



(51) International Patent Classification:

F23M 5/08 (2006.01) *F23C 3/00* (2006.01)
F22B 27/10 (2006.01) *F23M 9/10* (2006.01)
F22B 37/12 (2006.01) *F24H 1/16* (2006.01)
F23C 15/00 (2006.01)

(21) International Application Number:

PCT/CA2018/000010

(22) International Filing Date:

15 January 2018 (15.01.2018)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/446,362 13 January 2017 (13.01.2017) US
 2,963,239 05 April 2017 (05.04.2017) CA

(72) Inventor; and

(71) Applicant: **MOVASSAGHI, Mehrzad** [CA/CA]; 1185
 West Georgia Street, Suite 650, Vancouver, British Colum-
 bia V6E 4E6 (CA).

(74) Agent: **URBANEK, Ted B.**; Urbanek Intellectual Property
 Law, 2300 - 1066 West Hastings Street, Vancouver, British
 Columbia V6E 3X2 (CA).

(81) Designated States (unless otherwise indicated, for every
 kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
 CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,
 DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
 HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,
 KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,
 MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
 OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
 SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
 TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every
 kind of regional protection available): ARIPO (BW, GH,
 GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,
 UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
 TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
 EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
 MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
 TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
 KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: SCALABLE PULSE COMBUSTOR

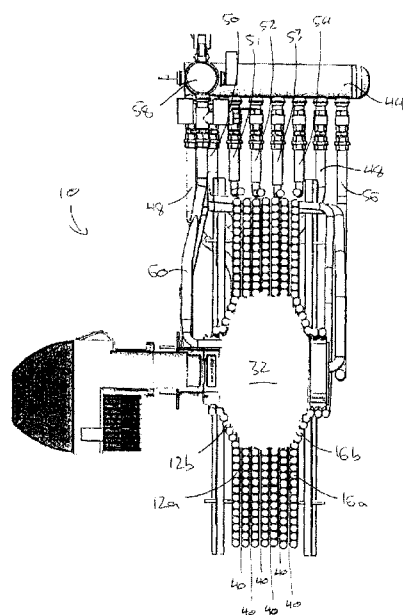


FIG. 3B

(57) Abstract: A scalable pulse combustor that can be deployed as the heat exchanger in high efficiency, low NO_x condensing boilers, water heaters and steam generators is provided. The combustor generally comprises an annular burner coil with a burner flange for accommodating the nozzle of a conventional burner/blower fitted into the central aperture thereof; a spaced-apart opposite annular spreader coil with a heat exchange hub fitted into the central aperture thereof; and a plurality of annular intermediate coils. Each of the burner, spreader and intermediate coils are preferably formed of spiral wound stainless steel tubing, with each winding directly abutting the preceding winding so as to create an annular wall. The heat exchange hub functions as a secondary heat exchanger with its own independently controllable coolant flow.



SCALABLE PULSE COMBUSTOR

Technical Field

In embodiments of the presently disclosed subject matter, there is provided a scalable pulse combustor for generation of heat energy with low NO_x emissions.

Background

A pulse combustor is a device in which air and fuel are mixed in a combustion chamber and periodically self-ignited to create a high energy pulsating flow of combustion products and pressure waves, and may be used for a variety of purposes including the production of heat energy in applications such as high efficiency boilers, water heaters and steam generators.

In a typical radially-configured pulse combustor, a mixture of air and fuel enters a central combustion chamber where it is ignited by a flame rod or spark plug. The explosive combustion of the air/fuel mixture generates a sudden steep rise in pressure and temperature within the combustion chamber, and the resultant pressure waves travel radially outward carrying the combustion gasses towards the perimeter of the combustor via one or more tailpipe regions. Simultaneously, the pressure rise prevents the flow of new volumes of air and fuel into the combustion chamber. Next, the rapid expansion of the combustion gasses, together with cooling through heat exchange at the combustor walls, generates a negative (below ambient) pressure within the combustion chamber. The pressure waves come to an instantaneous rest at the perimeter of the combustor and some combustion gasses exit the chamber, while the rest are taken back towards the chamber in the form of rarefaction waves. At the same time, due to the low pressure within the chamber, a new volume of air/fuel mixture is drawn into the combustion chamber. The rarefaction waves compress this new mixture volume, and with the temperature in the combustion chamber remaining elevated, the new air/fuel mixture is ignited without the need for a spark and the combustion cycle is repeated.

PCT Publication No. WO 97/20171 describes a pulse combustor having a central combustion chamber surrounded by an exhaust chamber, wherein the combustion and exhaust chambers are partially formed between two spaced apart annular “walls” of spiral wound coolant tubing. Each annular wall of coolant tubing comprises an inner frustoconical region and an outer flat-wound region. The central combustion chamber is defined between opposing inner frustoconical regions of two spaced apart walls and central hubs that are welded into the apertures at the center of each wall, and the exhaust chamber or “tailpipe” of the combustor is defined between the opposing generally parallel flat-wound outer regions of the walls. A fuel nozzle receptacle is formed through one of the central hubs, and the opposing central hub includes an inward facing, generally conical surface flame spreader for dispersing the flame radially outwardly through the combustion chamber. The coolant tubing provides a large heat transfer area, and water enters each tube at the perimeter and exits at the center in order to provide a counter flow heat exchange process. A fuel nozzle is located in the nozzle receptacle and a spark generator is provided in the combustion chamber proximate the nozzle in order to ignite the fuel entering the pulse combustor upon startup. Practical limitations as to the maximum reasonable radius of the combustion chamber and tailpipe structure of a two-walled pulse combustor of this sort have, however, generally been found to limit the total amount of power (i.e. BTU's of heat generation) that may be achieved by a two-walled combustor. In particular, two-walled pulse combustors of the sort described in WO 97/20171 are generally not considered to be scalable to achieve an increased power output beyond roughly 600,000 Btu/hr.

U.S. patent number 7,473,094 describes a scalable pulse combustor comprising two spaced apart outer plates and a plurality of annular intermediate plates that are located between the outer plates to enable the generation of increased levels of power as compared to a two-plate combustor. Each of the outer plates has a flat outer region and a frustoconical region inside the flat region, and an associated central hub, and the volume between opposing frustoconical regions and central hubs of the outer plates defines a combustion chamber. The intermediate plates have a larger central opening than that of the outer plates, and are held between the outer plates in generally parallel spaced-apart relationship, transverse to the axis of the combustion chamber, to define a plurality of tailpipes therebetween, and between the outer plates and

adjacent ones of the intermediate plates. Akin to the two-walled (aka two-plate) pulse combustor described in WO 97/20171, each of the outer and intermediate plates may comprise spiral wound coolant tubing. Alternatively, the outer and intermediate plates may comprise spiral coolant passageways formed therein for conducting a cooling fluid to cool expanding gases traveling between the plates through the tailpipe regions. Cooling fluid (e.g. water) enters each tube or passageway through an inlet at the outer perimeter thereof and exits through an outlet proximate the center thereof in order to provide a counter flow heat exchange process.

In embodiments of the '094 pulse combustor that are adapted for use with a conventional burner (illustrated in Fig. 1A of the '094 patent), a burner nozzle operative to ignite a fuel/air mixture within the combustion chamber is fitted into the central hub of a first outer plate, and the central hub of the second, opposite outer plate comprises a generally conical flame spreader (ref. no. 76, Fig. 1A) for dispersing the flame. Each time a fuel/air mixture is ignited, the flame rapidly spreads from the burner towards the flame spreader. Flame temperature varies along the length of a flame, with the tip of a flame normally being hotter than its origin, and consequently the exhaust gasses and air surrounding the flame within a pulse combustor will also have different temperatures along the axial depth (i.e. from the burner nozzle to the flame spreader) of the combustion chamber. As a result, exhaust gas velocity will also vary along the depth of the combustion chamber, with the highest velocity of exhaust gases normally being experienced at the tailpipe that is formed between the opposite outer plate (which holds the flame spreader) and the immediately adjacent intermediate plate. In order to balance and maintain exhaust gas velocity within a desired range as between each of the several individual tailpipes of the multi-plate combustor, and thereby facilitate heat transfer efficiency, and the continued pulsation and low noise operation of the combustor, the flow of gases is accordingly controlled in the '094 pulse combustor by adjusting the spacing between the intermediate plates to create appropriate resistance to flow, wherein each successive tailpipe is narrower than the preceding tailpipe as one approaches the flame spreader. However, as noted in the '904 patent, this method of adjusting the tailpipes becomes impractical if more than three intermediate plates are used, so conventional burner embodiments of the '094 pulse combustor are generally limited to a maximum total of five plates (including all outer and inner plates). In addition, it has been found

that during use of these conventional burner embodiments of the '904 pulse combustor, the flame spreader and the central hub of the opposite outer plate (i.e. the one facing the burner) acts as a heat sink and corrodes over time, in some cases being reduced to powder form within only a few days, and eventually resulting in complete failure of the hub and combustor. The sustained high temperatures of the flame spreader and hub (particularly after heat soak has set in) also result in the production of elevated levels of NO_x, which renders the combustor impractical for many uses. Furthermore, since the cooling fluid outlets for the intermediate plates of the '904 combustor exit through the central hub of the opposite outer plate (see Figs. 3 and 4), the outlet tubes are located in the path of the flame and disrupt its profile, thereby impairing proper flame spread within the combustion chamber.

In an alternative embodiment of the '094 pulse combustor (illustrated in FIG. 1B), a specialized burner assembly is mounted within the combustion chamber in order to minimize the effect that the spacing between the intermediate and outer plates has on exhaust gas velocity. The specialized burner assembly generally comprises an elongated hollow tube having a plurality of nozzle openings spaced around its cylindrical surface to help equalize gas flow into the tailpipe between adjacent ones of said intermediate and outer plates. The opposite central hub in such embodiments comprises a stainless steel plate that is referred to as a "spreader hub" and includes a parabolic cone structure on its inside surface for dispersing the flame (ref. nos. 11 and 22, Fig. 1B) so that the ignited gases may escape uniformly around and along the hollow tube. The arrangement of the holes on each strip, the length of each strip, nozzle profile, and the shape of the cone govern the velocity and distribution of the flame through the cylinder, resulting in a flame that is generally uniformly ejected or distributed from the surface of the cylinder, through the nozzles, and into consecutive tailpipe gaps of the heat exchanger. Although the use of a specialized burner may help overcome the impracticality of adjusting tailpipe spacing, it has been found that the addition of the specialized burner assembly nevertheless does not solve the other deficiencies of the '904 pulse combustor. In particular, the spreader hub and cone structure of such embodiments act as a heat sink in much the same way as do the flame spreader and hub of the alternate embodiments described above, and are similarly susceptible to corrosion and failure, as well as the production of high levels of NO_x.

It is accordingly an object of the present disclosure to provide a scalable pulse combustor for generation of heat energy with low NOx emissions.

Summary

In embodiments of the presently disclosed subject matter, there is provided a scalable pulse combustor that can be deployed as the heat exchanger in high efficiency, low NOx condensing boilers, water heaters and steam generators. The combustor generally comprises an annular burner coil with a burner flange (for accommodating the nozzle of a conventional burner/blower) fitted into the central aperture thereof; a spaced-apart opposite annular spreader coil with a heat exchange hub fitted into the central aperture thereof; and a plurality of annular intermediate coils. Each of the burner, spreader and intermediate coils are preferably formed of spiral wound stainless steel tubing, with each winding directly abutting the preceding winding so as to create an annular “wall” or “plate”, but alternate configurations such as solid annular discs with machined or cast internal fluid passageways may be also be used.

Each of the annular burner and spreader coils comprises a flat-wound outer region and a frustoconical region inside the flat region, and the volume between opposing inner frustoconical regions of: (1) a burner coil together with its associated burner flange, and (2) an opposite spreader coil together with its associated heat exchange hub, defines a combustion chamber. Each of the annular intermediate coils is flat-wound and has a larger central opening than that of the burner and spreader coils, and may preferably be dimensioned so as to generally correspond with or approximate the inner and outer diameters or dimensions of the flat-wound outer regions of the annular burner and spreader coils. The annular intermediate coils are positioned between the burner coil and the spreader coil in generally parallel spaced-apart relationship, transverse to the axis of the combustion chamber, so as to form a plurality of tailpipes between one another, and between an intermediate coil and the flat-wound outer region of an adjacent burner coil or spreader coil. In some embodiments, all of the coils are held in generally parallel orientation in a

vertical plane on support legs or within a frame by adjustable spacer assemblies that affix to tabs welded at selected points along the perimeter of each of the coils.

A cooling fluid such as water is passed under suitable selected pressure through each of the coils, entering through an inlet at the outer perimeter of each coil and exiting through an outlet proximate the center thereof so as to create a counter flow heat exchange process between the cooling fluid and the combustion gases within the combustor, such that a maximum temperature difference may be achieved at all points along the heat exchange surface provided by the coils. Coolant enters each coil at its perimeter where the combustion and exhaust gases are at their lowest temperature, and reaches its hottest point at the center where the gases are also at their hottest. Coolant counter flow accordingly provides a highly efficient process for the transfer of heat energy from the combustion and exhaust gases to the cooling fluid, and reduces or eliminates the possibility of a “thermal shock” occurrence. In order to avoid potential disruption of the flame profile within the combustion chamber, the outlet tubes of the burner coil and all intermediate coils are oriented so as to exit the combustor through the burner flange. The outlet tube of the spreader coil exits from the rear of the combustor, adjacent the heat exchange hub for the same reason. As outlined in further detail below, the inlets and outlets of all of the coils may preferably be connected to external common manifolds.

The heat exchange hub is generally disc shaped, and comprises a chamber through which a cooling fluid may be passed to function as a secondary heat exchanger located at the “opposite” end of the combustion chamber (i.e. opposite the burner/blaster), without appreciably increasing the external dimensions of the combustor. In some preferred embodiments, the internal chamber of the heat exchange hub defines a spiral passageway for the cooling fluid, with coolant entering the hub through an inlet adjacent the periphery thereof and exiting through an outlet near or at the center. In other embodiments, the internal passageway of the heat exchange hub may be sinusoidal or any other shape that promotes a one-way circulation of cooling fluid through the heat exchange hub, such that during use of the combustor, coolant may enter the heat exchange hub through an inlet at a first temperature and exit through an outlet at a second, higher temperature. By way of example, the heat exchange hub may comprise two plates of stainless

steel welded to one another, wherein at least one plate has had a spiral water passageway machined or cast into it before the other plate is welded on top. In another example, the heat exchange hub may comprise three components, wherein a middle element that comprises separator blades to form a zig-zag or sinusoidal passageway for coolant is welded between two outer plates that function as caps. Both the cooling fluid inlet and outlet of the heat exchange hub are formed along the outer rear flat surface of the hub. The lateral side profile of the hub comprises corrugations or “grooves” that correspond with the diameter of the tubing from which the spreader coil is constructed so that the heat exchange hub can be fitted into the innermost rows of the spreader coil without welding. Accordingly, even in cases where a very large temperature gradient may exist as between the heat exchange hub the adjacent spreader coil, the coil is free to expand/contract along the perimeter of the hub, and thermal stresses are not converted into shear stresses between the coil and hub. This greatly reduces the possibility of material failure due to destructive shear stresses generated by thermal stresses, and thus extends the service life of the combustor.

A separate control valve is associated with the cooling fluid inlet of the heat exchange hub so that the rate of coolant flow through the heat exchange hub can be separately and individually controlled, independently of the flow through the spreader coil, intermediate coils, and burner coil of the combustor. This enables the coolant within the heat exchange hub to be maintained at a suitable temperature that not only avoids possible overheating of the coolant, but importantly also prevents the heat exchange hub itself from becoming or behaving like a heat sink. This in turn enables control of the combustion gas temperature in the vicinity of the heat exchange hub, and thus also control of combustion gas velocity in the vicinity of the heat exchange hub within the combustion chamber.

This ability to control of the combustion gas temperature and velocity in the vicinity of the heat exchange hub reduces or eliminates the need to individually set the gaps between successive intermediate coils in the combustor (as is required in prior art multi-plate combustors to balance and maintain exhaust gas velocity within a desired range as between each of the individual tailpipes), whilst still accommodating the use of a conventional burner. Pulse combustors having

more than three intermediate coils may accordingly also be readily accommodated without requiring the use of a specialized burner assembly. Furthermore, although the highest flame temperatures within the combustor may be expected to occur in the vicinity of the heat exchange hub on account of the direction of flame travel (i.e. from the burner to the heat exchange hub), the temperature of the heat exchange hub can be maintained below the $\sim 1,500^{\circ}\text{C}$ that is required for the formation of NO_x , and below a temperature at which the hub becomes susceptible to corrosion and failure.

The burner flange is a generally annular structure with a central aperture or bore that is dimensioned to accommodate a conventional burner/blower that has desired suitable flame capacity, and with a plurality of smaller apertures or bores arranged peripherally around the central aperture to accommodate the cooling fluid outlet extensions and/or tubes of all intermediate coils (so as to permit the heated coolant from these coils to exit the combustor at the front and out of the main path of the burner flame). The number of peripheral apertures in the burner flange corresponds to the number of intermediate coils of the combustor. The lateral side profile of the burner flange is preferably corrugated or “grooved” akin to that of the heat exchange hub, with the grooves corresponding with the diameter of the tubing from which the burner coil is constructed so that the burner flange can be fitted into the first rows of the burner coil without welding.

The cross-sectional profiles of the spreader and burner coils are essentially mirror images of one another, with suitable changes made to the outlets and inlets as required to accommodate preferred orientations for cooling fluid intake and outlet extensions. In cases where either or both of the spreader and burner coils comprise solid discs with machined or cast internal fluid passageways, the corresponding heat exchange hub or burner flange may have a lateral profile that is slightly thicker than that of the corresponding coil, and include removable upper and/or lower bracket elements to enable the hub and/or burner to be fitted into its corresponding coil without welding in an analogous manner to the grooved embodiments described above.

As noted above, a cooling fluid such as water is passed under pressure through each of the coils when in use to generate a counter flow heat exchange process between the cooling fluid and the combustion gases within the combustor. In some embodiments, the cold water inlet tubes of the burner coil, spreader coil, all intermediate coils, and the heat exchanger hub are all connected by suitable tubing to a common cold water inlet manifold external to the combustor, and similarly the hot water outlet (i.e. exit) tubes of the burner coil, spreader coil, all intermediate coils, and the heat exchanger hub are all connected by suitable tubing to a common hot water outlet manifold. At least one of the common manifolds includes suitable valves for controlling the flow of coolant through the coils, and as noted above, at least one of the inlet and outlet tubes of the heat exchange hub (and/or at least one of the inlet and outlet manifolds themselves) include a separate control valve to enable the rate of coolant flow through the heat exchange hub to be separately and individually controlled, independently of the flow through the combustor coils. Embodiments in which additional valves are used to individually control of coolant flow through any one or more of the spreader coil, intermediate coils, and burner coil of the combustor are also contemplated.

In some embodiments, a flame detecting sensor may be installed inside the combustion chamber. As soon as flame is established, signals are sent from this sensor to a control panel and the flame rod or spark plug is switched off.

By employing a heat exchange hub instead of a spreader plate as in the prior art, the oxidation problems associated with the prior art spreader plate (which may occur due to direct flame impingement against a heat sink) and consequent additional maintenance/service work that would involve total dis-assembly of the combustor and re-welding of a new plate are generally avoided. Also avoided are the operational restrictions of prior art multi-plate pulse combustors, which are related to the need for certain optimum depth of the combustion chamber and readjustment of gaps between coils. In the presently described combustor, the hub functions as a heat exchanger and therefore it will never become a heat sink during normal use, especially in that it has its own flow valve and water flow rate that can be controlled independent of water flow rates through the coils. This virtually or entirely eliminates the possibility of NO_x

formation because the temperature of the heat exchange hub can be maintained below the $\sim 1,500$ °C required for NO_x formation.

Flame speed and length are a function of burner head configuration, as determined by the manufacturer, and are essentially independent of the dimensions of the chamber in which the flame front propagates. In preferred embodiments of the presently described combustor, combustion chamber axial depth is selected to be between 50% - 75% of the length of the flame, and depending on the flame length, speed and ratio of flame length to combustion chamber depth, the taper angle θ of the frustoconical region of the spreader coil is set within a range of between about $68 \geq \theta \geq 63$ degrees. Embodiments where combustion chamber depth is between about 25% - 85% are also possible. However if the combustion chamber depth is below about 25% of flame length, then combustion may become choked off and flame flashbacks may be experienced. If combustion chamber depth is above 85% of flame length, then proper flame distribution may not be achieved.

The term “specific heat transfer surface” defines how much heat is transferred per unit of surface area (e.g. per square foot or square meter), and to achieve the desired efficiency in a scalable pulse combustor, there should be no less than about 7500 Btu/hr for every square foot and no more than about 9500 Btu/hr for every square foot. For example, a 10 mBtu/hr combustor will require a total heat transfer surface of at least about 1,052 square feet (i.e. $10,000,000 \div 9500$) and at the most about 1,333 square feet (i.e. $10,000,000 \div 7500$). This gives the “total” required heat transfer surface. Then based on the ratio of the radial length of the frustoconical region of the spreader “r” to the radial length of the flat-wound region of the spreader “R” (i.e. r/R), and depth of the combustion chamber, one can determine how many intermediate coils are desired and what the ultimate radius “R” of the coils should be (or how many intermediate coils will be required if a certain radius “R” is mandated). Preferred values of tailpipe gap width are typically determined using computational fluid dynamic simulation modelling, using a series of fluid dynamic criteria and equations that involve the flame velocity of propagation, the temperature gradient along the length of the flame, the velocity of exhaust gases, and the angle θ . In a typical application, a tailpipe gap width of between about 4 – 6 mm has been found to be suitable.

Brief Description of the Drawings

For a fuller understanding of the nature and advantages of the disclosed subject matter, as well as the preferred modes of use thereof, reference should be made to the following detailed description, read in conjunction with the accompanying drawings. In the drawings, like reference numerals designate like or similar steps or parts.

Figure 1 is an isometric view of the rear (spreader coil) side of a scalable pulse combustor in accordance with one embodiment of the presently described subject matter.

Figure 2 is an isometric view of the front (burner coil) side of the combustor of Fig. 1.

Figures 3A and 3B are partially sectional side elevation views of the combustor of Fig. 1 in combination with a conventional burner/blower.

Figure 4 is a front elevation of the combustor of Fig. 1.

Figure 5 is a rear elevation of the spreader coil assembly of the combustor of Fig. 1, showing the water inlet and outlet extension tubes of the spreader coil and of the heat exchange hub that acts as a secondary heat exchanger.

Figure 6 is a partially sectional rear elevation view of the combustor of Fig. 1 with the spreader coil removed to show the inner orientation of the water outlet extension tubes of the first to fifth intermediate coils exiting the combustor through the burner flange.

Figures 7A – 7C are, respectively, isometric, side elevation and front elevation views of a representative burner coil for a scalable pulse combustor in accordance with embodiments of the presently described subject matter.

Figures 8A – 8C are, respectively, isometric, side elevation and front elevation views of the burner coil assembly of the combustor of Fig. 1, illustrating the burner coil in combination with the burner flange and with the burner coil inlet and outlet extension tubes.

Figures 9A – 9C are, respectively, isometric, side elevation and rear elevation views of a representative spreader coil for a scalable pulse combustor in accordance with embodiments of the presently described subject matter.

Figures 10A – 10C are, respectively, isometric, side elevation and rear elevation views of the spreader coil assembly of the combustor of Fig. 1, illustrating the spreader coil in combination with the heat exchange hub and with the inlet and outlet extension tubes for both of the spreader coil and heat exchange hub.

Figure 11 is a front elevation of a representative intermediate coil for a scalable pulse combustor in accordance with embodiments of the presently described subject matter.

Figures 12A – 12C are, respectively, isometric, side elevation and front elevation views of the first intermediate coil of the combustor of Fig. 1, illustrating the first intermediate coil in combination with its inlet and outlet extension tubes.

Figures 13A – 13C are, respectively, isometric, side elevation and front elevation views of the second intermediate coil of the combustor of Fig. 1, illustrating the second intermediate coil in combination with its inlet and outlet extension tubes.

Figures 14A – 14C are, respectively, isometric, side elevation and front elevation views of the third intermediate coil of the combustor of Fig. 1, illustrating the third intermediate coil in combination with its inlet and outlet extension tubes.

Figures 15A – 15C are, respectively, isometric, side elevation and front elevation views of the fourth intermediate coil of the combustor of Fig. 1, illustrating the fourth intermediate coil in combination with its inlet and outlet extension tubes.

Figures 16A and 16B are, respectively, isometric and front elevation views of the fifth intermediate coil of the combustor of Fig. 1, illustrating the fifth intermediate coil in combination with its inlet and outlet extension tubes.

Figure 17 is a partially sectional rear elevation view of the heat exchange hub of the combustor of Fig. 1, showing the spiral machined or cast inner passage ways for cooling fluid.

Figure 18 is a sectional side view of the spreader coil and heat exchange hub of the combustor of Fig. 1, showing the grooved lateral profile and the flat surfaces of the inner and outer caps of the heat exchange hub.

Figures 19A – 19C are, respectively, partially sectional isometric, rear elevation, and side elevation views of an alternate embodiment of a heat exchange hub for a scalable pulse combustor in accordance with embodiments of the presently described subject matter.

Figure 20A and 20B are, respectively, side elevation and isometric views of the burner flange of the combustor of Fig. 1.

Figure 21 is a schematic side elevation of the spreader coil of the combustor of Fig. 1, showing taper angle “ θ ” and ratio “ r/R ”.

Detailed Description of Specific Embodiments

The following description of specific embodiments is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses. With reference to Figures 1 - 4, one embodiment of a scalable pulse combustor 10 in accordance with the presently described subject

matter is illustrated. Combustor 10 generally comprises an annular burner coil 12 with a burner flange 14 fitted into the central aperture thereof; a spaced-apart opposite annular spreader coil 16 with a heat exchange hub 18 fitted into the central aperture thereof; and five annular intermediate coils 20, 21, 22, 23 and 24. As illustrated in Figures 3A and 3B, the burner head 26 of a conventional burner/blower 28 may be accommodated within a central bore 30 of burner flange 14, and may be secured therein by conventional fasteners such as bolts or screws (not shown).

Each of the burner coil 12, spreader coil 16 and intermediate coils 20 – 24 are preferably formed of spiral wound stainless steel tubing, with each winding directly abutting the preceding winding so as to create a “wall” or “plate”. However, alternate configurations such as solid cast or machined annular discs with internal fluid passageways are also contemplated. Annular burner coil 12 and annular spreader coil 16 each comprise a flat-wound outer region (12a and 16a, respectively) and a frustoconical inner region (12b and 16b, respectively), whilst each of the annular intermediate coils 20 – 24 are flat-wound and have a central opening that is larger than that of burner coil 12 or spreader coil 16. The central opening of intermediate coils 20 – 24 is selected with reference to the diameter of the flame produced by conventional burner/blower 28, such that the intermediate coils 20 – 24 do not disturb the flame profile or its boundary layer. In some embodiments, each of the annular intermediate coils 20 – 24 are further dimensioned so as to correspond with or approximate the inner and outer diameters of the flat-wound outer regions of the annular burner coil 12a and spreader coil 16a.

As illustrated in Figure 3B, the volume delineated between frustoconical inner region 12b of burner coil 12 together with its associated burner flange 14, and opposing frustoconical inner region 16b of spreader coil 16 together with its associated heat exchange hub 18, defines a combustion chamber 32 having a central axis that extends between the burner flange 14 and the heat exchange hub 18. Support legs 34 with adjustable brackets 36, preferably comprising stainless steel bolt and nut spacer assemblies that affix to tabs 38 welded at selected points along the perimeter of each of the coils, are provided to hold the annular burner coil 12, spreader coil 16 and intermediate coils 20 – 24 in generally parallel spaced-apart relationship at a selected distance from one another and oriented transverse to the axis of the combustion chamber 32,

thereby forming a plurality of tailpipes 40 between adjacent intermediate coils, and between an intermediate coil and the flat-wound outer region of an adjacent burner coil or spreader coil. In other words, in the specific embodiment illustrated, the tailpipes 40 comprise the gaps formed on either side of each of intermediate coils 21 – 23, the gap formed between intermediate coil 20 and outer region 12a of burner coil 12, and the gap formed between intermediate coil 24 and outer region 16a of spreader coil 16.

As outlined in the summary above, a cooling fluid such as water is passed under suitable selected pressure through each of the annular burner coil 12, spreader coil 16 and intermediate coils 20 – 24 when the combustor 10 is in use in order to generate a counter flow heat exchange process between the cooling fluid and the combustion gases within the combustor 10. Heat exchange hub 18 functions as a secondary heat exchanger with its own independently controllable coolant flow. The cooling fluid enters each of the coils through an inlet at the outer perimeter of each coil and exits through an outlet proximate the center thereof so as to create the counter flow heat exchange process between the cooling fluid and the combustion gases within the combustor, such that a maximum temperature difference may be achieved at all points along the heat exchange surface provided by the coils. Coolant enters each coil at its perimeter where the combustion and exhaust gases are at their lowest temperature, and reaches its hottest point at the center where the gases are also at their hottest. Coolant counter flow accordingly provides a highly efficient process for the transfer of heat energy from the combustion and exhaust gases to the cooling fluid, and reduces or eliminates the possibility of a “thermal shock” occurrence.

In the illustrated embodiment, the coolant inlets of coils 12, 16 and 20 – 24, and heat exchange hub 18, are connected by stainless steel tubing to a common cold water inlet manifold 44, and the coolant outlets of coils 12, 16 and 20 – 24, and heat exchange hub 18, are connected by stainless steel tubing to a common hot water outlet manifold 58. Figure 1 illustrates the connection by between common cold water inlet manifold 44 and burner coil 12, spreader coil 16, intermediate coils 20 – 24 and heat exchange hub 18, respectively, via inlet tubes 46, 48, 50-54 and 56, respectively. Figure 2 illustrates the connection between common hot water outlet manifold 58 and the burner coil 12, spreader coil 16, intermediate coils 20 – 24 and heat

exchange hub 18 via outlet tubes 60, 62, 64-68 and 70, respectively. Control valves 60a, 62a, 64a-68a and 70a of outlet tubes 60, 62, 64-68 and 70, respectively, are provided adjacent the hot water outlet manifold 58 to enable individual control of the rate of coolant flow through the heat exchange hub 18, as well as through each of burner coil 12, spreader coil 16 and intermediate coils 20 – 24.

A separate control valve 70a is associated with the cooling fluid outlet 70 of the heat exchange hub 18 so that the rate of coolant flow through the heat exchange hub 18 can be separately and individually controlled, independently of the flow of coolant through the spreader coil 16, intermediate coils 20 – 24, and burner coil 12 of the combustor 10. This enables the coolant within the heat exchange hub 18 to be maintained at a suitable temperature that not only avoids possible overheating of the coolant, but importantly also prevents the heat exchange hub 18 itself from becoming or behaving like a heat sink. This in turn enables control of the combustion gas temperature in the vicinity of the heat exchange hub 18, and thus also control of combustion gas velocity in the vicinity of the heat exchange hub 18 within the combustion chamber 10. This ability to control of the combustion gas temperature and velocity in the vicinity of the heat exchange hub 18 reduces or eliminates the need to individually set the gaps between successive intermediate coils 20 – 24 in the combustor 10 whilst still accommodating the use of a conventional burner 28. Pulse combustors having more than three intermediate coils may accordingly also be readily accommodated without requiring the use of a specialized burner assembly. Furthermore, although the highest flame temperatures within the combustor 10 may be expected to occur in the vicinity of the heat exchange hub 18 on account of the direction of flame travel (i.e. from the burner 28 to the heat exchange hub 18), the temperature of the heat exchange hub 18 can be maintained below the ~1,500 °C that is required for the formation of NO_x, and below a temperature at which the hub 18 becomes susceptible to corrosion and failure.

As best seen in Figure 6, hot water outlet (exit) tubes 64 – 68 of intermediate coils 20 – 24, respectively, all exit the combustion chamber 32 through the burner flange 14. In this case, since combustor 10 comprises five intermediate coils, burner flange 14 has five corresponding peripheral apertures to accommodate the five outlet (exit) tubes 64 – 68. The number of

peripheral apertures in the burner flange thus corresponds with the number of intermediate coils of the combustor, such that for a combustor having, say, ten intermediate coils, the burner flange would comprise ten corresponding peripheral apertures. As best seen in Figures 5 and 10, coolant inlet tube 48 of spreader coil 16 and coolant inlet tube 56 of heat exchange hub 18, as well as coolant outlet tube 62 of spreader coil 16 and coolant outlet tube 70 of heat exchange hub 18, are routed along the rear side of combustor 10 so as not to pass through the combustion chamber 32.

Referring to Figures 17 and 18, heat exchange hub 18 of combustor 10 is generally disc shaped, and comprises an internal chamber 72 through which a cooling fluid may be passed to function as a secondary heat exchanger located at the “opposite” end of the combustion chamber 10 (i.e. opposite the burner/blaster 28), without appreciably increasing the external dimensions of the combustor 10. Internal chamber 72 of heat exchange hub 18 defines a spiral passageway for the cooling fluid, with coolant entering the hub through inlet 56 adjacent the periphery of the hub 18 and exiting through outlet 70 at the center of hub 18. Both the inlet 56 and the outlet 70 are formed along the outer rear flat surface 74 of hub 18 so that the inlet and outlet tubes do not pass through combustion chamber 32 as discussed above. The lateral side profile 76 of hub 18 comprises corrugations or “grooves” that correspond with the diameter of the tubing from which spreader coil 16 is constructed so that hub 18 can be fitted into the innermost rows of spreader coil 16 without welding. Accordingly, even in cases where a very large temperature gradient may exist as between the heat exchange hub 18 the adjacent spreader coil 16, coil 16 is free to expand/contract along the perimeter of hub 18, and thermal stresses are not converted into shear stresses between the coil 16 and hub 18. This greatly reduces the possibility of material failure due to destructive shear stresses generated by thermal stresses, and thus extends the service life of the combustor 10.

Figures 19A – 19C illustrate an alternative embodiment of a heat exchange hub 18x comprising a plurality of internal water spreaders 78 in place of the spiral internal chamber 72 of the embodiment shown in Figures 17 and 18. As with the hub 18 of Figures 17 and 18, water spreaders 78 of this alternate embodiment promote a one-way circulation of cooling fluid

through the heat exchange hub, such that during use of the combustor 10, coolant may enter the heat exchange hub through an inlet at a first temperature and exit through an outlet at a second, higher temperature. In order for the flow of coolant to complete a full “circuit” through the entirety of the alternative heat exchange hub 18x of Figure 19, coolant inlet 56x is positioned at one end along rear flat surface 74x of the hub 18x (as is the case with hub 18 of Figures 17 and 18) corresponding to a first end of the internal maze created by water spreaders 78, and coolant outlet 70x is positioned at the opposite end of alternative hub 18x (unlike hub 18, in which outlet is positioned at the center) corresponding to the opposite end of the internal maze created by water spreaders 78. As with heat exchange hub 18 of combustor 10, the lateral side profile 76x of hub 18x also comprises corrugations or “grooves” that correspond with the diameter of the tubing from which spreader coil 16 is constructed so that hub 18x can be fitted into the innermost rows of spreader coil 16 without welding. This is best illustrated in Figure 19C.

Referring to Figures 20A and 20B, burner flange 14 of combustor 10 is a generally annular structure with a central aperture or bore 30 that is dimensioned to accommodate a conventional burner/blower with desired flame capacity. A plurality of smaller apertures or bores 80 are arranged peripherally around the central aperture to accommodate the cooling fluid outlet extensions and/or tubes of all intermediate coils 20 – 24 (so as to permit the heated coolant from these coils to exit the combustor at the front and out of the main path of the burner flame). In the illustrated embodiment, there are five bores 80, one to accommodate the outlet tube of each of intermediate coils 20 – 24. As noted above, the number of peripheral apertures in a given burner flange corresponds with the number of intermediate coils of the combustor in which it is employed. As with heat exchange hub 18 discussed above, the lateral side profile of burner flange 14 comprises corrugations or “grooves” 82 that correspond with the diameter of the tubing from which burner coil 12 is constructed so that burner flange 18 can be fitted into the innermost rows of burner coil 12 without welding.

Every conventional burner/blower assembly is equipped with an ignition system (e.g. an ignition rod or spark plug). In the illustrated embodiment, a conventional burner/blower 28 is secured in combustor 10, with burner head 26 installed through the central aperture 30 of burner flange 14

of burner coil 12. A volume of air and gas mixture is ignited by the ignition rod or spark plug (not shown) of conventional burner/blower 28 as it leaves the burner head 26 and enters the combustion chamber 32. The combustion results in instantaneous rise of pressure inside the combustion chamber 32. This generates pressure waves that carry the exhaust products radially outwards through the tailpipe 40 gaps between the coils 12, 16 and 20 – 24 towards the perimeter of the coils. As well, this rapid rise in pressure stops the flow of fresh air and gas mixture into the combustion chamber 32. At the same time, cold water flows through each coil 12, 16, and 20 – 24 from the perimeter towards the center of each coil, resulting in a counter flow heat exchange between the water and hot exhaust gases. Rapid expansion of the exhaust gases (carried by said pressure waves) together with cooling of said gases through said counter flow heat exchange results in a negative pressure being created inside the combustion chamber 32. Consequently, with the pressure inside the combustion chamber 32 being below that of the surrounding ambient atmospheric pressure, the exhaust gases reaching the perimeter of the coils of the scalable combustor come to an instantaneous rest; some exit the combustor and the remaining exhaust gases return towards the combustion chamber through rarefaction waves (i.e. waves moving in opposite direction to the pressure waves at lower velocities). The negative pressure created inside the combustion chamber 32 draws a new volume of air/gas mixture into the combustion chamber from the burner 28. The rarefaction waves entering the combustion chamber compress this new mixture volume, and with the temperature of the combustion chamber still being high, this new volume of air and gas mixture is ignited, another combustion occurs, and the cycle is repeated.

The flame tip impinges on the heat exchange hub 18, which is functioning as a secondary heat exchanger. Furthermore, all water outlet tubes associated with internal coils 20 – 24 exit the combustion chamber through the perimeter of burner flange 14, which is above the burner head 26. As well, the diameters of the hollow central sections of the intermediate coils 20 – 24 are always larger than flame diameter. As such, the flame profile and its velocity remain undisturbed along the depth of the combustion chamber 32 throughout the flame length. The flame impinges on the flat surface of the heat exchange hub 18 and spreads over the inner frustoconical region 16b of the spreader coil 16. The length “r” (see Figure 21) of the frustoconical section of

the spreader coil 16 and the taper angle θ (Figure 21) are so calculated that the flame is spread uniformly along the said lengths and over the intermediate coils and the burner coil, thus maintaining the combustion gases at a uniform temperature along the depth of the combustion chamber. Therefore, all tailpipe 40 gaps between adjacent coils can be the same and there is no need to adjust each gap separately.

As noted above, by employing a heat exchange hub 18 instead of a spreader plate as in the prior art, the oxidation problems associated with the prior art spreader plate (which may occur due to direct flame impingement) and consequent additional maintenance/service work that would involve total dis-assembly of the combustor and re-welding of a new plate are avoided. Also avoided are the operational restrictions of prior art multi-plate pulse combustors, which are related to the need for certain optimum depth of combustion chamber and readjustment of gaps between coils. In the presently described combustor, the heat exchange hub 18 will never become a heat sink during normal use, especially in that it has its own flow valve and water flow rate that can be controlled independent of water flow rates through the coils. This virtually or entirely eliminates the possibility of NO_x formation because the temperature of the heat exchange hub can be maintained below the ~1,500 °C required for NO_x formation.

Flame speed and length are a function of burner head configuration, as determined by the manufacturer, and are essentially independent of the dimensions of the chamber in which the flame front propagates. In preferred embodiments of the presently described combustor, combustion chamber depth is selected to be between 50% - 75% of the length of the flame, and depending on the flame length, speed and ratio of flame length to combustion chamber, the taper angle θ of the frustoconical region of the spreader coil is set within a range of between about $68 \geq \theta \geq 63$ degrees. Embodiments where combustion chamber depth is between about 25% - 85% are also possible. However if the combustion chamber depth is below about 25% of flame length, then combustion may be choked off and flame flashbacks may be experienced. If combustion chamber depth is above 85% of flame length, then proper flame distribution may not be achieved.

Specific heat transfer surface defines how much heat is transferred per unit of surface area (e.g. per square foot or square meter), and to achieve the desired efficiency in a scalable pulse combustor, there should be no less than about 7500 Btu/hr for every square foot and no more than about 9500 Btu/hr for every square foot. For example, a 10 mBtu/hr combustor will require a total heat transfer surface of at least about 1,052 square feet (i.e. $10,000,000 \div 9500$) and at the most about 1,333 square feet (i.e. $10,000,000 \div 7500$). This gives the “total” required heat transfer surface. Then based on the ratio of the radial length of the frustoconical region of the spreader “r” to the radial length of the flat-wound region of the spreader “R” (i.e. r/R – see Figure 21), and depth of the combustion chamber, one can determine how many intermediate coils are desired and what the ultimate radius “R” of the coils should be (or how many intermediate coils will be required if a certain radius “R” is mandated). Preferred values of tailpipe gap width are typically determined using computational fluid dynamic simulation modelling, using a series of fluid dynamic criteria and equations that involve the flame velocity of propagation, the temperature gradient along the length of the flame, the velocity of exhaust gases, and the angle θ . In a typical application, a tailpipe gap width of between about 4 – 6 mm has been found to be suitable.

The present description is of the best presently contemplated mode of carrying out the subject matter disclosed herein. The description is made for the purpose of illustrating the general principles of the subject matter and not to be taken in a limiting sense; the described subject matter can find utility in a variety of implementations without departing from the scope of the invention made, as will be apparent to those of skill in the art from an understanding of the principles that underlie the invention.

CLAIMS

1. A scalable pulse combustor for use with a conventional burner, the pulse combustor comprising:
 - an annular burner coil or plate with a burner flange for accommodating the conventional burner fitted into a central aperture thereof;
 - a spaced-apart opposite annular spreader coil or plate with a heat exchange hub fitted into a central aperture thereof; and
 - at least one annular intermediate coil or plate located in spaced-apart relationship between and substantially parallel to the burner coil and the spreader coil;
 - wherein a combustion chamber is defined between the burner coil or plate and the spreader coil or plate, and a plurality of tailpipe regions are defined on both sides of each of the at least one annular intermediate coils;
 - wherein each of the burner, spreader and intermediate coils or plates comprises a coolant passageway for conducting coolant therethrough, and an inlet and outlet for the coolant passageway; and
 - wherein the heat exchange hub comprises a coolant passageway for conducting coolant therethrough, and an inlet and outlet for the coolant passageway.
2. A heat exchanger comprising the scalable pulse combustor of claim 1 in combination with a conventional burner.
3. The scalable pulse combustor of claim 1, wherein each of the burner and spreader coils or plates comprises an inner frustoconical region and an outer flat region, and wherein each of the at least one intermediate coils is flat.
4. The scalable pulse combustor of claim 1, further comprising a valve body operatively connected to the inlet and outlet of each of the burner, spreader and intermediate coils and the heat exchange hub for controlling the flow of coolant therethrough, and wherein

the valve body is configured to permit independent control of coolant flow through the heat exchange hub vis-à-vis the flow of coolant through the burner, spreader and intermediate coils.

5. The scalable pulse combustor of claim 1, wherein the coolant outlet of each of the burner, spreader and intermediate coils exits the combustor through the burner flange.
6. The scalable pulse combustor of claim 1, wherein the heat exchange hub comprises a grooved outer lateral profile dimensioned for fitting into the central aperture of the spreader coil without welding.
7. The scalable pulse combustor of claim 1, wherein the burner flange comprises a grooved outer lateral profile dimensioned for fitting into the central aperture of the burner coil without welding.
8. The scalable pulse combustor of claim 1, wherein the combustion chamber depth is between 25% and 85% of the flame length of the conventional burner.
9. The scalable pulse combustor of claim 1, wherein the combustion chamber depth is between 50% and 75% of the flame length of the conventional burner.
10. The scalable pulse combustor of claim 3, wherein the inner frustoconical region of the spreader coil has a taper angle θ of between $68 \geq \theta \geq 63$ degrees.

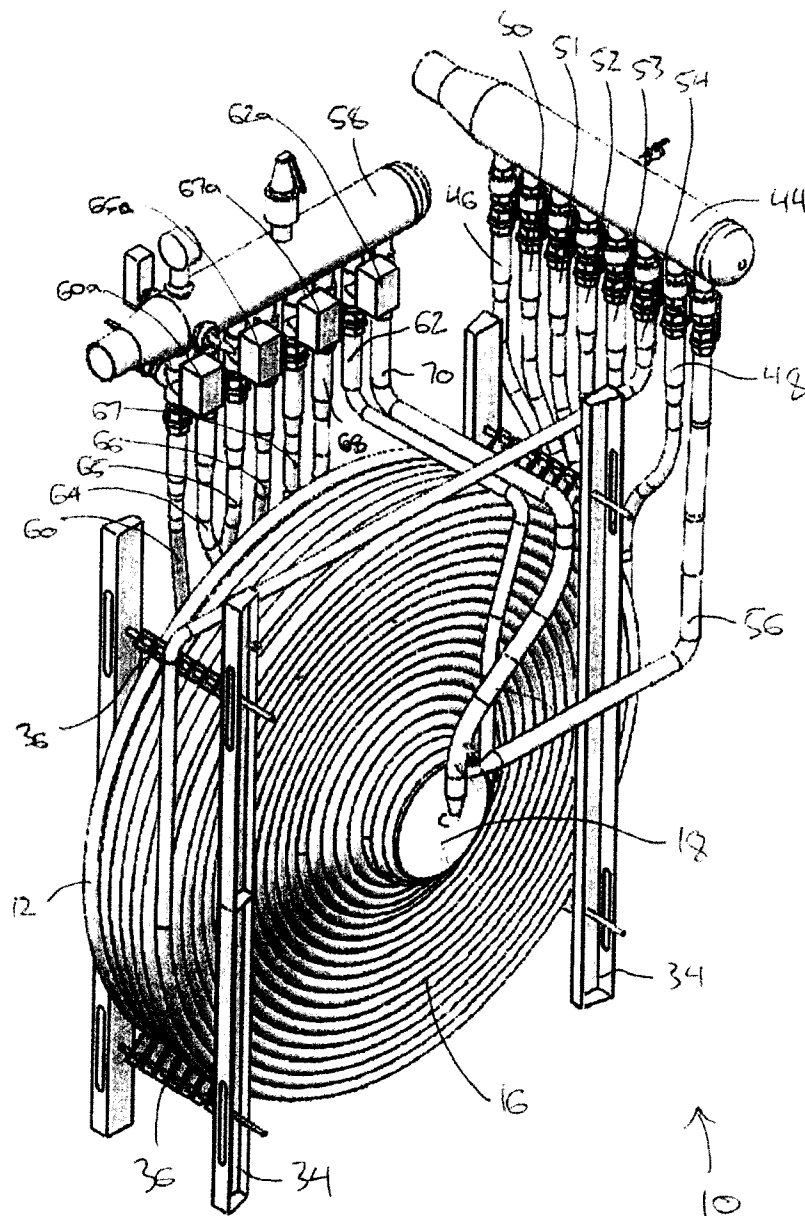


FIG. 1

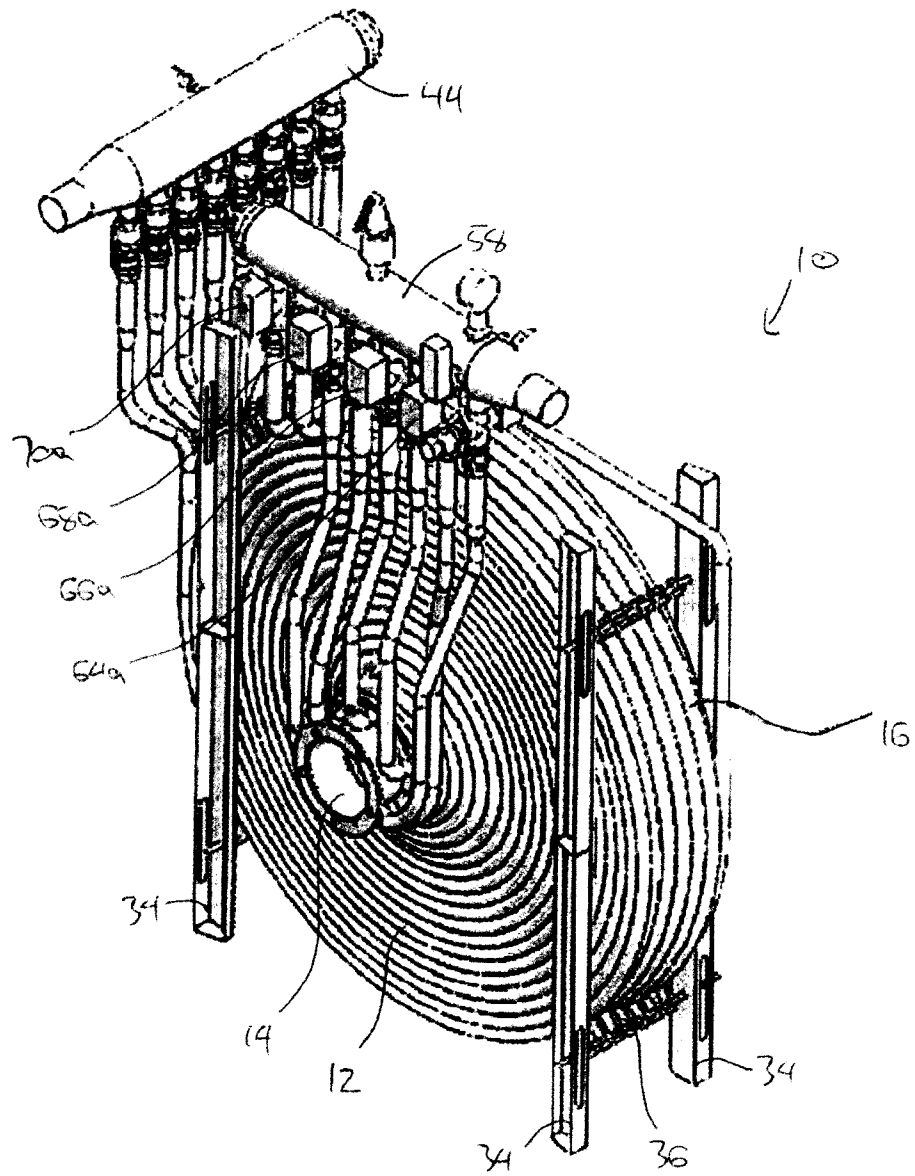


FIG. 2

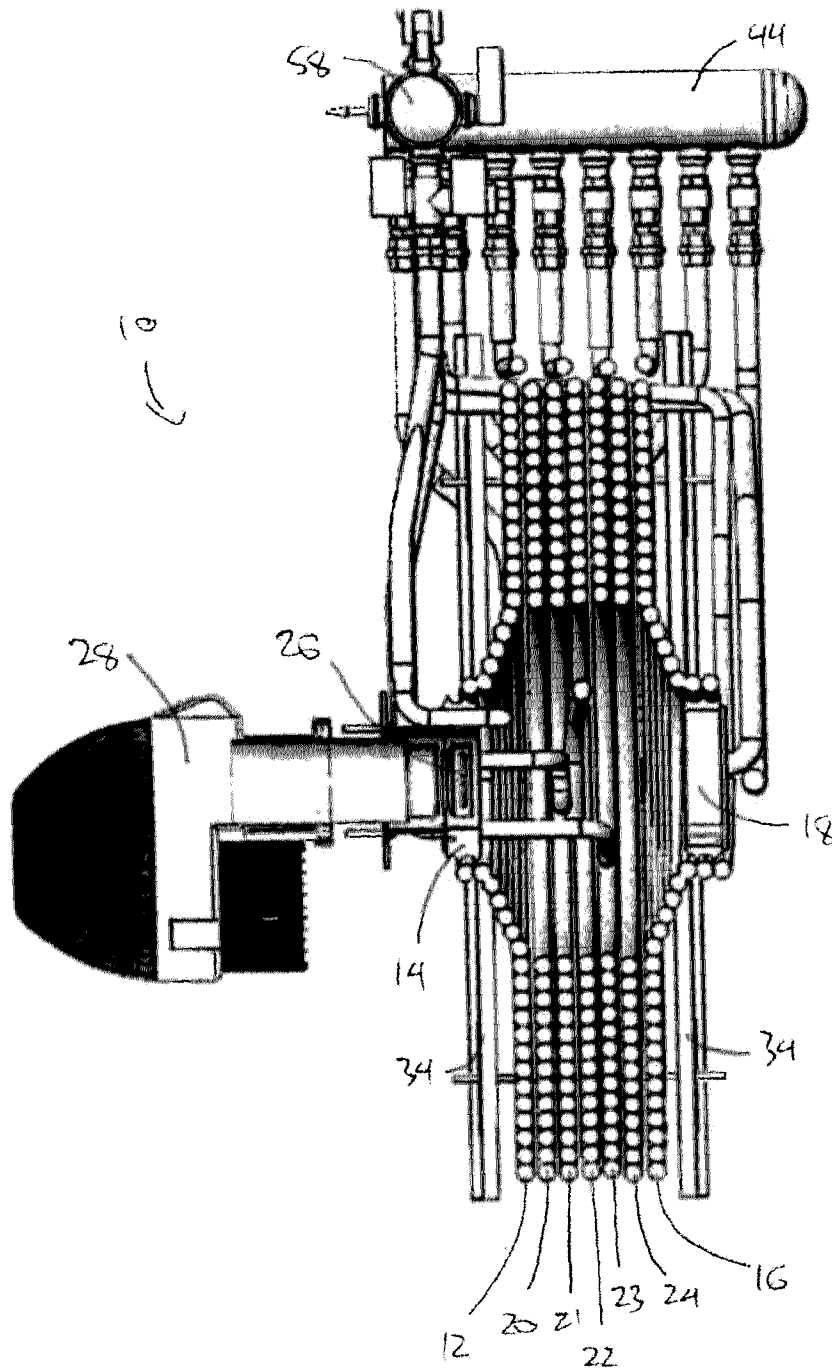


FIG. 3A

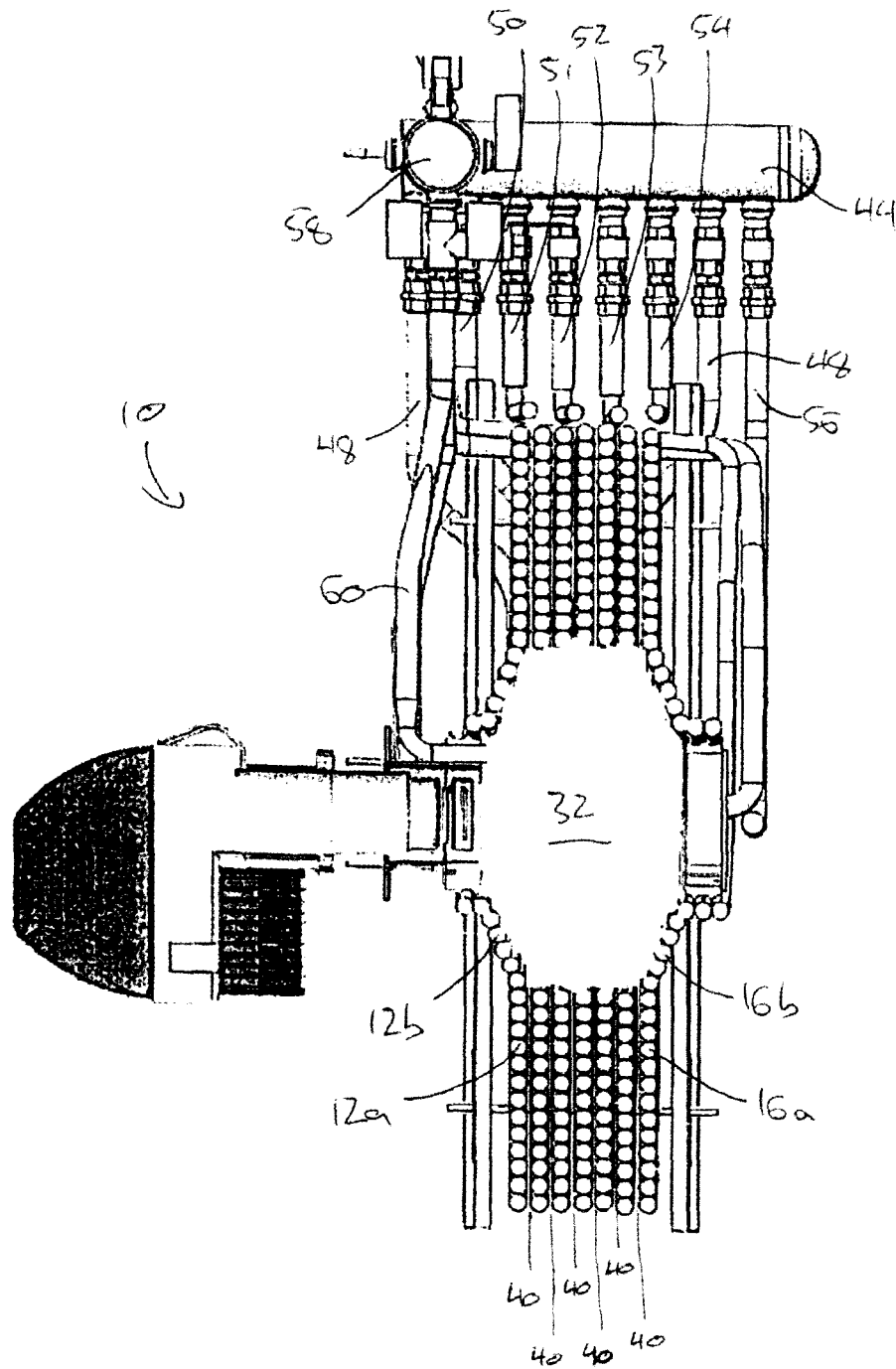


FIG. 3B

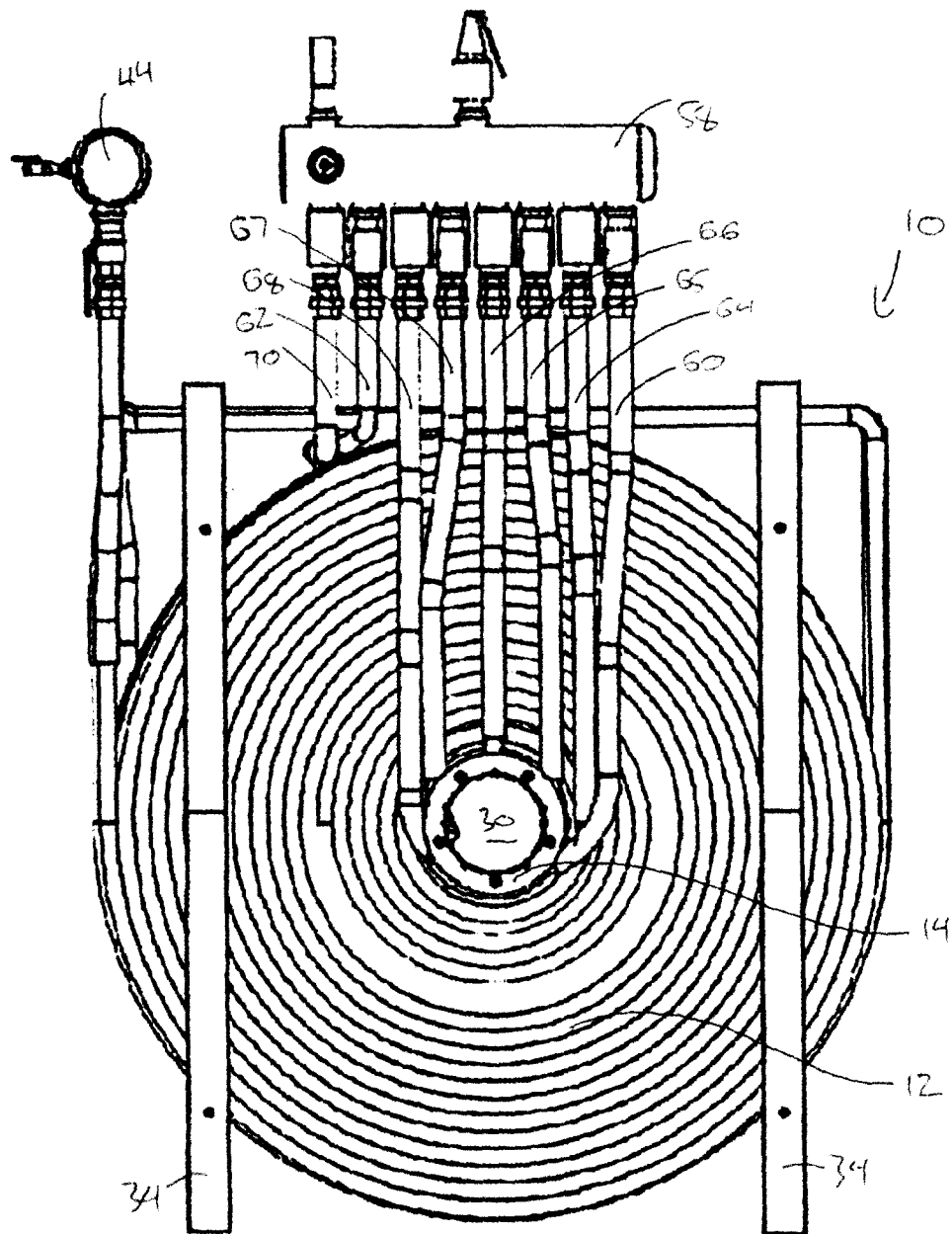


FIG. 4

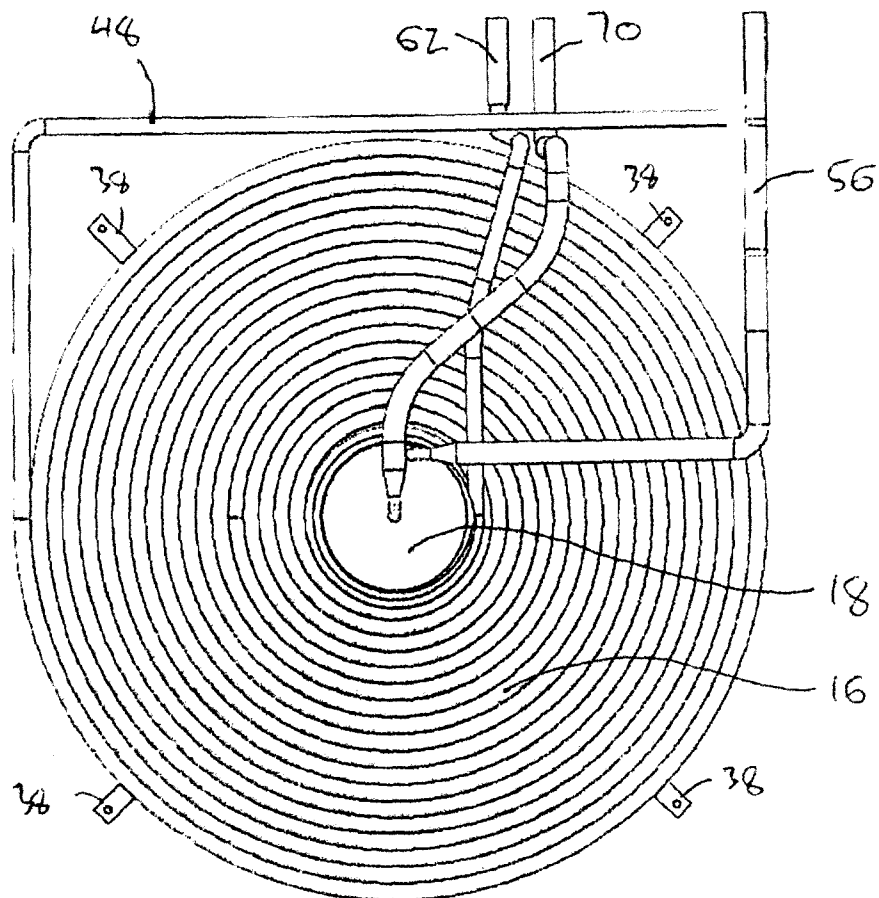


FIG. 5

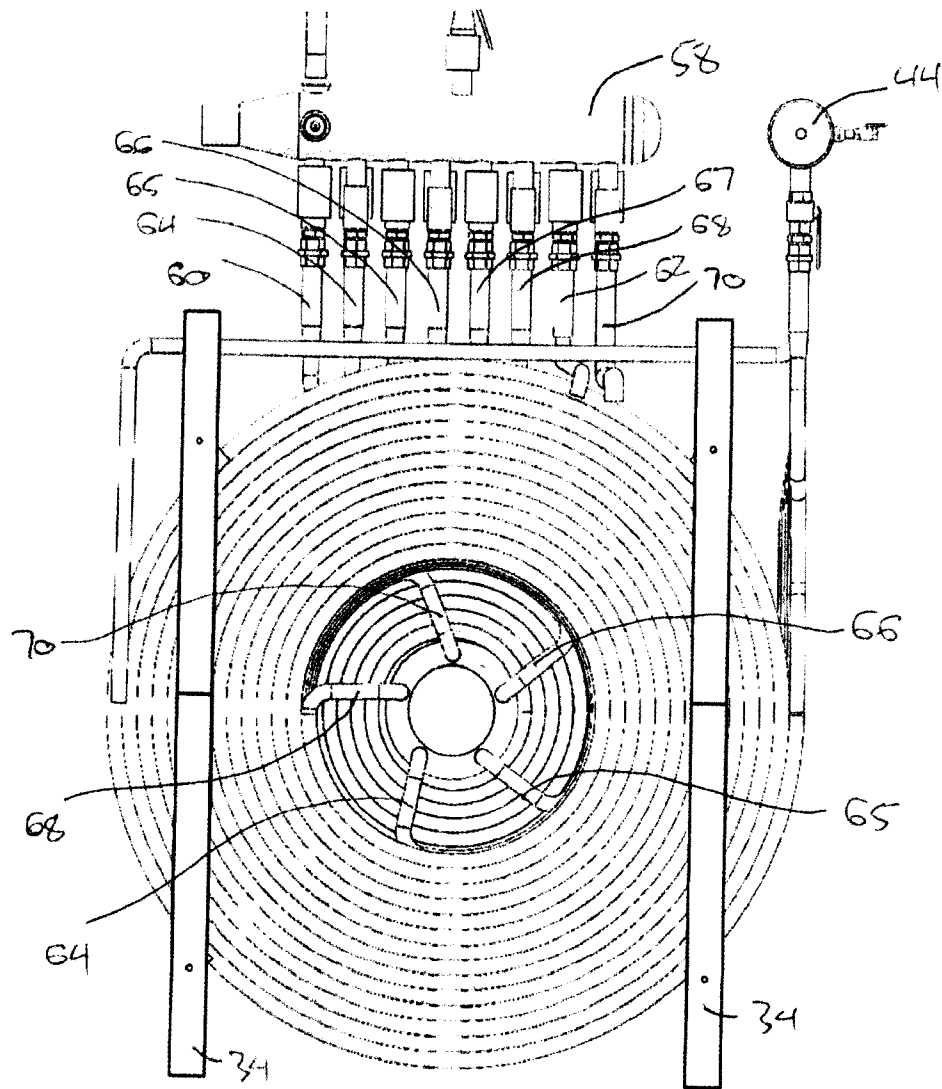


FIG. 6

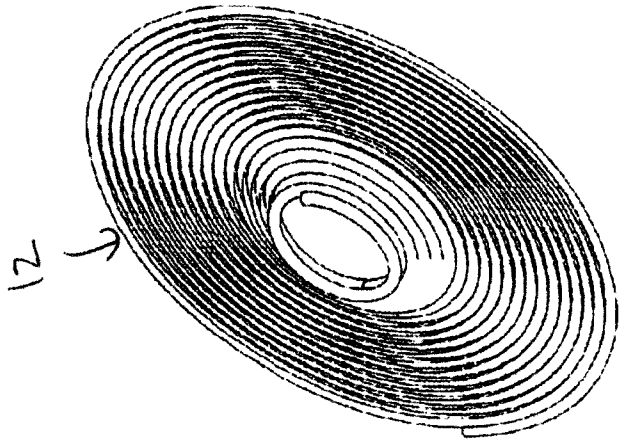


FIG. 7A

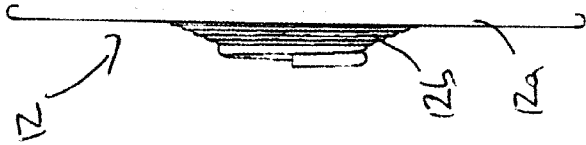


FIG. 7B

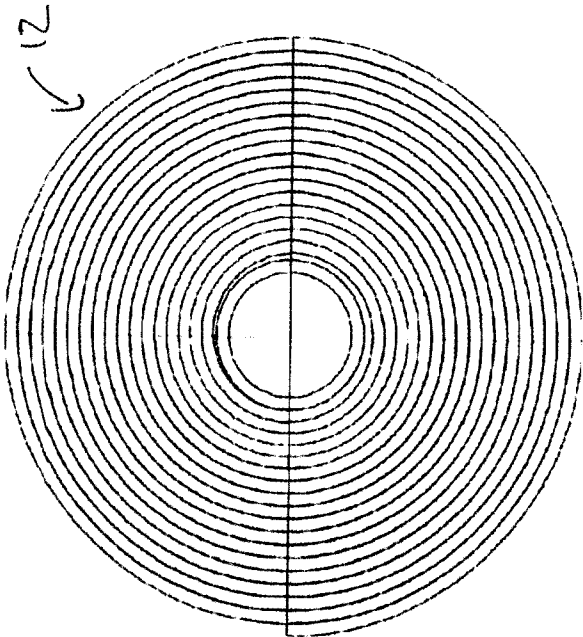


FIG. 7C

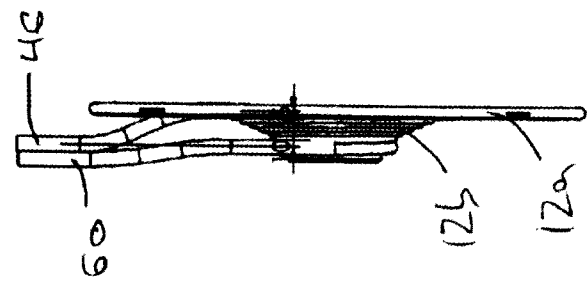


FIG. 8B

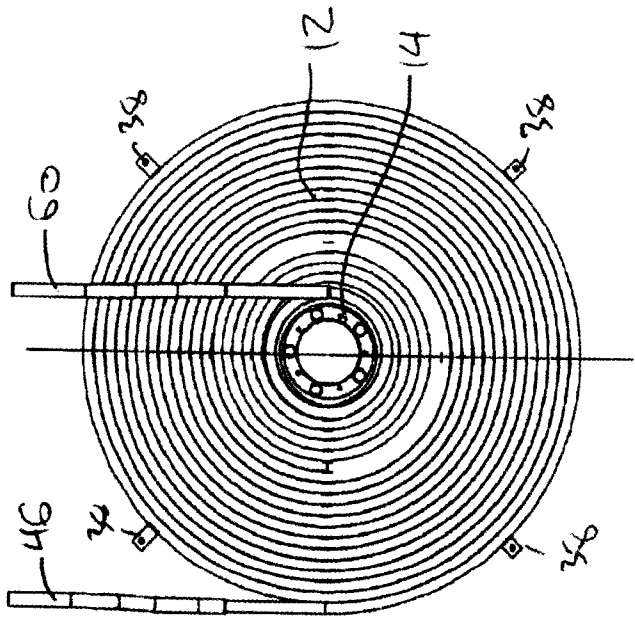


FIG. 8C

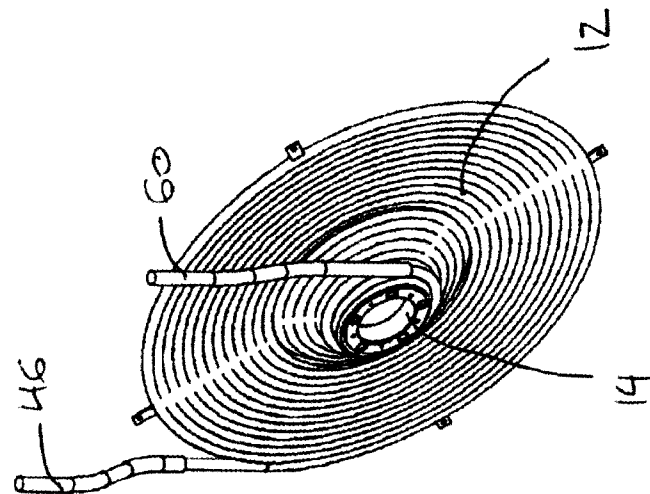


FIG. 8A

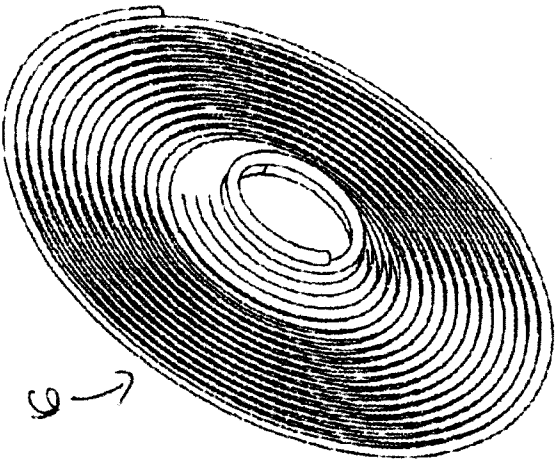


FIG. 9A

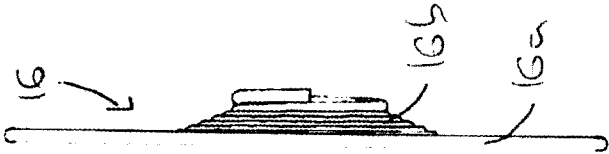


FIG. 9B

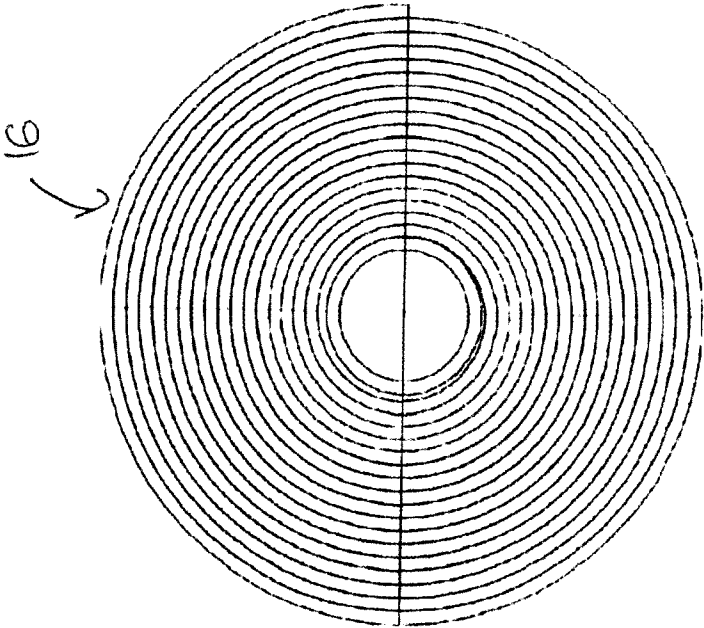


FIG. 9C

FIG. 10C

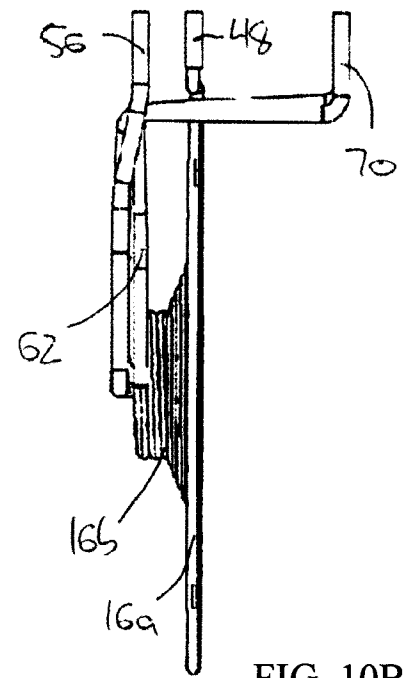
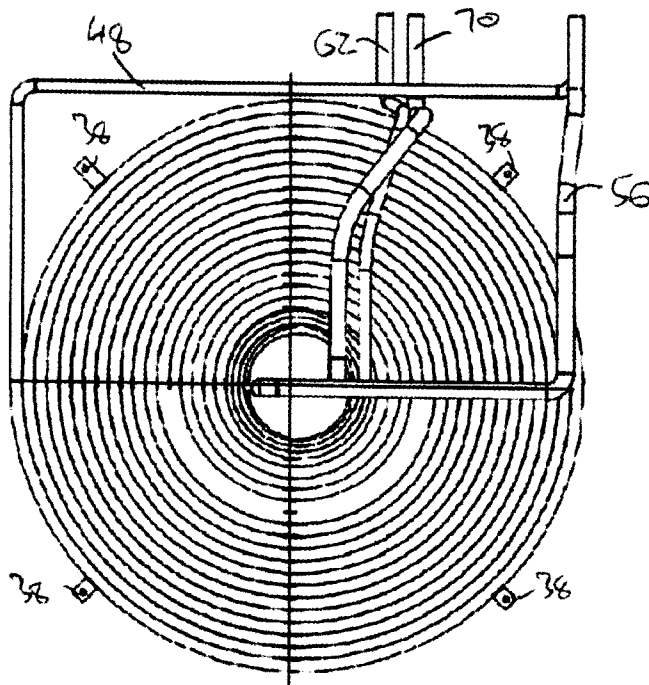


FIG. 10B

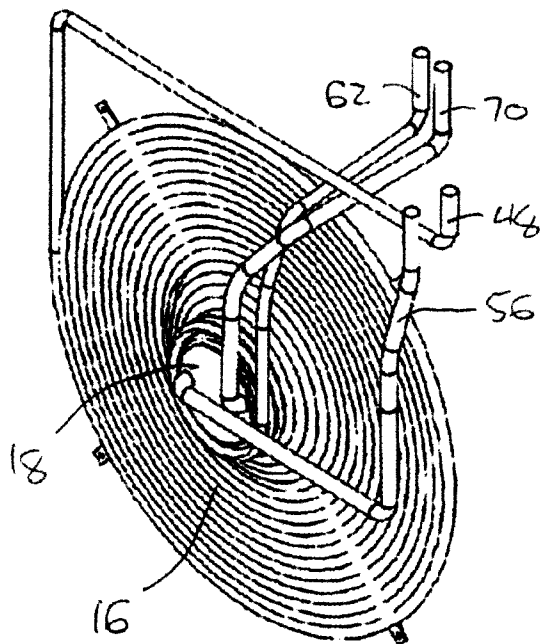


FIG. 10A



FIG. 11

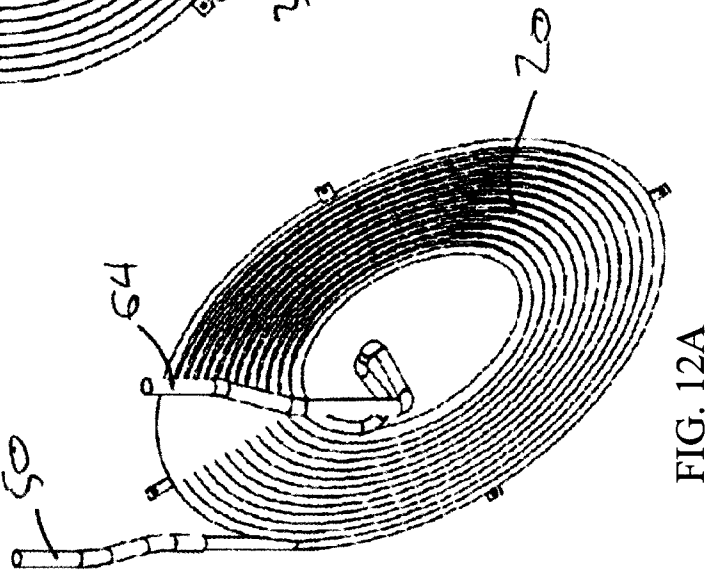


FIG. 12A

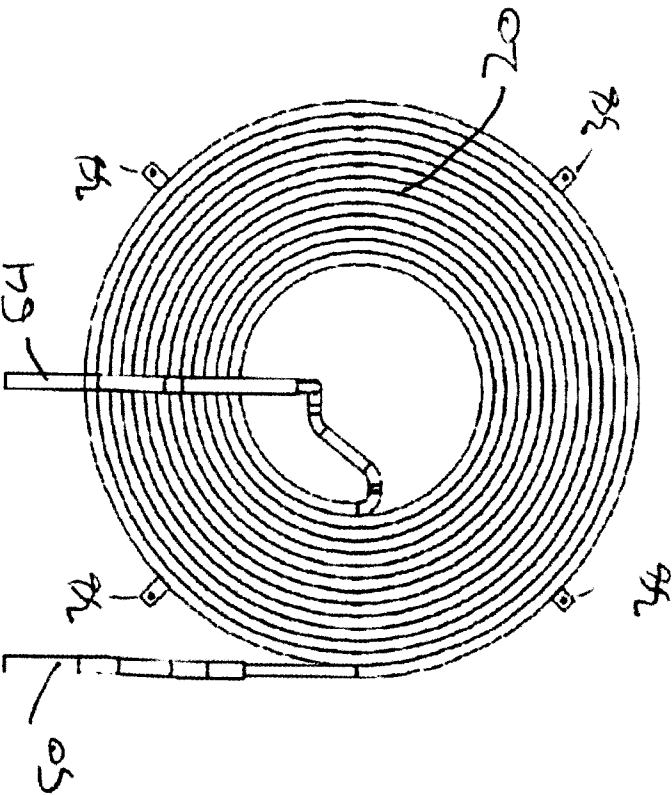


FIG. 12C

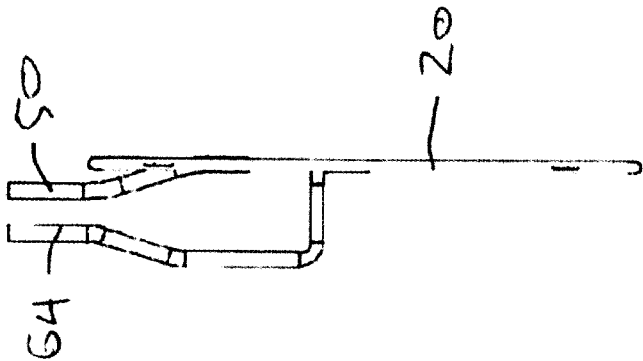


FIG. 12B

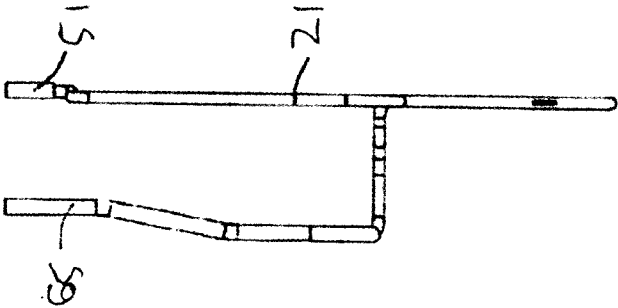


FIG. 13B

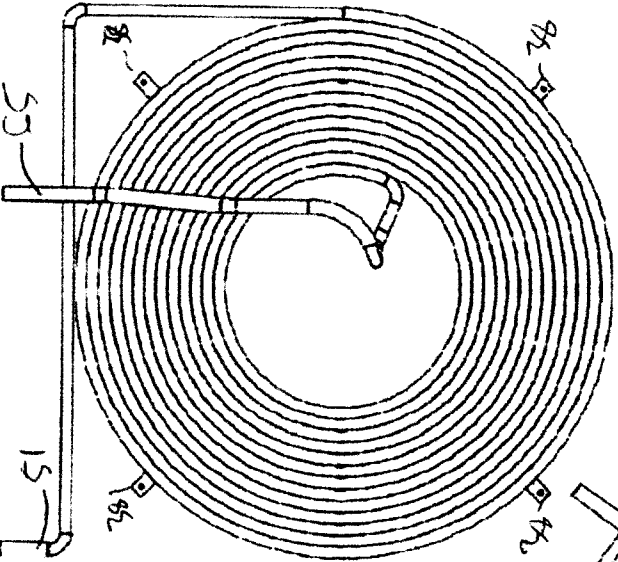


FIG. 13C

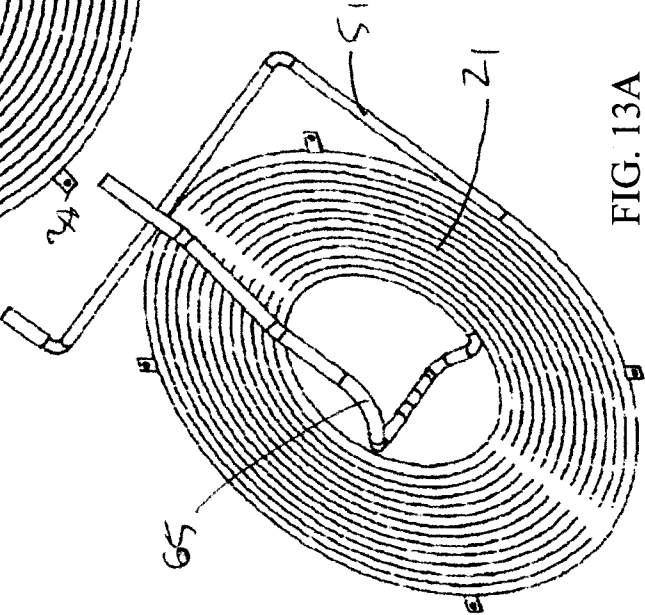


FIG. 13A

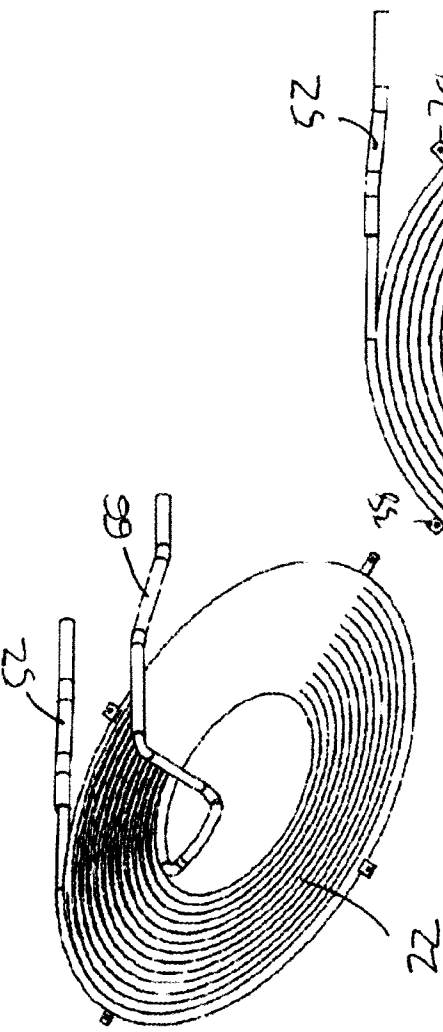


FIG. 14A

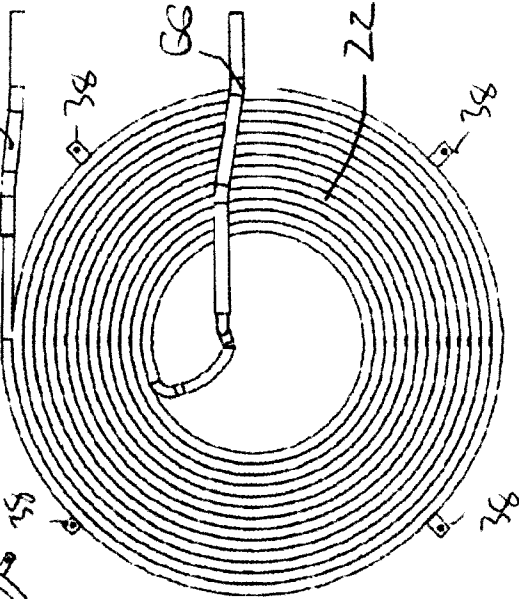


FIG. 14C

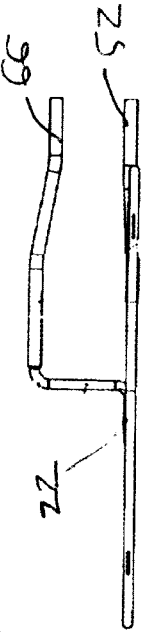


FIG. 14B

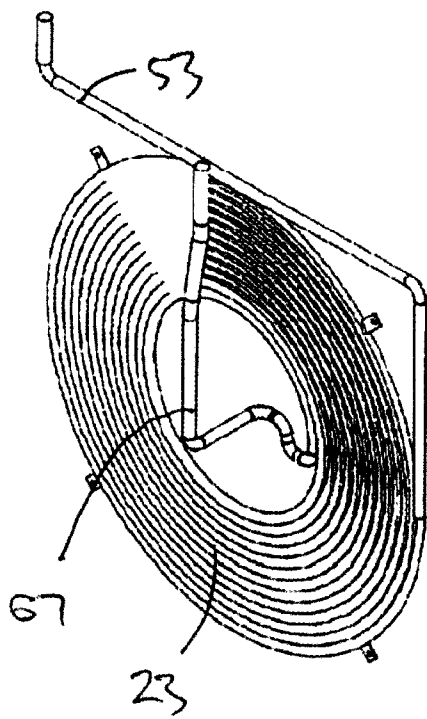


FIG. 15A

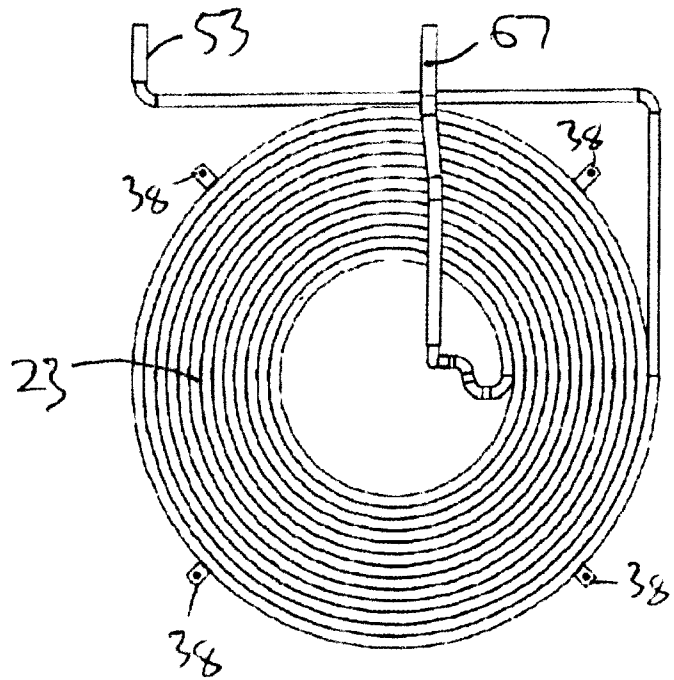


FIG. 15C

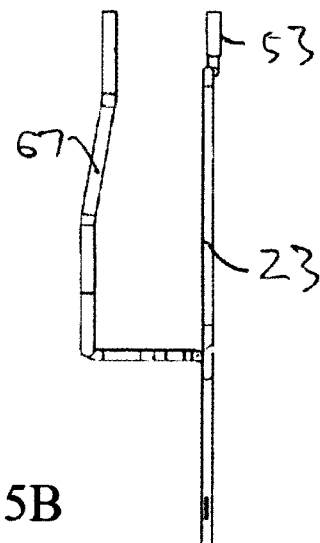
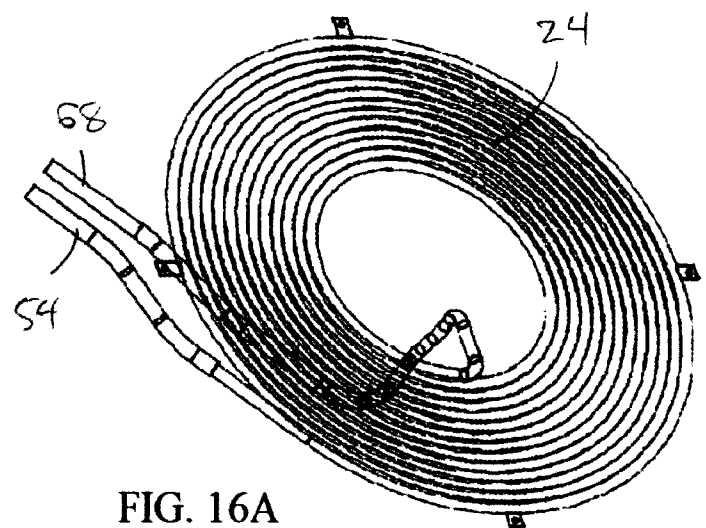
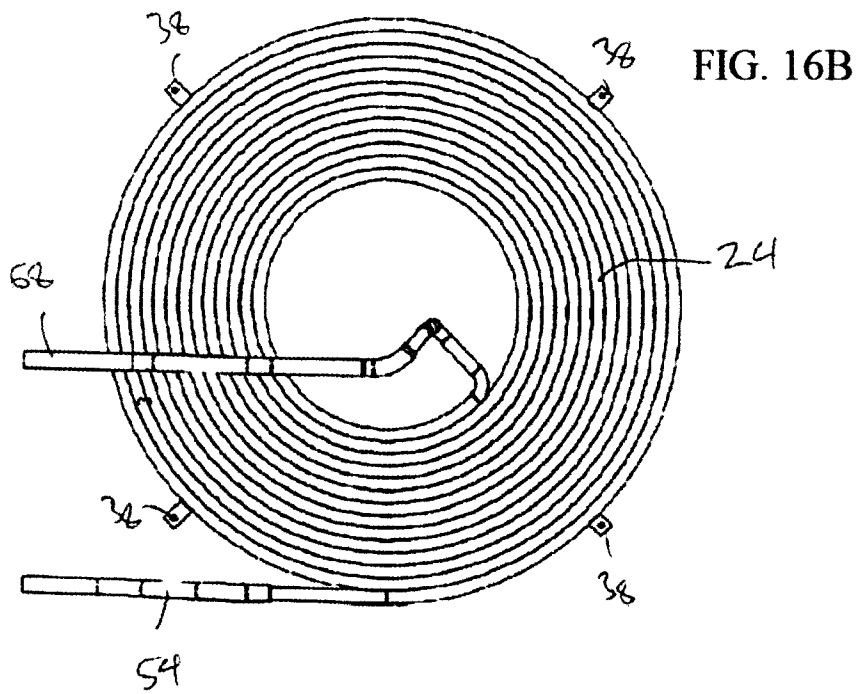


FIG. 15B



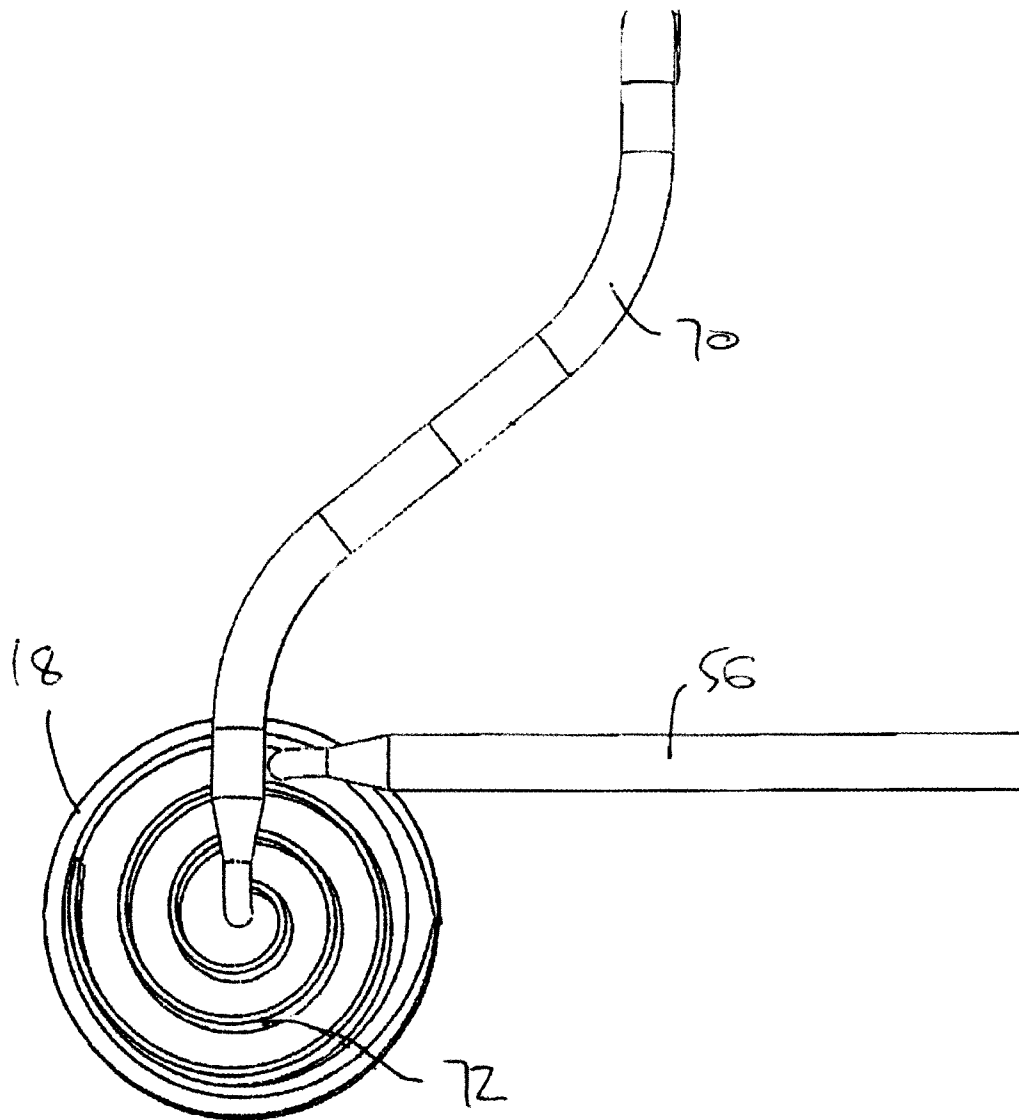


FIG. 17

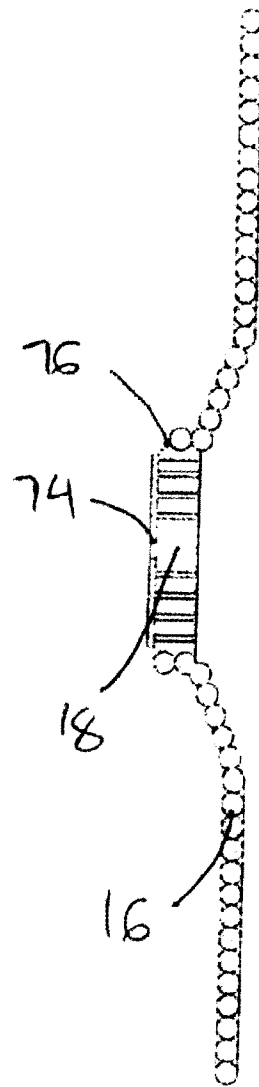


FIG. 18

FIG. 19B

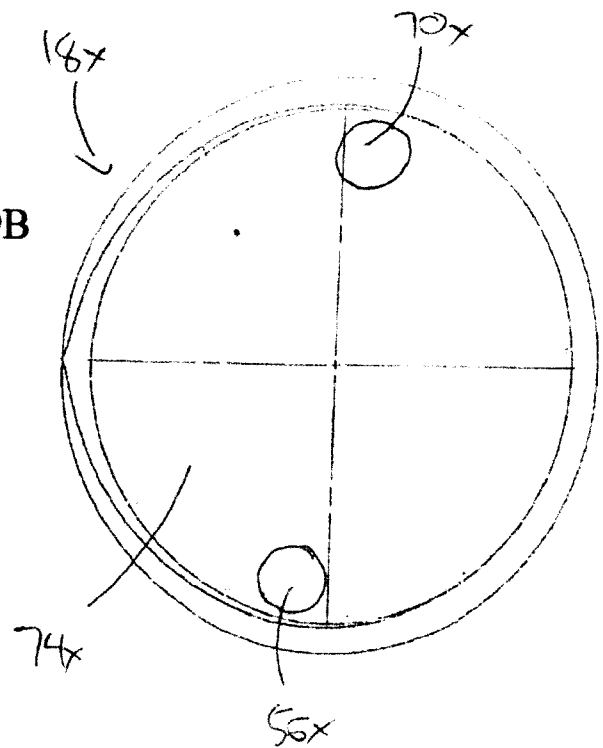


FIG. 19A

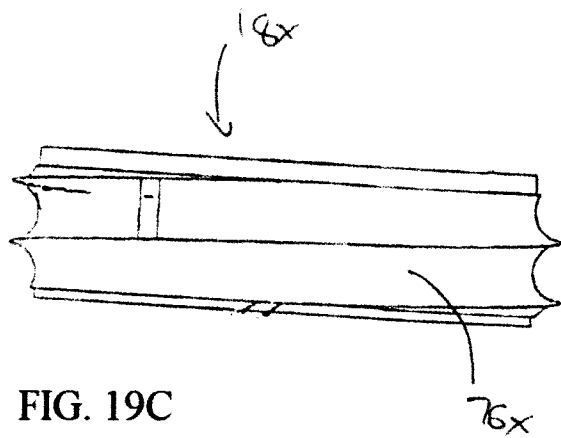
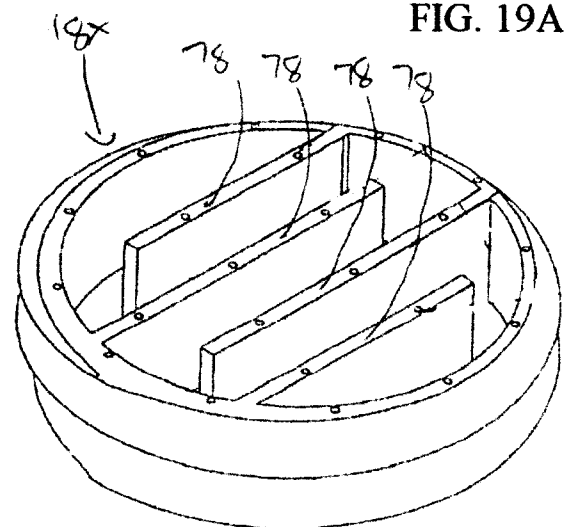


FIG. 19C

FIG. 20A

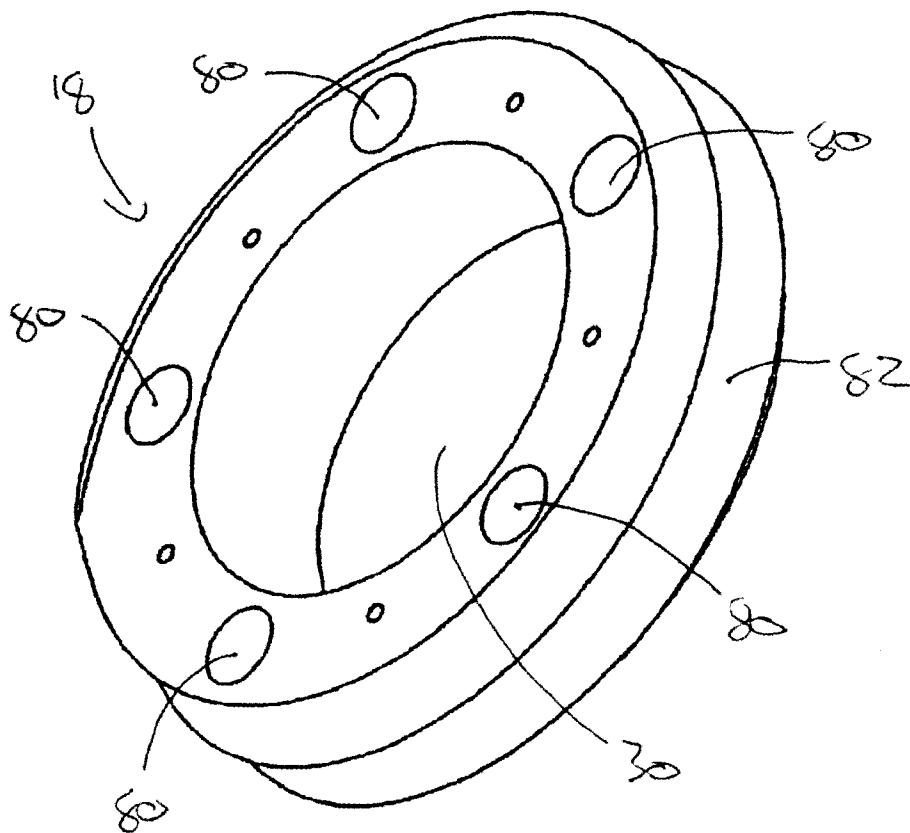
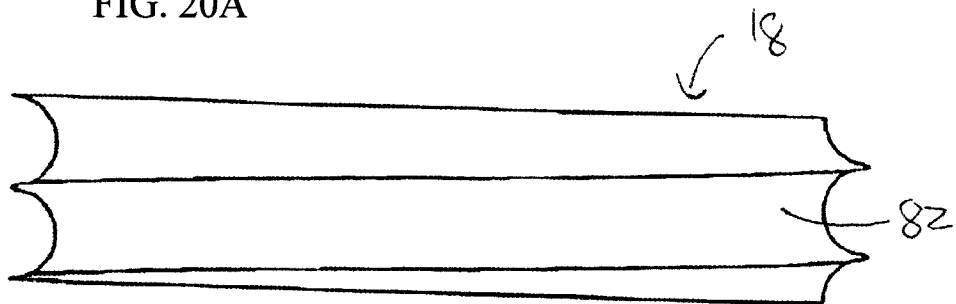


FIG. 20B

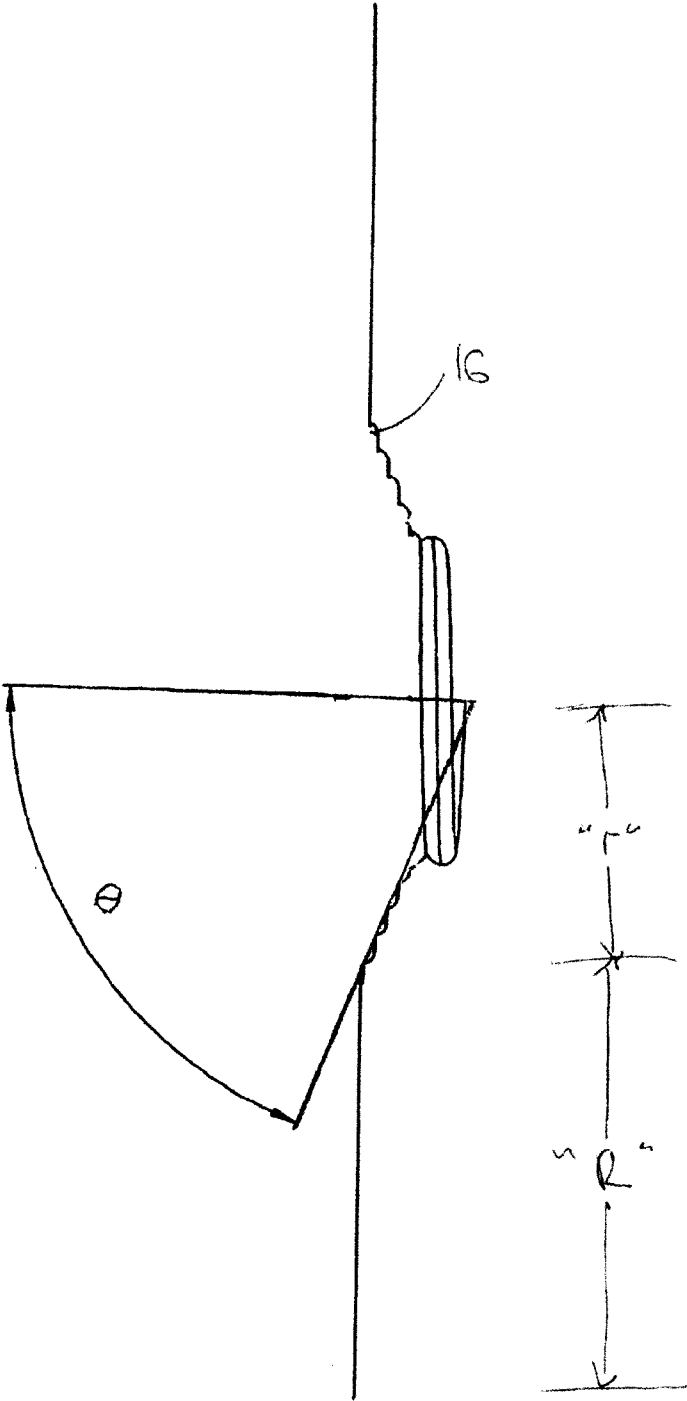


FIG. 21

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2018/000010

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **F23M 5/08** (2006.01), **F22B 27/10** (2006.01), **F22B 37/12** (2006.01), **F23C 15/00** (2006.01), **F23C 3/00** (2006.01), **F23M 9/10** (2006.01), **F24H 1/16** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC/CPC: F22B-027/00, F23M 5/08, F23M 9/10, F23C 15/00, F22B 27/10, F22B 37/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

Questel Orbit (Fampat), Google, Library Discovery Tool, Intellect (Canadian Patent Database) (Keywords: inventor's name, heat exchanger, burner, boiler, plate, coil, tube, scalable, pulse, combustor, annular, ring, thermal expansion)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US7473094B2 (MOVASSAGHI, M.) 06 January 2009 (06-01-2009) *Abstract; Fig. 1A, 2A; claim 1*	
A	WO0012934A1 (CHATO, J.) 09 March 2000 (09-03-2000) *whole document*	
A	US6035810A (MOVASSAGHI, M.) 14 March 2000 (14-03-2000) *whole document*	
A	US4968244A, (MOVASSAGHI, M.) 06 November 1990 (06-11-1990) *whole document*	

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* "A" "E" "L" "O" "P"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance earlier application or patent but published on or after the international filing date document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed	"I" "X" "Y" "&"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art document member of the same patent family
--------------------------------------	--	--------------------------	--

Date of the actual completion of the international search
15 March 2018 (15-03-2018)

Date of mailing of the international search report
16 April 2018 (16-04-2018)

Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 819-953-2476

Authorized officer

Vincent Pellerin (819) 639-7884

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2018/000010

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US7473094B2	06 January 2009 (06-01-2009)	US2007042300A1	22 February 2007 (22-02-2007)
		US7473094B2	06 January 2009 (06-01-2009)
		AU2003273663A1	23 April 2004 (23-04-2004)
		AU2003273663A8	23 April 2004 (23-04-2004)
		CA2500769A1	15 April 2004 (15-04-2004)
		CA2500769C	13 July 2010 (13-07-2010)
		CN1720414A	11 January 2006 (11-01-2006)
		CN100532934C	26 August 2009 (26-08-2009)
		EP1546608A2	29 June 2005 (29-06-2005)
		ITTO20020850A1	02 April 2004 (02-04-2004)
		JP2006501429A	12 January 2006 (12-01-2006)
		JP4413141B2	10 February 2010 (10-02-2010)
		KR20050071541A	07 July 2005 (07-07-2005)
		KR100937787B1	20 January 2010 (20-01-2010)
		WO2004031651A2	15 April 2004 (15-04-2004)
		WO2004031651A3	20 January 2005 (20-01-2005)
		WO2004031651B1	24 March 2005 (24-03-2005)
US6035810A	14 March 2000 (14-03-2000)	US6035810A	14 March 2000 (14-03-2000)
		AR004827A1	10 March 1999 (10-03-1999)
		ATA910396A	15 June 2000 (15-06-2000)
		AT407293B	26 February 2001 (26-02-2001)
		AU4781296A	19 June 1997 (19-06-1997)
		CH693464A5	15 August 2003 (15-08-2003)
		CH693464A9	31 October 2003 (31-10-2003)
		DE19681671B4	21 August 2008 (21-08-2008)
		DE19681671T1	15 October 1998 (15-10-1998)
		DK72598A	30 June 1998 (30-06-1998)
		DK177564B1	21 October 2013 (21-10-2013)
		GB9811684D0	29 July 1998 (29-07-1998)
		GB2323662A	30 September 1998 (30-09-1998)
		GB2323662B	08 December 1999 (08-12-1999)
		JP2000500562A	18 January 2000 (18-01-2000)
		JP3670020B2	13 July 2005 (13-07-2005)
		SE9801925D0	29 May 1998 (29-05-1998)
		SE9801925L	29 July 1998 (29-07-1998)
		SE522084C2	13 January 2004 (13-01-2004)
		WO9720171A1	05 June 1997 (05-06-1997)
WO0012934A1	09 March 2000 (09-03-2000)	WO0012934A1	09 March 2000 (09-03-2000)
		AU5403599A	21 March 2000 (21-03-2000)
		US6464490B1	15 October 2002 (15-10-2002)
US4968244A	06 November 1990 (06-11-1990)	US4968244A	06 November 1990 (06-11-1990)
		CA1319885C	06 July 1993 (06-07-1993)