removed to show an oven cavity;

[0012] Fig. 4 is a side view of the air heater;

[0013] Fig. 5 is a top view of the air heater;

[0014] Fig. 6 is an exploded view of a portion of the air heater that includes a redirector, a core and a nozzle;

[0015] Fig. 7 is a rear perspective view of the nozzle;

[0016] Fig. 8 is a sectional view of the air heater taken along line 8-8 of Fig. 5;

[0017] Fig. 9 is a sectional view of the air heater taken along line 9-9 of Fig. 4;

[0018] Fig. 10 is a schematic sectional view of the air heater taken along line 10-10 of Fig. 5 and schematically showing the flow of air through the air heater;

[0019] Fig. 11 is a sectional view of the air heater taken along line 11-11 of Fig. 5;

[0020] Fig. 12 is a side sectional view of a second air heater constructed in accordance with a second embodiment of the present invention;

[0021] Fig. 13 is a front view of a director plate of the second air heater;

[0022] Fig. 14 is an end view of an interior tube coaxially disposed inside a main flow tube of the second air heater;

[0023] Fig. 15 shows an exploded view of a third air heater constructed in accordance with a third embodiment of the present invention;

[0024] Fig.16 shows a perspective view of a heating element of the third air heater disposed on a dielectric substrate, wherein the heating element and the dielectric substrate are shown in a flattened state; and

[0025] Fig. 17 shows a schematic sectional view of the third air heater showing the flow of air through the third air heater;

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0026] It should be noted that in the detailed description that follows, identical components have the same reference numerals, regardless of whether they are shown in different embodiments of the present invention. It should also be noted that in order to clearly and concisely disclose the present invention, the drawings may not necessarily be to scale and certain features of the invention may be shown in somewhat schematic form.

[0027] As used herein, the following abbreviations shall have the following meanings:

"GC" shall mean gas chromatograph.

"PCB" shall mean printed circuit board.

[0028] The present invention is directed to an air heater 10 that is adapted for use in a gas chromatograph, such as the gas chromatograph 12 shown in Fig. 1 and as described more fully below. It should be appreciated, however, that the air heater 10 may be used in other gas chromatographs and other applications requiring heating.

[0029] The gas chromatograph 12 includes a housing 14 having an oven assembly 16, a pressure control assembly 18, a purge air assembly 20 and a GC control assembly 22, which are secured together in a vertical arrangement, with the oven assembly 16 being disposed on the bottom. The GC control assembly 22 includes a display 24 and keyboard 26. The oven assembly 16 is insulated and defines an interior oven cavity 28 that may be accessed through an enlarged front opening closed by a pivotable door, which has been removed in Fig. 1 to show the oven cavity 28. At least one air heater 10, at least one separation column 32, at least one sample loop 34 (shown in Fig. 2) and at least one detector 38 are mounted inside the oven cavity 28. At least one sample valve 40 extends into the oven cavity 28.

[0030] Each separation column 32 may be a packed column, which comprises a stainless steel tube having an inner diameter of 2 to 4 mm and a length of 1 to 4 meters. The tube is packed with a suitable adsorbent, which may be organic and/or inorganic, and which is ground and screened to provide a range of particle sizes that extend from about 30 mesh to about 120 mesh. In lieu of being a packed column, each separation column 32 may instead be open tubular column, such as a fused silica open tubular (FSOT) column. A FSOT column comprises a fused silica tube having an exterior polyimide coating and an interior stationary phase coating comprising a support and an adsorbent.

[0031] The detector(s) 38 may be selected from the group consisting of a flame ionization detector (FID), a thermal conductivity detector (TCD), a flame photometric detector (FPD) and combinations of the foregoing. A TCD may utilize a filament, or a thermistor. A sequential dual detector arrangement, or a simultaneous dual detector arrangement may be utilized.

[0032] The sample valve(s) 40 may be selected from the group consisting of a liquid sample valve, a gas sample valve and combinations thereof. A liquid sample valve has a vaporizer for vaporizing a liquid sample. The vaporizer is typically heated by a heater block.

[0033] Referring now to Fig. 2, there is shown an analytical flow system 42 that may be included in the gas chromatograph 12. The analytical flow system 42 includes a sample valve 40, three separation columns 32a, 32b, 32c, first and second analytical valves 44, 46, a sample loop 34 and a detector 38. The sample valve 40 provides measurement and control of a sample. Each of the first and second analytical valves 44, 46 is air-actuated by an electrical solenoid valve that is controlled by a solenoid driver PCB (not shown) mounted in the GC control assembly 22. An operational cycle for the first and second analytical valves 44, 46 includes three modes: sample purge, sample inject, and backflush. In the sample purge mode, a sample flows through the sample loop 34 to a sample vent 48. In the sample inject mode, the first analytical valve 40 switches, capturing a plug of gaseous sample which the carrier gas then sweeps through the separation columns 32a, 32b, 32c to the detector 38. In the backflush mode, the carrier gas backflushes separation column 32a to a backflush vent 50.

[0034] The first analytical valve 44 captures a sample plug in the sample loop 34. When the first analytical valve 44 switches, the carrier gas sweeps the sample plug through the first analytical valve 44, through separation column 32a and then through separation column 32b. From separation column 32b, the sample plug travels through second analytical valve 46 and then through separation column 32c. Separation column 32a performs preliminary separation to remove heavier non-desired components, which are then backflushed to backflush vent 50. Separation column 32b separates the remaining components, which elute sequentially. The second analytical valve 46 operates to select the eluted components that are to be measured. The components that are to be measured are directed by the second analytical valve 46 to separation column 32c, which further separates the components. From separation column 32c, the components to be measured travel to the detector 38, which generates an electrical detection signal representative of the component distribution.

[0035] In the process described above, as the sample travels through the separation columns 32a, 32b, 32c, the components of the sample separate from one another by virtue of differences in their rates of interaction (absorption and de-absorption) with the adsorbents in the separation columns 32a, 32b, 32c. The different components are therefore retained in the separation columns 32a, 32b, 32c for different lengths of time, which permits the removal of the heavier components and the selection of the components to be measured, etc. The design of the separation columns 32a, 32b, 32c, their operating conditions, such as temperature, and gas flow, are optimized and carefully controlled so as to provide good and consistent separation between the components. This optimization and control, coupled with a selection of a carrier gas (such as helium) having a much different thermal conductivity then the sample gas, creates a component distribution and, thus, a detection signal from the detector 38 with bell-like distributions, which are often referred to as Gaussian peaks.

[0036] For repeatable quantification of gas components, the temperature in the oven cavity 28 is closely regulated using an air bath that is created by the air heater 10. At least one temperature sensor (not shown) mounted in the oven cavity 28 provides a temperature signal to a digital temperature controller mounted in the GC control assembly 22. The digital temperature controller controls power to the air heater 10 to maintain the temperature at a constant temperature so that the analysis of the sample occurs isothermally.

[0037] In another embodiment of the present invention shown in Fig. 3, programmed temperature control may be provided. In this embodiment, first and second air heaters 10a, 10b and an insulated inner oven enclosure 54 are provided. The inner oven enclosure 54 is disposed inside the oven cavity 28, toward the bottom thereof. The second air heater 10b and separation column(s) 32 is/are mounted inside the inner oven enclosure 54, while the detector 38, a portion of the sample valve 40 and the first air heater 10a are mounted in the oven cavity 28, outside the inner oven enclosure 54. The digital temperature controller controls the second air heater 10b to change the temperature in the inner oven enclosure 54 in accordance with a preset program, such as linearly increasing the temperature from a low initial temperature to an elevated final temperature. Such an increase in temperature accelerates the elution rate of higher molecular weight components that would otherwise take a long time to elute.

[0038] As shown in Fig. 1, the air heater 10 is mounted inside the oven cavity 28 such that its longitudinal axis is disposed vertically or substantially vertically. The air heater 10 has a nozzle 56 that is directed toward a bottom wall of the oven assembly 16. Pressurized air enters the air heater 10, is heated and then is ejected through the nozzle 56, toward the bottom wall. The ejected heated air is deflected by the bottom wall and swirls around the oven cavity 28 to form a heated air bath. This swirling of the heated air minimizes temperature gradients that could adversely affect the sample analysis performed by the analytical flow system 42. Thus, the air heater 10 functions to both heat and stir the air. In the embodiment shown in Fig. 3, the first and second air heaters 10a, 10b are similarly mounted and function in a similar manner.

[0039] Both the oven cavity 28 and the inner oven enclosure 54 are provided with spark arresting vent assemblies (not shown) to permit air to exit the oven cavity 28 and the inner oven enclosure 54, respectively. At the end of an analysis cycle, vortex-cooled air from one or more fans may be admitted into the oven cavity 28 and the inner oven enclosure 54 to rapidly cool the same.

[0040] Referring now to Figs. 4-10, the air heater 10 is cylindrical and generally includes a core 58, the nozzle 56, a redirector 60, a main outer housing 62 and an insulation assembly 64.

[0041] The core 58 is cylindrical in shape and is comprised of a metal, such as stainless steel, or graphite. The core 58 includes an outer side surface and first and second end surfaces. A central passage 66 extends through the core 58 and is disposed along a longitudinal axis thereof. A plurality of outer passages 68 are circumferentially disposed around the central passage 66. Each outer passage 68 extends through the core 58 and is disposed parallel to the longitudinal axis of the core 58. A pair of resistance coils or wires 70 comprised of a metal, such as rhenium, tungsten, platinum, tantalum, a nickel/chrome alloy, a nickel/copper alloy, or an iron/chrome/aluminum alloy, are secured in a pair of opposing outer passages 68. A pair of lead wires 72 are connected to the resistance wires 70 and extend out of the core 58. The resistance wires 70 are connected through the lead wires 72 to a power circuit controlled by the digital temperature controller. When the power circuit provides power to the resistance wires 70, the resistance wires 70 warm up and heat the core 58. The power circuit may provide AC or DC power.

[0042] The nozzle 56 is also cylindrical in shape and is composed of a metal, such as stainless steel. The nozzle 56 includes first and second sections 74, 76 that are separated by an annular groove 78. A conical flow chamber 82 (shown in Figs. 9 and 10) is located inside the nozzle 56 and has an enlarged input opening 84 disposed inside the first section 74 and a narrower output orifice 86 that extends through the second section 76. The second section 76 has an end with an outer annular surface 88 disposed around a protruding outer surface 90. The first section 74 has an interior side wall 92 and an interior end wall 94 that define an interior recess or socket 96. The interior end wall 94 is annular and extends around the input opening 84 of the flow chamber 82. The socket 96 communicates with the flow chamber 82 through the input opening 84. A tube passage 100 extends through the first section 74 from an end surface to the annular groove 78. The tube passage 100 is disposed within a circular pattern of smaller nozzle air passages 102 that also extend through the first section 74 from the end surface to the annular groove 78.

[0043] The redirector 60 is also cylindrical in shape and is composed of a metal, such as stainless steel. The redirector 60 has a side surface 104, a first end surface (not shown) and an annular second end surface 106. The second end surface 106 is disposed around a generally cylindrical cavity 108 formed by an interior side surface and an interior end surface. A series of circumferentially spaced-apart grooves 110 are formed in the interior side surface and extend around the circumference thereof. Successive grooves 110 are separated by narrow, inwardly extending ridges 112. As best shown in Fig. 9, each ridge 112 has a longitudinally arranged first portion 112a and second portion 112b. In each ridge 112, the first portion 112a extends radially inward farther, i.e., is higher, than the second portion 112b. Thus, the first and second portions 112a, 112b of each ridge 112 form a shoulder facing toward the second end surface 106. A pair of wire passages extend through the redirector 60, from the first end surface into the cavity 108. Radially outward from the wire passages and the cavity 108, a tube passage 114 extends through the redirector 60 from the first end surface to the second end surface 106.

[0044] As shown in Figs. 9, 10 and 11, a first end 58a of the core 58 is disposed in the cavity 108 of the redirector 60 such that the first end surface abuts the shoulders of the ridges 112. With the first end of the core 58 so positioned, the grooves 110 in the redirector 60 cooperate with the outer side surface of the core 58 to define a circular pattern of redirector air passages 118 (shown in Fig. 11). A second end 58b of the core 58 is disposed in the socket 96 and abuts the interior end wall 94 of the nozzle 56. With the core 58 positioned between the redirector 60 and the nozzle 56 as described above, the tube passage 114, the redirector air passages 118 and the nozzle air passages 102 are all disposed radially outward from the core 58.

[0045] The main outer housing 62 is cylindrical and is composed of a metal, such as stainless steel. The main outer housing 62 has open first and second ends and encloses the redirector 60, the core 58 and a portion of the nozzle 56. The core 58 is disposed coaxial with the main outer housing 62. The redirector 60 is located at the first end, while the nozzle 56 is located at the second end. The first section 74 and the annular groove 78 of the nozzle 56 are disposed inside the main outer housing 62, while the protruding surface 90 of the nozzle 56 extends out of the second end of the main outer housing 62. An annular flange 124 at the second end of the main outer housing 62 extends radially inward so as to cover the annular outer surface 88 of the nozzle 56.

[0046] The insulation assembly 64 is secured to the main outer housing 62 and the redirector 60 and includes a potting layer 120 and an insulation plug 122 disposed inside a housing 126 composed of a metal, such as stainless steel.

[0047] With the core 58, the redirector 60 and the nozzle 56 mounted inside the main outer housing 62 as described above, an inner side surface of the main outer housing 62 cooperates with the outer side surface of the core 58 to define a tubular main air passage 128 with an annular cross-section. In addition, a first manifold 130 is formed between the interior end surface of the redirector 60 and the first end surface of the core 58. The interior side surface of the main outer housing 62 and the annular groove 78 of the nozzle 56 cooperate to define an annular second manifold 132 that extends around the flow chamber 82 of the nozzle 56. The redirector air passages 118 are in air flow communication with the first manifold 130, and the nozzle air passages 102 are in air flow communication with the second manifold 132. The central passage 66 and the outer passages 68 of the core 58 extend between and are in air flow communication with the first manifold 130 and the flow chamber 82. A first end of the main air passage 128 is in air flow communication with the redirector air passages 118 and a second end of the main air passage 128 is in air flow communication with the nozzle air passages 102.

[0048] An air tube 134 with first and second ends is provided. The first end is connected to a manifold in the purge air assembly 20 through which pressurized air is supplied. The second end is positioned inside the second manifold 132. From the first end, the air tube 134 extends through the insulation assembly 64, the redirector 60, the main air passage 128 and the first section 74 of the nozzle 56, and into the second manifold 132.

[0049] Referring now to Fig. 10, there is shown a schematic diagram of the air flow through the air heater 10 that occurs when pressurized air is provided to the air heater 10. Air is shown as a series of dots with lines extending in the direction of flow. Air from the air source flows in a first direction through the air tube 134 into the second manifold 132. Inside the second manifold 132, the air changes direction and enters the nozzle air passages 102. The air moves through the nozzle air passages 102 and then travels through the main air passage 128 in a second direction. From the main air passage 128, the air flows through the redirector air passages 118 and into the first manifold 130. Inside the first manifold 130, the air changes direction again and enters the central passage 66 and the outer passages 68 of the core 58. The air travels through the central passage 66 and the outer passages 68 of the core 58 in the first direction and then enter the flow chamber 82 of the nozzle 56 through the input opening 84. Inside the flow chamber 82, the air is channeled into a narrow stream and exits the air heater 10 through the output orifice 86.

[0050] When power from the power circuit is provided to the resistance wires 70, the core 58 is heated. The air flowing through the main air passage 128 cools the core 58 and, in the process, is pre-heated. When the pre-heated air travels through the central passage 66 and the outer passages 68 in the core 58, the air is heated to a significantly higher temperature. The hot air then passes through the output orifice 86 and into the oven cavity 28.

[0051] As described above, cooler air in the main air passage 128 is disposed radially outward from the warmer air in the central passage 66 and the outer passages 68. Thus, the cooler air in the main air passage 128 functions as a cooling envelope or shroud that lowers the surface temperature of the main outer housing 62. This cooling shroud keeps the temperature of the outer surface of the main outer housing 62 below a rated temperature (T-Rating) for an explosive atmosphere without requiring a limitation on the power provided to the resistance wires 70. In this manner, the air heater 10 has a faster ramp up time and can heat air to a higher temperature than other conventional air heaters used in gas chromatographs.

[0052] Referring now to Fig. 12, there is shown an air heater 140 constructed in accordance with a second embodiment of the present invention. The air heater 140 may be installed in the gas chromatograph 12 in lieu of the air heater 10. The air heater 140 is installed in the gas chromatograph 12 in the same manner as the air heater 10. The air heater 140 generally includes an outer housing 142, a director plate 144, an intermediate tube 146 and a main flow tube 148.

[0053] The outer housing 142 is composed of a metal, such as stainless steel, and includes a cylindrical side wall 150 secured between an anterior wall 152 and a posterior wall 154. An air tube 156 extends into an interior of the outer housing 142 through an opening in the posterior wall 154. A nozzle portion 160 of the main flow tube 148 extends through an enlarged opening in the anterior wall 152. The nozzle portion 160 is secured to the anterior wall 152 around the enlarged opening.

[0054] Referring now also to Fig. 13, the director plate 144 is disc-shaped and is composed of a metal, such as stainless steel. A circular pattern of flow openings 158 is formed in the director plate 144, toward an outer periphery thereof. The director plate 144 is disposed inside the outer housing 142 and is secured at its periphery to the side wall 150. The director plate 144 is disposed toward, but is spaced from the posterior wall 154 so as to form a first manifold 162 in-between. The air tube 156 opens into the first manifold 162.

[0055] With reference to Fig. 12, the intermediate tube 146 is cylindrical and is comprised of a metal, such as stainless steel. The intermediate tube 146 is coaxially disposed inside the outer housing 142 and has an outer surface that cooperates with an inner surface of the outer housing 142 to define a tubular outer air passage 164 with an annular cross-section. A first end of the intermediate tube 146 is secured to the director plate 144, radially inward from the flow openings 158, such that the flow openings 158 are in airflow communication with the outer air passage 164. A free second end of the intermediate tube 146 is spaced inward from the anterior wall 152 so as to help define a second manifold 166 in-between.

[0056] The main flow tube 148 is cylindrical and is comprised of a metal, such as stainless steel. An outside surface of the main flow tube 148 may be coated with a dielectric material, such as a ceramic. A first end of the main flow tube 148 is spaced inwardly from the director plate 144 so as to help define a third manifold 168 in-between. An open second end 161 of the main flow tube 148 in the nozzle portion 160 is disposed outwardly from the anterior wall 152. The main flow tube 148 is coaxially disposed inside the intermediate tube 146 and has an outer surface that cooperates with an inner surface of the intermediate tube 146 to define a tubular intermediate air passage 170 with an annular cross-section.

[0057] Referring now also to Fig. 14, an interior tube 172 with a main inner air passage 174 extending therethrough is coaxially disposed inside the main flow tube 148 and is secured to the main flow tube 148 by three dividers 178 (shown in Fig. 14). The interior tube 172 is comprised of a metal, such as stainless steel. An outside surface of the interior tube 172 may be coated with a dielectric material, such as a ceramic. An inner surface of the main flow tube 148, an outer surface of the interior tube 172 and the dividers 178 cooperate to define three inner air passages 180. A first end of the interior tube 172 is aligned with the first end of the main flow tube 148, while a second end of the interior tube 172 is spaced inwardly from the second end of the main flow tube 148. In this manner, the inner air passages 180 and the main inner air passage 174 open into the nozzle portion 160 of the main flow tube 148.

[0058] An outer heating element 182 is secured to the exterior of the main flow tube 148 so as to be disposed inside the intermediate air passage 170, and inner heating elements 184 are secured to the exterior of the interior tube 172 so as to be disposed inside the inner air passages 180, respectively. The inner heating elements 184 collectively have a higher power rating than the outer heating element 182. In one embodiment, the inner heating elements 184 have a combined power rating of 500W, while the outer heating element 182 has a power rating of 250W. The outer heating element 182 and the inner heating elements 184 may each be comprised of a resistance wire composed of a metal, such as rhenium, tungsten, platinum, tantalum, a nickel/chrome alloy, a nickel/copper alloy, or an iron/chrome/aluminum alloy. Alternately, the outer heating element 182 and the inner heating elements 184 may each be comprised of a thick film heating element, or a thin film heating element. A thick film heating element may be formed by screen printing a mixture of a metal (such as silver, gold, nickel, copper, palladium, ruthenium, or an alloy of the foregoing) and a ceramic or vitreous material on a substrate (i.e, the main flow tube 148 and/or the interior tube 172) in a manner described in more detail below with regard to an air heater 200. A thick film typically has a thickness in a range from several microns to about 100 microns. A thin film heating element may be formed by depositing a conductive compound, such as a nickel/chrome alloy, nickel phosphide, tin oxide, or pyrolytic graphite on a substrate (i.e, the main flow tube 148 and/or the interior tube 172) via plating, chemical vapor deposition or sputtering. A thin film typically has a thickness in a range from several nanometers to several microns.

[0059] The outer heating element 182 and the inner heating elements 184 are connected to the power circuit by a pair of lead wires (not shown). When provided with power from the power circuit, the outer heating element 182 and the inner heating elements 184 warm up and heat the main flow tube 148 and the interior tube 172.

[0060] When the air heater 140 is in operation, power (AC or DC) from the power circuit is provided to the outer heating element 182 and the inner heating elements 184, thereby heating the main flow tube 148 and the interior tube 172. Pressurized air from the air source is provided to the air tube 156 and flows into the first manifold 162. From the first manifold 162, the air flows through the flow openings 158 in the director plate 144 and into the outer air passage 164. Inside the outer air passage 164, the air flows in a first direction toward the anterior wall 152. The air flowing through the outer air passage 164 cools the intermediate tube 146 and, in the process, is slightly pre-heated. When the air contacts the anterior wall 152, inside the second manifold 166, the air changes direction and then travels through the intermediate air passage 170 in a second direction, toward the posterior wall 154. The air flowing through the intermediate air passage 170 is heated by the outer heating element 182. When the air contacts the director plate 144 inside the third manifold 168, the air changes direction again and then travels through the main inner air passage 174 and the inner air passages 180 in the first direction. The air flowing through the main inner air passage 174 and the inner air passages 180 is further heated by the inner heating elements 184. Streams of the heated air exit the main inner air passage 174 and the inner air passages 180 and enter the nozzle portion 160 of the main flow tube 148, where they are mixed together. The mixed air then exits the nozzle portion 160 through the open second end 161.

[0061] During the operation of the air heater 140 described above, the air temperature of the pressurized air entering the first manifold 162 is typically about 70°F. After being pre-heated in the outer air passage 164, the air has a temperature of about 100°F in the second manifold 166. With the surface temperature of the outer heating element 182 reaching about 950°F, the air is heated in the intermediate air passage 170 so as to have a temperature of about 450° in the second manifold 166. With the surface temperatures of the inner heating elements 184 reaching about 1350°F to about 1400°F, the air is heated in the main inner air passage 174 and the inner air passages 180 so as to have a temperature of about 1150°F when the air exits the air heater 140 through the nozzle portion 160 thereof.

[0062] As described above, cooler air in the outer air passage 164 is disposed radially outward from the warmer air in the intermediate air passage 170, which, in turn, is disposed radially outward from the still warmer air in the main inner air passage 174 and the inner air passages 180. Thus, the cooler air in the outer air passage 164 and, to a lesser extent, the air in the intermediate air passage 170 function as cooling envelopes or shrouds that lower the surface temperature of the outer housing 142. These cooling shrouds keep the temperature of the outer surface of the outer housing 142 below a rated temperature (T-Rating) for an explosive atmosphere without requiring a limitation on the power provided to the outer heating element 182 and the inner heating elements 184. In this manner, the air heater 140 has a faster ramp up time and can heat air to a higher temperature than other conventional air heaters used in gas chromatographs.

[0063] Referring now to Fig. 15, there is shown an exploded view of an air heater 200 constructed in accordance with a third embodiment of the present invention. The air heater 200 may be installed in the gas chromatograph 12 in lieu of the air heater 10. The air heater 200 is installed in the gas chromatograph 12 in the same manner as the air heater 10. The air heater 200 generally includes an outer housing 202, an intermediate tube 204 and a main flow tube 206.

[0064] The outer housing 202 is composed of a metal, such as stainless steel, and is tubular in shape, having a cylindrical side wall with open anterior and posterior ends. A disc-shaped end cap 208 is secured within the posterior end. The end cap 208 is composed of a metal, such as stainless steel, and has a central opening 210 extending axially therethrough. As will be described more fully below, air enters the air heater 200 through the central opening 210. A plurality of smaller openings are disposed radially outward from the central opening 210 and extend through the end cap 208 as well.

[0065] The intermediate tube 204 is also composed of a metal, such as stainless steel, and is tubular in shape, having a cylindrical side wall with open anterior and posterior ends. The intermediate tube 204, however, has a smaller diameter than the outer housing 202 and is axially shorter than the outer housing 202. A disc-shaped end plate 212 is secured to the posterior end of the intermediate tube 204. The end plate 212 has a plurality of tabs 214 extending radially outward from an outer circumferential edge. The tabs 214 are evenly spaced around the circumferential edge. A plurality of holes
extend through the end plate 212. A support protrusion 216 (shown in Fig. 17) is secured to an interior surface of the end plate 212 and projects therefrom. The support protrusion 216 may be generally rectangular in shape and includes a main portion joined to a wider base portion at a pair of shoulders. The main portion of the support protrusion 216 is sized to snugly fit inside the main flow tube 206 to form a connection therebetween. The base portion of the support protrusion 216 is joined to the end plate 212 and cannot fit inside the main flow tube 206.

[0066] The main flow tube 206 is tubular in shape, having a cylindrical side wall with open anterior and posterior ends and an inner air passage 207 extending therethrough. The main flow tube 206 comprises a dielectric substrate 218 (shown in Fig. 16) to which a resistive heating element 220 is affixed. The dielectric substrate 218 may form the entirety of the main flow tube 206 or may be a layer of dielectric material disposed over a support tube comprised of a metal, such as stainless steel. For example, the dielectric substrate 218 may be a ceramic tube or may be a ceramic layer coating a metal tube. The heating element 220 has a power rating of 900W and may be a thick film heating element, or a thin film heating element. Referring now also to Fig. 16, the heating element 220 extends around the circumference of the main flow tube 206 and comprises a serpentine film trace having elongated segments 222 connected by bends 224 that are alternately disposed proximate the posterior and anterior ends of the main flow tube 206, respectively. The elongated segments 222 extend in the longitudinal or axial direction of the main flow tube 206 and, thus, the air heater 200. Ends of the heating element 220 are connected to studs 226 that are secured to the main flow tube 206 at the posterior end thereof and extend radially outward therefrom. A stud 230 is secured to the main flow tube 206 at the anterior end thereof and extends radially outward therefrom. An end of a thermocouple wire 232 is secured to the stud 230, such as by a nut (as shown) or by welding. Ends of power wires 234 are secured to the studs 226, such as by nuts (as shown) or by welding.

[0067] It should be noted that for purposes of improving illustration, Fig. 16 shows the heating element 220 and the dielectric substrate 218 in flattened states and not in cylindrical states as they really are inside the air heater 200.

[0068] In an embodiment where the heating element 220 is a thick film heating element, the heating element 220 may be formed from a paste comprised of a mixture of metal, an inorganic binder and a liquid carrier or solvent. The metal may be selected from the group consisting of silver, gold, platinum, aluminum, nickel, copper, palladium, ruthenium and oxides, mixtures and alloys of the foregoing. Silver/palladium (Ag/Pd) compositions and ruthenium oxide compositions are most commonly used in thick film heating elements. The inorganic binder binds the metal particles to one another and to the dielectric substrate 218 after firing. Examples of inorganic binders include glass binders (frits), metal oxides and ceramics. Useful glass binders include borosilicates and aluminosilicate glasses. The solvent adjusts the consistency, rheology and volatility of the paste to meet the requirements for a particular method of application of the paste. The solvent may be an organic or aqueous liquid medium. Commonly used organic solvents include ethyl acetate, terpenes and high boiling alcohols and alcohol esters.

[0069] The heating element 220 may be applied to the main flow tube 206 by a decal process, a wrapping process or a direct process. After the heating element 220 is applied to the main flow tube 206, the dielectric substrate 218 with the heating element 220 applied thereto is typically dried and then fired in an oven, usually at temperatures between about 600 and 900 °C, to volatilize or burn off the solvent and sinter or melt the inorganic binder and the metal components.

[0070] In the decal process, a resistive thick film pattern is printed (such as by screen printing) on a sheet of silicone coated paper using a paste, such as described above. The paste is allowed to dry and then the thick film pattern is covered with a clear acrylic coating. When the sheet with the thick film pattern is soaked in water, the thick film pattern with the acrylic coating (the "decal") separates from the sheet. The separated decal is rolled onto the dielectric substrate 218, which is then dried and fired. Firing in a conventional furnace burns off the acrylic coating and sinters the thick film pattern onto the dielectric substrate 218.

[0071] If the wrapping process is used, a resistive thick film pattern is printed (such as by screen printing) on the dielectric substrate 218, which is initially a flat, green ceramic substrate. The printing uses a paste, such as described above. Since the dielectric substrate 218 is green (i.e., unfired), the dielectric substrate 218 is flexible. The dielectric substrate 218 is wrapped around a metal tube of the main flow tube 206 and then is fired in the furnace.

[0072] In the direct method, the thick film heating element is printed directly on the dielectric substrate 218 using a precision printing pen, such as is disclosed in U.S. Patent No. 4,485,387 to Drumheller, which is hereby incorporated by reference.

[0073] The heating element 220 may be printed such that the watt density of the heating element 220 varies along the length of the main flow tube 206. More specifically, the heating element 220 is printed such that the watt density of the heating element 220 decreases in the direction from the posterior end of the main flow tube 206 to the anterior end of the main flow tube 206. In this manner, the watt density is the highest toward the posterior end of the main flow tube 206 and is the lowest toward the anterior end of the main flow tube 206. Since a higher watt density results in a greater electrical resistance, the heating element 220 generates more heat at the posterior end of the core 20, which is proximate to where the air enters the air heater 200 and is coolest. The watt density of the heating element 220 may be changed by changing the width and/or thickness of the film trace of the heating element 220. For example, the width of each elongated segment 222 may be increased along the length of the elongated segment 222, with the width being the narrowest toward the posterior end of the main flow tube 206 and the broadest toward the anterior end of the main flow tube 206. In addition to, or in lieu of, this change in width, the thickness of each elongated segment 222 may be increased along the length of the elongated segment 222, with the thickness being the least toward the posterior end of the main flow tube 206 and the greatest toward the anterior end of the main flow tube 206.

[0074] An annular end cap 236 is secured to the anterior end of the main flow tube 206. The end cap 236 is composed of a metal, such as stainless steel, and has a central opening 237 that is aligned with the opening in the anterior end of the main flow tube 206. A terminal loop of a thermocouple wire 238 is secured to an inner surface of the end cap 236, such as by welding.

[0075] Referring now to Fig. 17, there is shown a sectional view of the assembled air heater 200. The main flow tube 206 is coaxially disposed inside the intermediate tube 204 in a spaced apart manner such that an inside surface of the intermediate tube 204 and the exterior of the main flow tube 206 cooperate to define a tubular intermediate air passage 242 with an annular cross-section. The intermediate tube 204 (with the main flow tube 206 disposed therein) is coaxially disposed inside the outer housing 202 in a spaced apart manner such that an inside surface of the outer housing 202 cooperates with an outside surface of the intermediate tube 204 to define a tubular outer air passage 244 with an annular cross-section.

[0076] The intermediate tube 204 is disposed over the main flow tube 206 such that the main portion of the support protrusion 216 extends inside the main flow tube 206 and the shoulders of the support protrusion 216 abut against a posterior edge of the main flow tube 206. In this manner, the base portion of the support protrusion 216 spaces the posterior end of the main flow tube 206 from the end plate 212 so as to form a gap through which air may flow from the intermediate air passage 242 into the inner air passage 207. With the intermediate tube 204 so positioned relative to the main flow tube 206, a gap is formed between the anterior end of the intermediate tube 204 and the end cap 236 through which air may flow from the outer air passage 244 into the intermediate air passage 242.

[0077] The outer housing 202 is disposed over the intermediate tube 204 and the main flow tube 206 such that the end cap 236 snugly fits inside the anterior end of the outer housing 202, with an outer surface of the end cap 236 being disposed flush with an anterior edge of the outer housing 202. The posterior end of the intermediate tube 204 is supported within, and spaced from, the outer housing 202 by the tabs 214 of the end plate 212. With the intermediate tube 204 so positioned relative to the outer housing 202, a spacing or manifold 246 is formed between the end plate 212 and the end cap 208. Circumferential gaps between the tabs 214 help form openings through which air from the manifold 246 may travel into the outer air passage 244.

[0078] Inside the air heater 200, the power wires 234 and the thermocouple wires 232, 238 extend through the intermediate air passage 242, through the holes in the end plate 212 and thence through the openings in the end cap 208. Outside the air heater 200, the power wires 234 and the thermocouple wires 232, 238 are connected to the power circuit.

[0079] When the air heater 200 is in operation, power from the power circuit is provided to the heating element 220, thereby heating the main flow tube 206 and the surrounding environs, including the intermediate tube 204. Pressurized air from the air source is provided to the central opening 210 and flows into the manifold 246. From the manifold 246, the air flows through the gaps between the tabs 214 and into the outer air passage 244. Inside the outer air passage 244, the air flows in a first direction toward the end cap 236. The air flowing through the outer air passage 244 cools the intermediate tube 204 and, in the process, is slightly pre-heated. When the air contacts the end cap 236, the air changes direction and then travels through the intermediate air passage 242 in a second direction, toward the end plate 212. The air flowing through the intermediate air passage 242 is heated by the heating element 220. When the air contacts the end plate 212, the air changes direction again and then travels into the inner air passage 207 through the gap between the posterior end of the main flow tube 206 and the end plate 212. The air flowing through the inner air passage 207 is further heated by the heating element 220. After flowing through the inner air passage, the hot air exits the air heater 200 through the central opening 237 in the end cap 236.

[0080] As described above, cooler air in the outer air passage 244 is disposed radially outward from the warmer air in the intermediate air passage 242, which, in turn, is disposed radially outward from the still warmer air in the inner air passage 207. Thus, the cooler air in the outer air passage 244 and, to a lesser extent, the air in the intermediate air passage 242 function as cooling envelopes or shrouds that lower the surface temperature of the outer housing 22. These cooling shrouds keep the temperature of the outer surface of the outer housing 202 below a rated temperature (T-Rating) for an explosive atmosphere without requiring a limitation on the power provided to the heating element 220. In this manner, the air heater 200 has a faster ramp up time and can heat air to a higher temperature than other conventional air heaters used in gas chromatographs.

[0081] While the invention has been shown and described with respect to particular embodiments thereof, those embodiments are for the purpose of illustration rather than limitation, and other variations and modifications of the specific embodiments herein described will be apparent to those skilled in the art, all within the intended spirit and scope of the invention. Accordingly, the invention is not to be limited in scope and effect to the specific embodiments herein described, nor in any other way that is inconsistent with the extent to which the progress in the art has been advanced by the invention.

WHAT IS CLAIMED IS:

1. An air heater having a central axis and comprising:

a housing having first and second ends;

an air flow inlet for connection to an air source;

a core disposed in the housing and comprising an electrically resistive heating element, said core having an air passage extending parallel to the central axis of the air heater;

an air flow outlet disposed toward the first end of the housing and being connected to the air passage of the core; and

a conduit extending parallel to the central axis of the air heater and being disposed farther outward from the central axis of the air heater than the air passage of the core, said conduit being connected between the air flow inlet and the air passage in the core such that when the air flow inlet is connected to the air source, air from the air inlet flows through the conduit to the air passage in the core and thence through the air flow outlet, whereby the air flowing through the conduit is cooler than the air flowing through the air passage in the core.

2. The air heater of claim 1, wherein the flow of air through the conduit is in an opposite direction to the flow of air through the air passage in the core.

3. The air heater of claim 2, wherein the conduit is at least partially defined by the housing and the core.

4. The air heater of claim 3, wherein the housing and the core are each cylindrical in shape and the conduit has an annular cross-section, and wherein the conduit is disposed radially outward from the air passage in the core.

5. The air heater of claim 4, wherein the air passage is a first air passage, and where the core further comprises a second air passage extending parallel to the central axis of the air heater.

6. The air heater of claim 5, wherein the flows of air through the first and second air passages in the core are in an opposite direction to the flow of air through the conduit.

7. The air heater of claim 5, wherein the flow of air through the first air passage in the core is in an opposite direction to the flow of air through the conduit, and wherein the flow of air through the second air passage in the core is in the same direction as the flow of air through the conduit.

8. The air heater of claim 7, wherein the core comprises a main flow tube disposed coaxially inside an intermediate tube, wherein an outer surface of the main flow tube cooperates with an inner surface of the intermediate tube to define the first air passage, wherein a passage through the main flow tube comprises the second air passage, and wherein the first air passage is connected to the air flow outlet by the second air passage.

9. The air heater of claim 8, wherein the heating element is secured to the outer surface of the main flow tube.

10. The air heater of claim 9, wherein the heating element is a thick film heating element.

11. The air heater of claim 10, wherein the main flow tube comprises a dielectric substrate on which the heating element is formed.

12. The air heater of claim 11, wherein the main flow tube comprises a metal tube coated with the dielectric substrate, and wherein the dielectric substrate comprises a ceramic.

13. The air heater of claim 9, wherein the core further comprises an interior tube disposed coaxially inside the main flow tube, wherein an outer surface of the

interior tube cooperates with an interior surface of the main flow tube to define third, fourth and fifth air passages, and wherein the air heater further comprises at least one inner heating element secured to the outer surface of the interior tube.

14. The air heater of claim 9, further comprising:

a flow director disposed toward the second end of the housing and secured to the intermediate tube, the flow director being disc-shaped and at least partially forming a plurality of flow openings; and

an end wall having an opening through which pressurized air from the air source may enter the air heater, the end wall with the opening comprising the air flow inlet;

wherein the flow director is spaced from the end wall so as to form a manifold in-between;

and wherein the flow director guides air from the manifold through the flow openings into the conduit and guides air from the first air passage into the second air passage, and wherein the intermediate tube is secured to the flow director radially inward from the flow openings.

15. The air heater of claim 14, further comprising:

an end cap secured to the main flow tube and including the air flow outlet; and

a thermocouple secured to the end cap.

16. The air heater of claim 5, further comprising:

a nozzle that includes the air flow outlet; and

a flow director disposed toward the second end of the housing; and

wherein the flow of air through the air heater changes direction in the nozzle, and changes direction again in the flow director.

17. The air heater of claim 16, wherein the nozzle cooperates with the housing to define a first manifold, and wherein the air heater further comprises an air tube for guiding pressurized air from the air source into the first manifold, said air

tube comprising the air flow inlet.

18. The air heater of claim 17, wherein the flow director and the core cooperate to define a second manifold connecting the conduit to the air passage, said manifold having a plurality of spaced-apart flow openings arranged around the periphery of the core, said flow openings being in air flow communication with the conduit.

19. A gas chromatograph comprising the air heater of claim 1.

20. The gas chromatograph of claim 19, further comprising:

a housing defining an oven cavity;

at least one separation column disposed in the oven cavity; and

a detector disposed in the oven cavity and connected to the at least one separation column; and

wherein the air heater is disposed in the oven cavity.

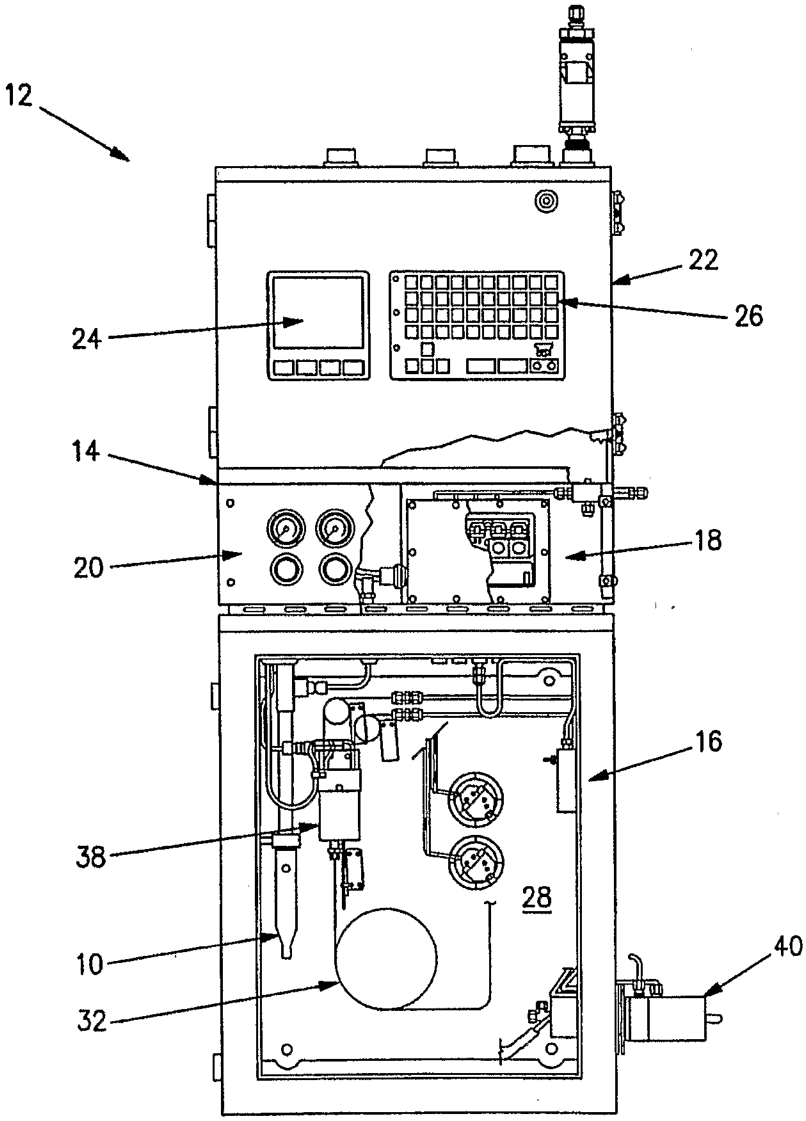

FIG. 1

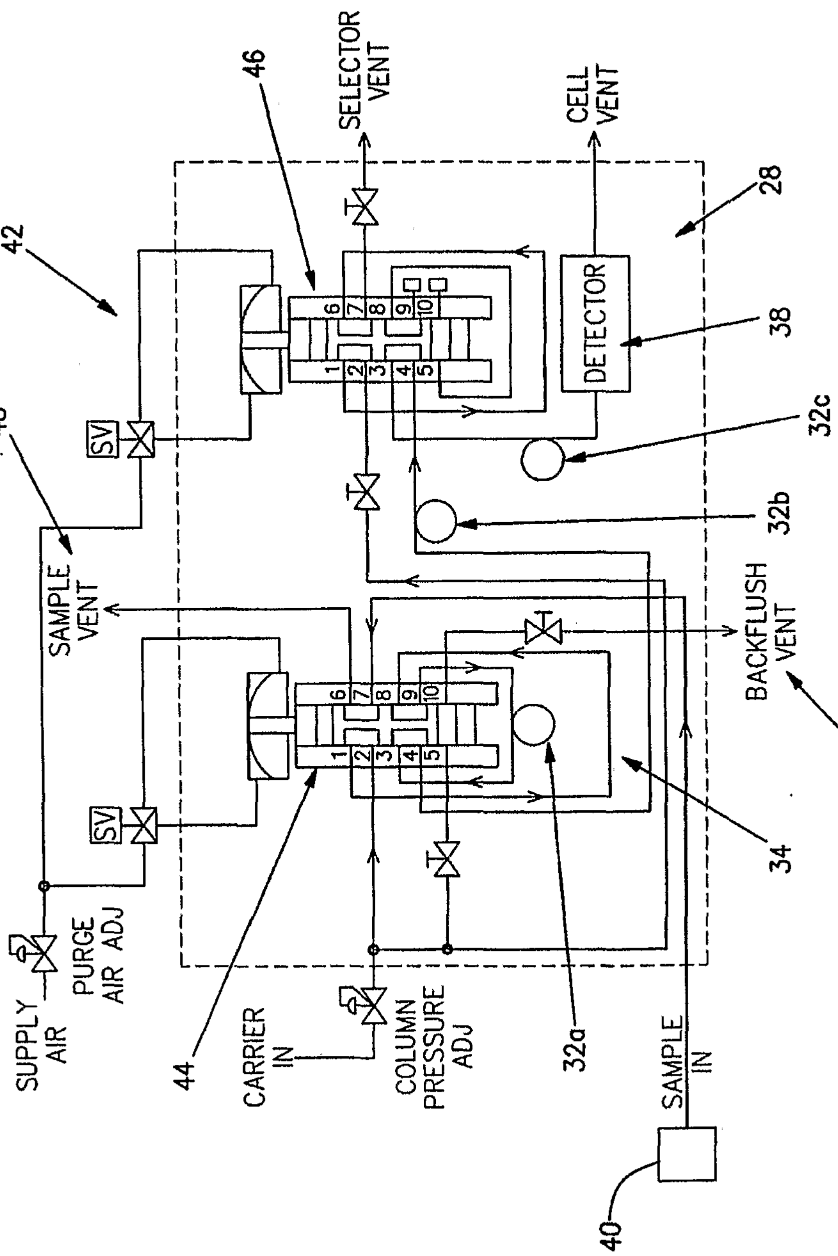
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FIG. 2

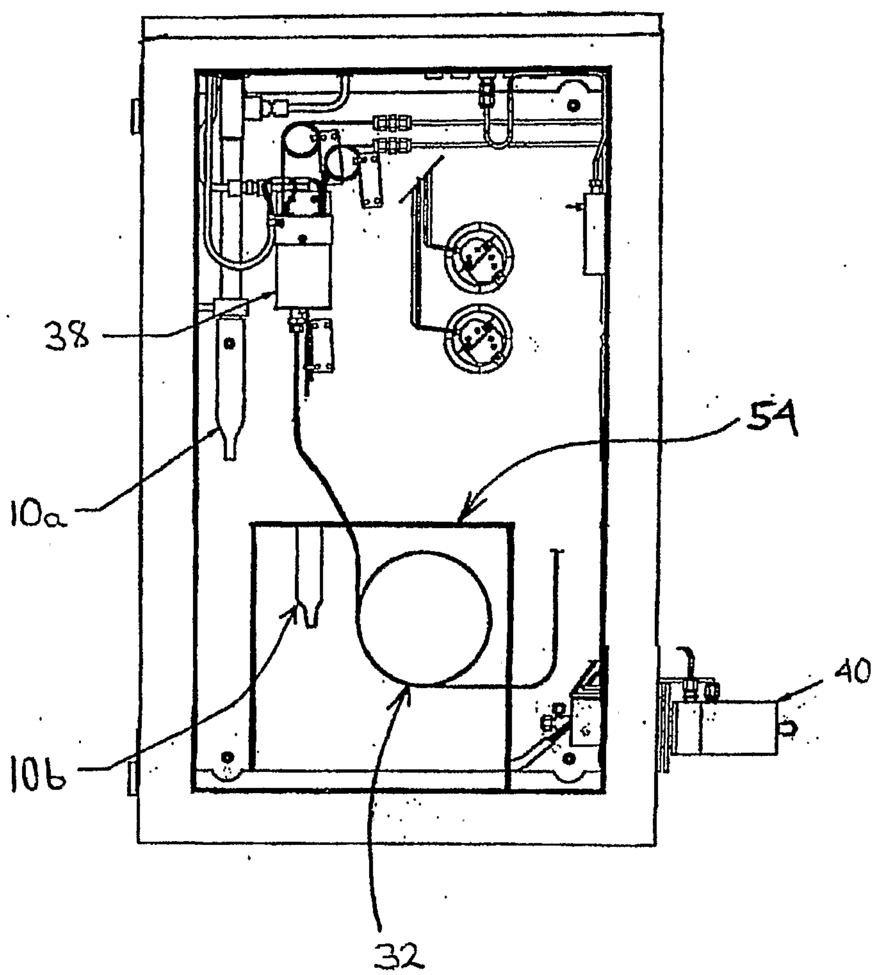

FIG. 3

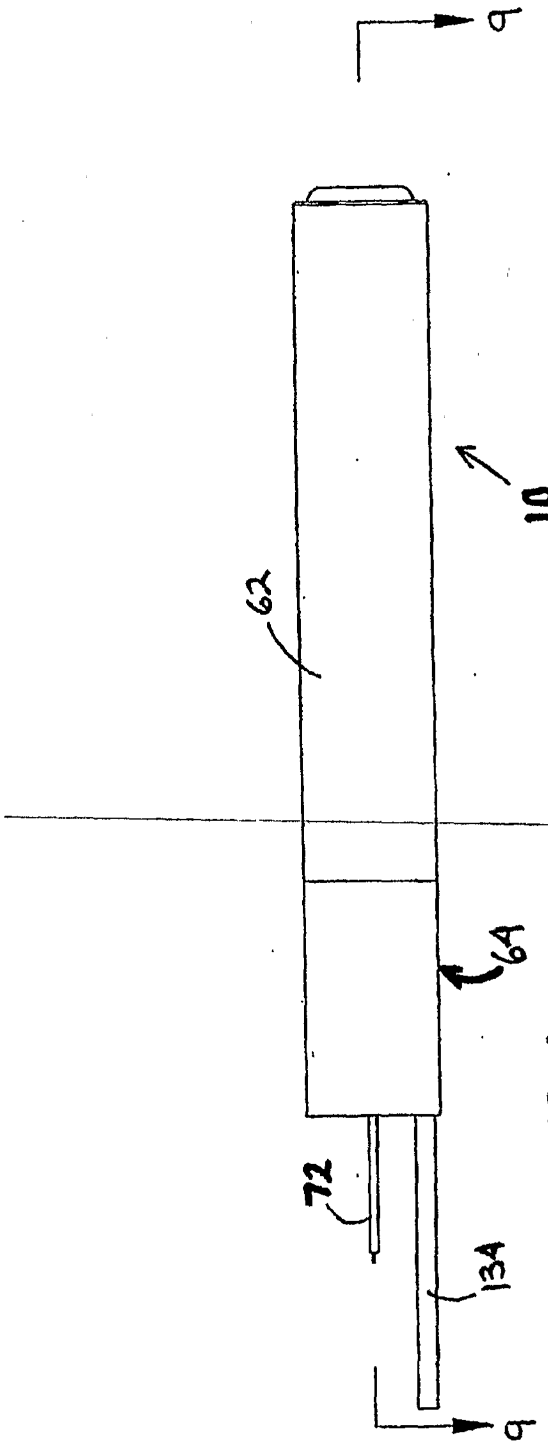

FIG. 4

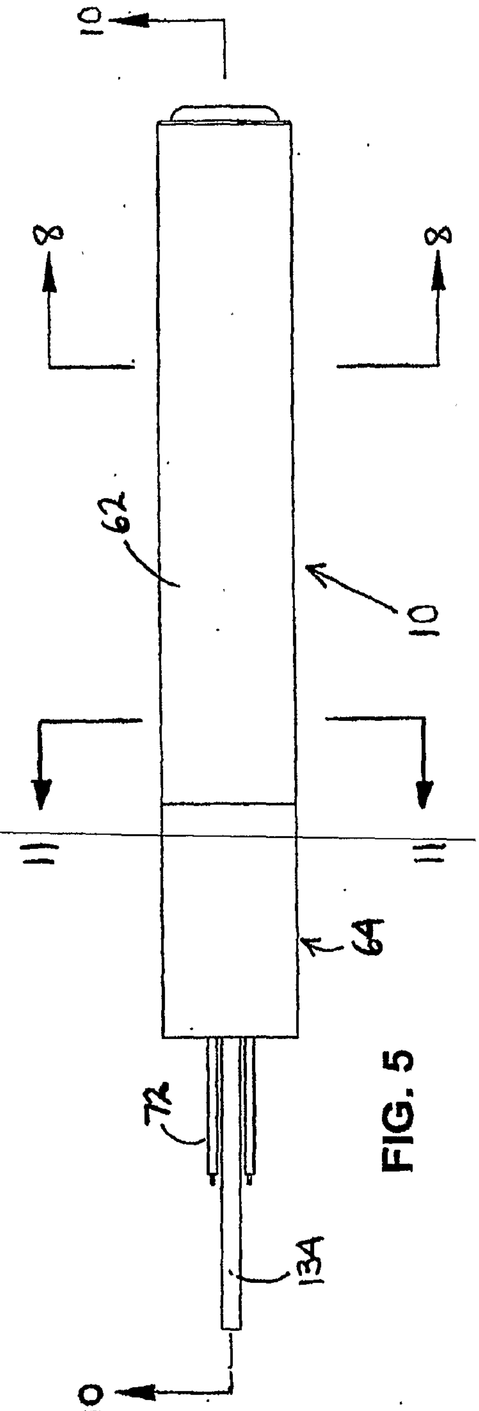

FIG. 5

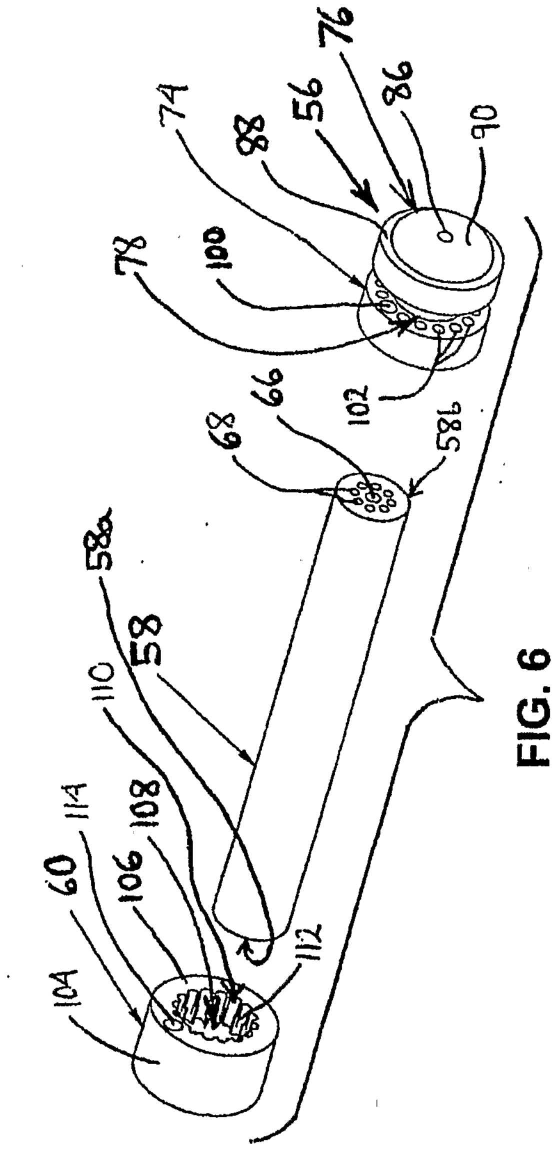

FIG. 6

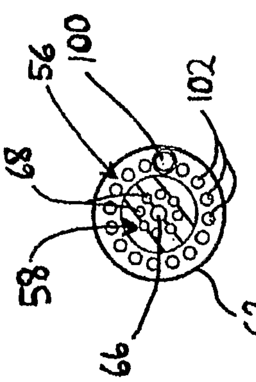

FIG. 8

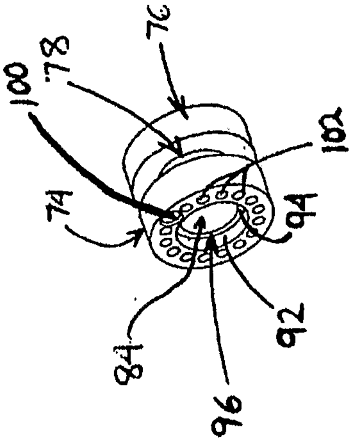

FIG. 7

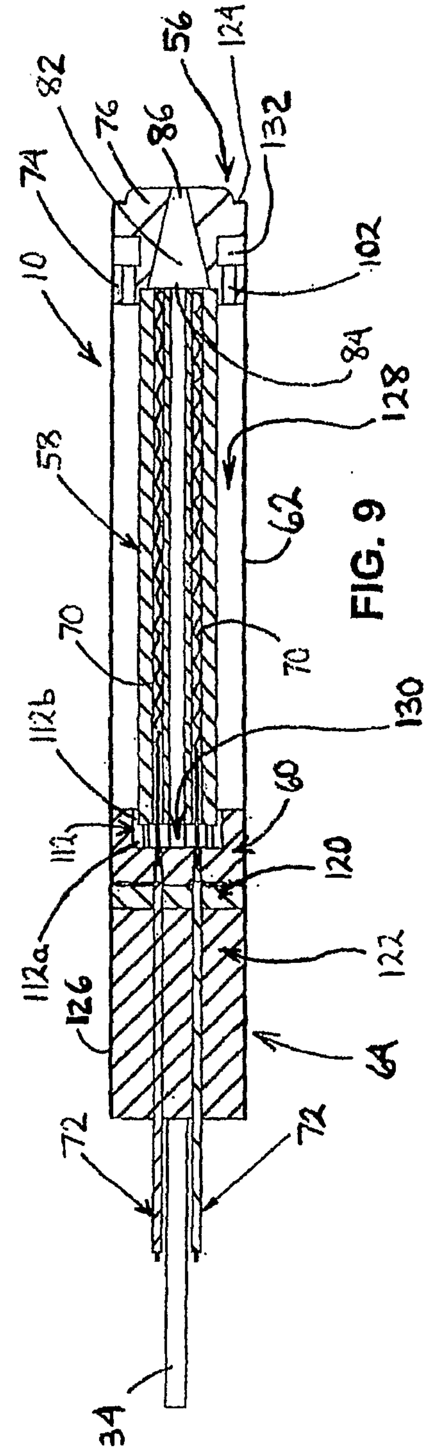
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FIG. 9

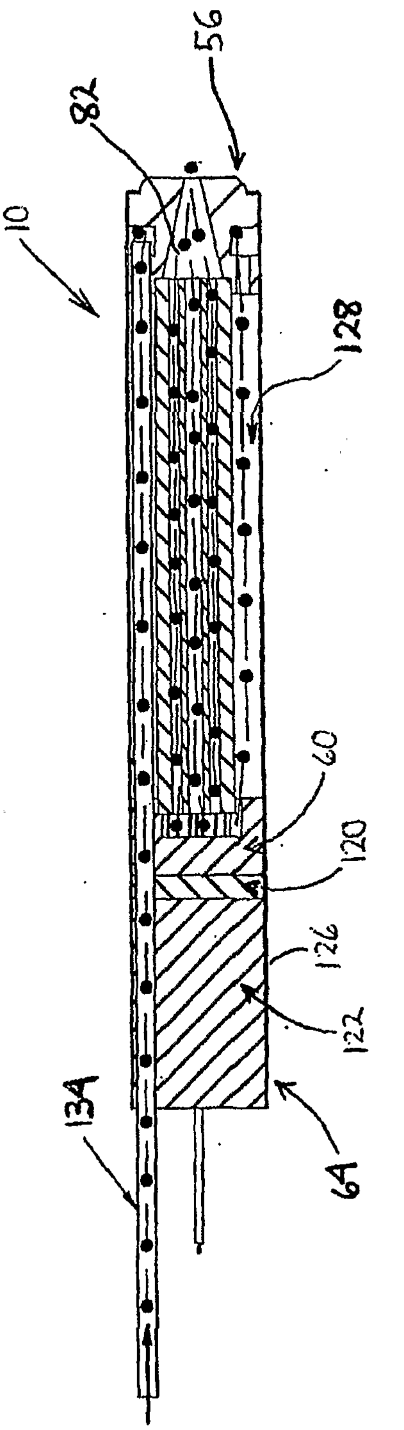
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FIG. 10

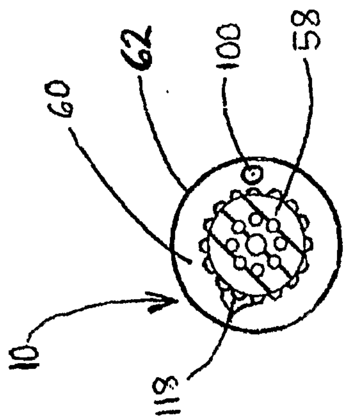

FIG. 11

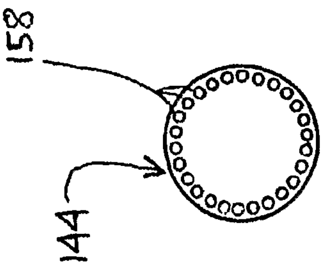

FIG. 13

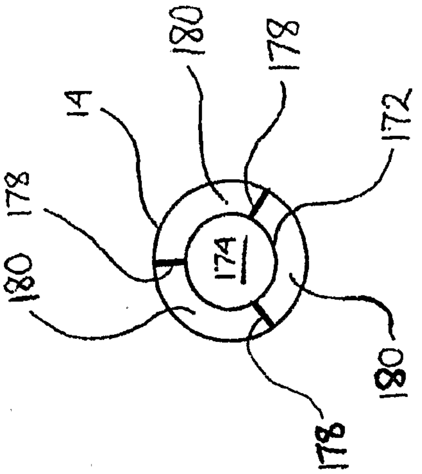

FIG. 14

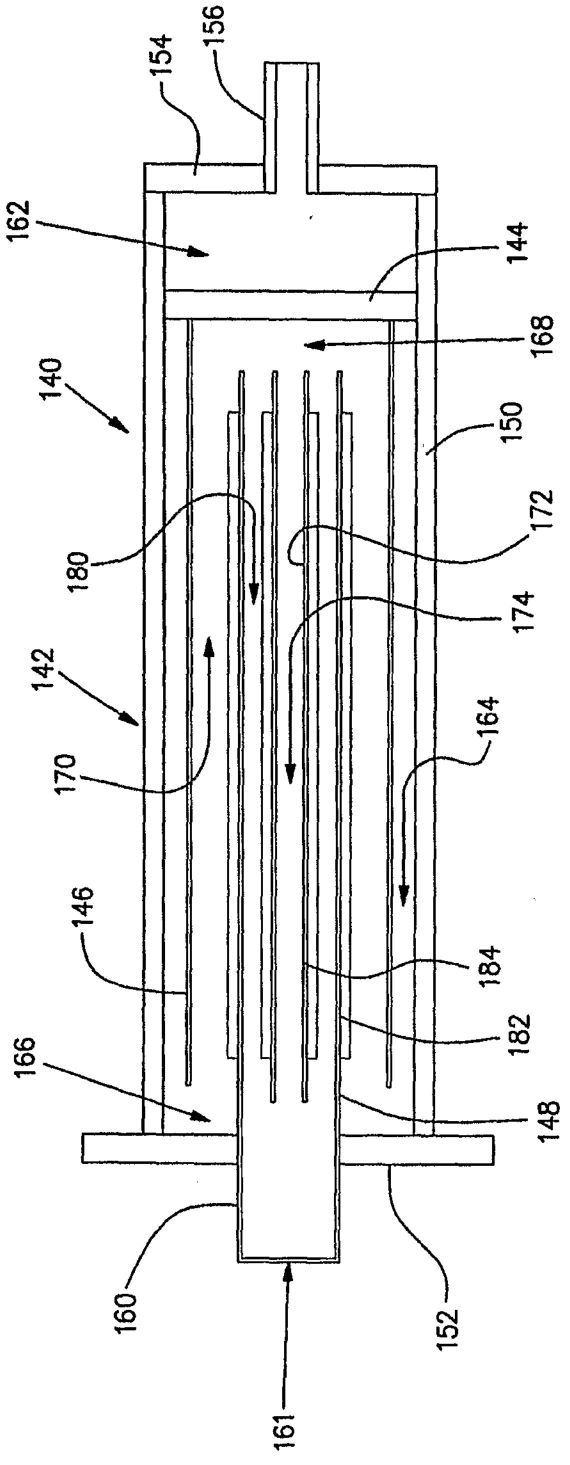
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FIG. 12

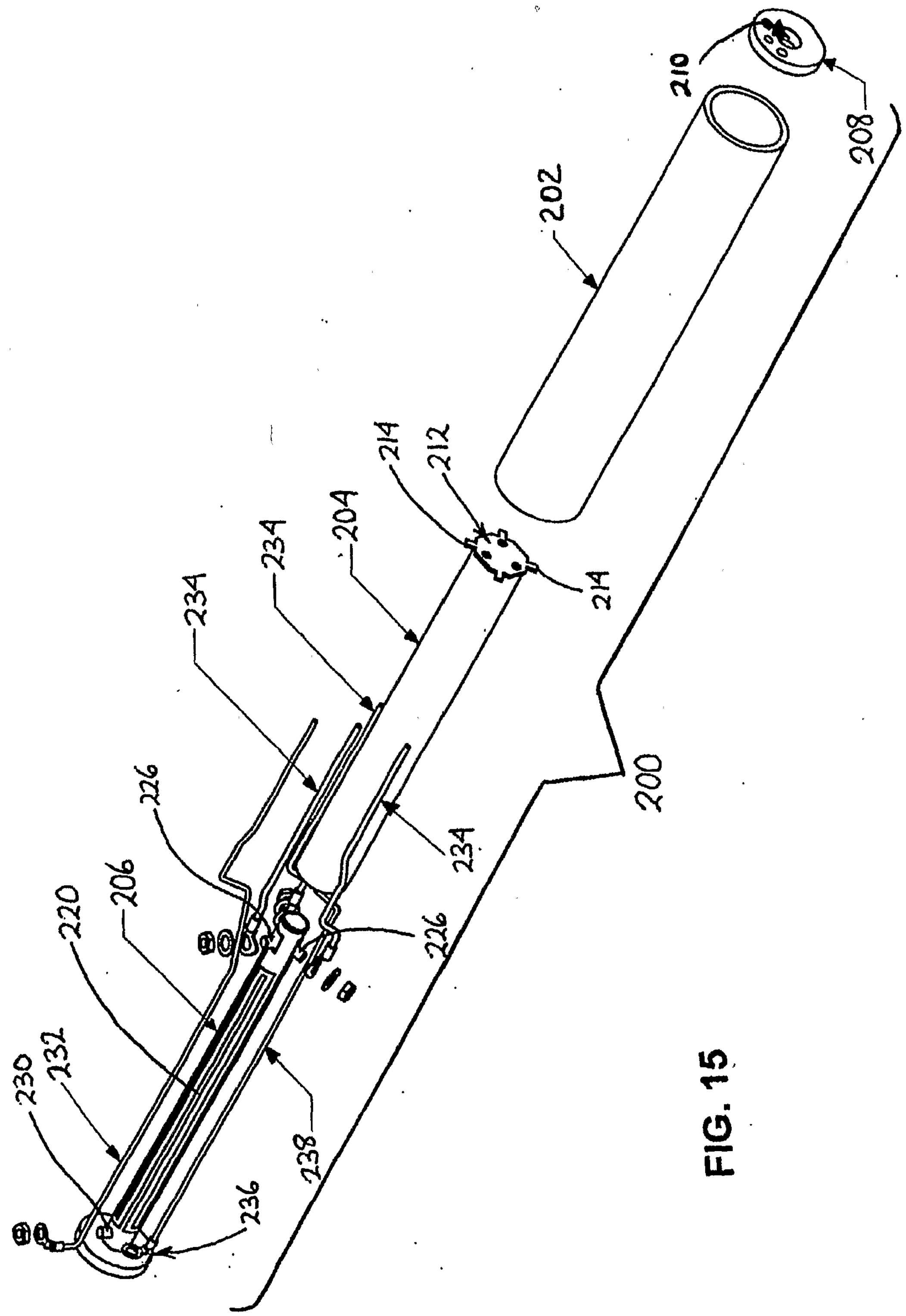
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FIG. 15

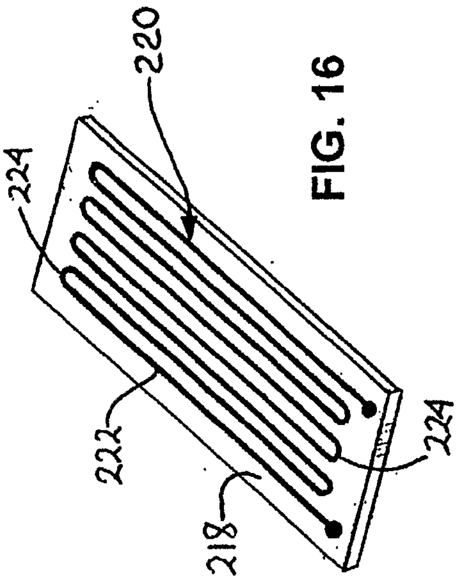
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FIG. 16

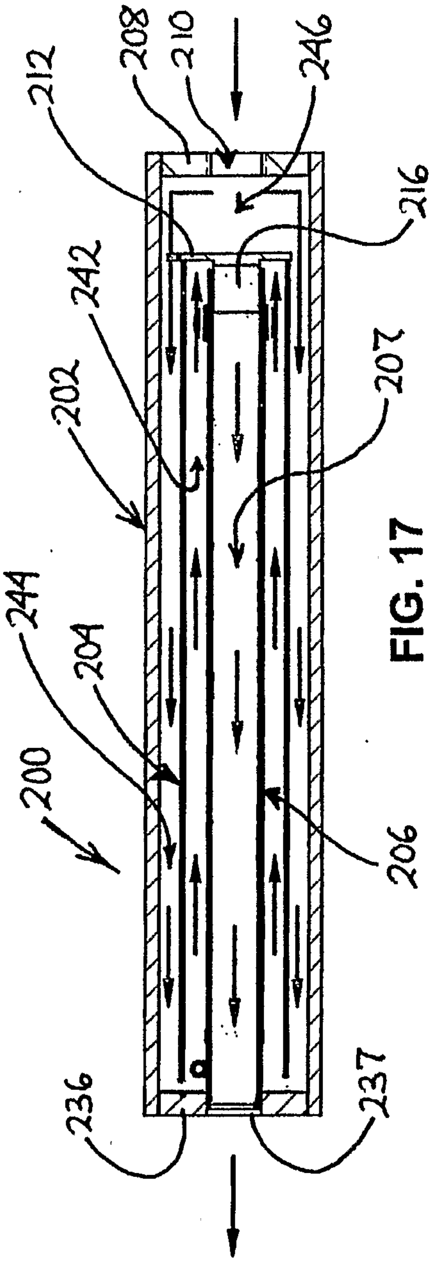
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FIG. 17