CALORIMETER FOR LOW ENERGY NUCLEAR REACTION EXPERIMENTS

FIELD OF INVENTION

[0001] The present invention relates generally to a calorimeter operative to measure excess heat from an exothermic reaction.

BACKGROUND

[0002] The phenomenon of excess heat generation has been observed when hydrogen/deuterium reaches high loading in a variety of metals or alloys. This excess heat has been attributed to exothermic reactions between occluded nuclei. In one theory, two deuterium nuclei, when trapped in the small confinement inside the metal lattice, have a wide spread of momentum based on the Heisenberg uncertainty principle. The combined probability of two deuterium nuclei having requisite momenta to overcome the Coulomb barrier may become statistically significant, triggering fusion reactions in the trapped deuterium gas. According to a second theory, the two trapped deuterium nuclei overcome the Coulomb barrier by going through a quantum tunnel to reach the lower energy state, i.e., to form a ^{4}He nucleus.

[0003] One type of exothermic reactions is the so-called Low Energy Nuclear Reactions. Many LENR experiments have been replicated around the world, and numerous different conditions, in which the generation of excess heat can be triggered at will and with control, have been documented. However, the triggering of exothermic reactions to generate excess heat in a metal or alloy loaded with hydrogen/deuterium are not well understood, and are a topic of significant ongoing theoretical and practical research. A significant impediment to the systematic exploration of such triggering mechanisms is the lack of a consistent, reliable, calibrated means for both detecting and quantifying exothermic reactions if and when they do occur, particularly at relatively high temperatures.

[0004] The Background section of this document is provided to place embodiments of the present invention in technological and operational context, to assist those of skill in the art in understanding their scope and utility. Approaches described in the Background section could be pursued, but are not necessarily approaches that have been previously conceived or pursued. Unless explicitly identified as such, no statement herein is admitted to be prior art merely by its inclusion in the Background section.

SUMMARY

[0005] The following presents a simplified summary of the disclosure in order to provide a basic understanding to those of skill in the art. This summary is not an extensive overview of the disclosure and is not intended to identify key/critical elements of embodiments of the invention or to delineate the scope of the invention. The sole purpose of this summary is to present some concepts disclosed herein in a simplified form as a prelude to the more detailed description that is presented later.

[0006] According to one or more embodiments described and claimed herein, a calorimeter provides a high-temperature environment for an exothermic reaction chamber, and precisely measures any excess heat generated by an exothermic reaction. The calorimeter features a thermally-conductive metal block, with a bore formed to hold an exothermic reaction chamber. The block also holds, in a plurality of bores, heater elements to heat the block and thermocouples to monitor the block temperature. Seebeck effect thermoelectric generators (TEG) cover substantially the entirety of the exterior of the block. The TEGs are biased against the block with spring washers. The TEGs are in turn substantially completely covered by heat sinks, and fans may direct convective airflow over the heat sinks. The calorimeter may be operated within a refrigerated container to further increase the temperature gradient across the TEGs. The TEGs are connected in series, and their collective output voltage is determined by the temperature difference between their hot side, pressed against the block, and their cold side, cooled by the heat sinks and optionally convective airflow and/or a refrigerated environment. The exothermic reaction may be triggered in a variety of ways, and excess heating of the block as a result of an exothermic reaction will be reflected in the TEG output voltage. A

gas manifold facilitates experimentation by controlling the reaction chamber pressure and gas flow into and out of the reaction chamber. This facilitates experimentation using, e.g., hydrogen, deuterium, or some other gas, and allows for the collection of sample gas from the reactor.

[0007] One embodiment relates to a calorimeter operative to measure excess heat from an exothermic reaction. The calorimeter includes a block of thermally conductive material. A first bore operative to hold an exothermic reactor is formed in the block. A plurality of second bores, each operative to hold a heating element, is formed in the block. A plurality of third bores, each operative to hold a thermocouple, is formed in the block. The calorimeter also includes plurality of thermoelectric generators (TEG). Each TEG has a hot side and a cold side. The hot side of each TEG is affixed to the block. The TEGs are connected in series and are operative to generate an output voltage in response to the temperature of the block.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. However, this invention should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout. Parts referenced in discussion of one drawing may not appear in that drawing, but are still provided with reference numbers in the text.

[0009] Figure 1 is a section view of a calorimeter.

[0010] Figure 2 is a perspective view of a calorimeter block.

[0011] Figure 3 is a plan view of first, second, and third bores formed in the calorimeter block.

[0012] Figure 4 is a perspective view of TEGs covering the calorimeter block

[0013] Figure 5 is a view of TEGs in TEG retention housings.

[0014] Figure 6 is a sectional view of a shoulder bolt and Bellville washers biasing a TEG against the calorimeter block.

[0015] Figure 7A is a perspective view depicting heat sinks mounted over TEGs on one face of the calorimeter block.

[0016] Figure 7B is a sectional view of heat sinks mounted over TEGs on one face of the calorimeter block.

[0017] Figure 8 is a perspective view depicting heat sinks mounted over TEGs on all faces of the calorimeter block.

[0018] Figure 9 is a perspective view depicting fans directing convective air over the heat sinks.

[0019] Figure 10 depicts the convective block and fans in a refrigerated housing.

[0020] Figure 11 is a perspective view depicting couplings to the exothermic reaction chamber in the calorimeter.

[0021] Figure 12 is a more detailed perspective view of the couplings.

[0022] Figure 13 is a perspective view of a gas flow manifold operative to connect to an exothermic reaction chamber in the calorimeter.

[0023] Figure 14 is a section view of an exothermic reaction chamber having a magnet retention flange.

[0024] Figure 15 is a section view of an exothermic reaction chamber in the calorimeter.

DETAILED DESCRIPTION

[0025] For simplicity and illustrative purposes, the present invention is described by referring mainly to an exemplary embodiment thereof. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be readily apparent to one of ordinary skill in the art that the present invention may be practiced without limitation to these specific details. In this description, well known methods and structures have not been described in detail so as not to unnecessarily obscure the present invention.

[0026] There has been extensive research into exothermic reactions. One known type of exothermic reaction chambers comprises a cylinder formed of a rugged metal, e.g., stainless steel. For example, the cylinder may be approximately a foot long and an inch in diameter. The cylinder is hermetically sealed and configured with fittings allowing the interior to be drawn to a vacuum of 10^{-6} – 10^{-7} Tor. The interior wall of the cylinder may be plated with gold (Au), and then with palladium (Pd). Hydrogen (H) has a known affinity for the metal lattice of palladium, and an aversion to that of gold. Hence, the gold may act as a seal to maintain hydrogen nuclei in the palladium. Gold also exhibits surface phenomena, such as phonon and/or plasmon activity, which may contribute to the exothermic reaction within the hydrogen-loaded palladium. The metal cylinder is grounded (cathode), and an anode rod is positioned in the center. Hydrogen or deuterium (^{2}H, a stable isotope of H, also known as “heavy H”) is introduced into the cylinder at a low pressure. High-voltage, low-current power is applied to the anode. In a process known as “dry electrolysis,” the high voltage along the anode generates an electric field directed radially outwardly, which ionizes the deuterium and accelerates it toward and into the palladium coating. The palladium may achieve a 0.85 – 0.90 loading ratio. Deuterium nuclei in the palladium metal lattice may then fuse, for example according to one of the theories described above. In the above described embodiment, palladium is used as an example. In some embodiments, a transition metals such as nickel, platinum, etc., can be used to plate the electrode.

[0027] Quantifying the excess heat produced, and documenting when it occurs, are important to validate exothermic reaction experiments, and to assess the efficacy of various triggering mechanisms. These tasks can be difficult, particularly at relatively high temperatures (compared to room temperature).

[0028] Figure 1 is a functional section diagram of some parts of a calorimeter 10 operative to measure the excess heat of an exothermic reaction, according to one or more embodiments of the present invention. The basis of the calorimeter 10 is a metal block 12, which may for example comprise a copper block 12. An exothermic reaction chamber 68, in some experiments surrounded by magnets 70, is disposed in a first bore 14 formed in the block 12. The block 12 is heated to a relatively high temperature, such as 150 º - 300º C, by a plurality of heating elements 74, each disposed in a second bore 16. The temperature of the block 12 is monitored by a plurality of thermocouples 76, each disposed in a third bore 18. A controller 100 receives input from the thermocouples 76, and controls the heating elements 74, to maintain the block 12 temperature at a predetermined level.

[0029] In some embodiments, a gas flow manifold 48 controls the pressure and flow of gasses into and out of the exothermic reaction chamber 68, facilitating experimentation with various conditions and reaction triggering events. The controller 100 provides high voltage (e.g., 5 kVDC) to an anode in the exothermic reaction chamber 68, and in some embodiments may superimpose an RF signal on the voltage.

[0030] When an exothermic reaction is triggered in the exothermic reaction chamber 68, the excess heat is conducted away by the block 12, raising the temperature of the block 12. This rise in temperature is detected by a plurality of thermoelectric generators (TEG) 20, which surround the block 12. The TEGs generate a voltage proportional to the temperature difference between a “hot side,” which is pressed against the block 12, and a “cold side,” which faces away from the block 12. Due to the high temperature of the block, heat sinks 30 are affixed to the cold side of the TEGs 20 to help cool the cold side, to maintain a thermal differential. In some embodiments, fans (not shown) direct convective cooling air over the fins of the heat sinks 30. In some embodiments, the entire calorimeter 10 may be placed in a refrigerated container (not shown).

[0031] The above description of the structure and operation of the calorimeter 10 provides an overview of various embodiments of the present invention. Each of its constituent parts is disclosed in greater detail herein. Note that a feature of the calorimeter 10 described herein is its flexibility. Accordingly, it is important to keep in mind that, in any given experiment, some but not all of the features, parts, systems, components, and functions described herein may be present or utilized; others may be omitted.

[0032] Figure 2 depicts a metal block 12 of the calorimeter 10. The block 12 holds an exothermic reaction chamber 68 and optionally magnets 70. The block 12 also holds heating elements 74 to heat the block 12, and thermocouples 76 to monitor its temperature. The block 12 spreads heat evenly from the heating elements 74 around the exothermic reaction chamber 68 and magnets 70. Additionally, the block 12 quickly and easily conducts excess heat from the exothermic reaction chamber 68 to the exterior surface of the block 12.

[0033] In one embodiment, the block 12 is formed from copper. In other embodiments, other metals may be used, taking into account their thermal transfer properties. The block 12 must have a high melting point, and good thermal conductivity. In one embodiment the block 12 is formed from aluminum, due to its thermal conductivity and ease of machining.

[0034] The block 12 must completely cover the exothermic reaction chamber 68 and magnets 70, and additionally have room for the heating elements 74 and thermocouples 76. Accordingly, the block 12 must exceed the dimensions of the exothermic reaction chamber 68 and magnets 70. However, the block 12 is not required to mimic the shape of the exothermic reaction chamber 68. In fact, in a preferred embodiment the block 12 is rectangular (or other regular polygonal shape), with flat sides to which the “hot side” of thermoelectric generators (TEG) 20 may be easily affixed. In the embodiment depicted in Figure 2, the block 12 is approximately three inches square by 1 foot long.

[0035] As depicted in Figures 2 and 3, the block 12 has a number of holes, or bores 14, 16, 18 drilled or otherwise formed therein. In the center of the block 12, a first bore 14 is of sufficient diameter to just accommodate the exothermic reaction chamber 68 and magnets 70. Preferably, the toroidal magnets 70 arrayed around the exothermic reaction chamber 68 make solid, constant contact with the inner walls of the first bore 14. The first bore 14 may be tapped to receive a threaded portion of the exothermic reaction chamber 68.

[0036] A plurality of second bores 16 – four, in the embodiment depicted in Figures 2 and 3 – is formed in the block 12, evenly spaced radially around the first bore 14. The second bores are sized, in diameter and depth, to accommodate heating elements 74. The heating elements 74 may comprise electrical resistive heating elements, which may be cylindrical in shape. In one embodiment, the plurality of second bores 16 may be formed all the way through the block 12, and two heating elements 74, each less than half the length of the block 12, may be inserted into the second bores 16 from either end of the block 12. In another embodiment, a plurality of second bores 16 is formed in the opposite end of the block 12, that are not aligned with the second bores 16 formed in the first end of the block 12. This may more evenly heat the block 12. In one embodiment, the heating elements 74 are operative to heat the block 12 to 150º - 300º C. A suitable heating element 74 is model SWH16519-00 available from Watlow Electric Manufacturing Company, Inc. of St. Louis, Missouri.

[0037] A plurality of third bores 18 – also four, in the embodiment depicted in Figures 2 and 3 – is formed in the block 12, evenly spaced radially around the first bore 14, and generally disposed in between the plurality of second bores 16. The third bores are sized, in diameter and depth, to accommodate thermocouples 76. The thermocouples 76 may be cylindrical in shape. The thermocouples are operative to monitor the temperature of the block 12. The second bores 16 should be deep enough that, when installed, the most sensitive portion of the thermocouples 76 are even with the center of the exothermic reaction chamber 68, where an exothermic reaction is most likely to occur. The thermocouples 76 should be precise to 0.1º C and withstand temperatures up to 1100º C. A suitable thermocouple 76 is model TJ72-CASS-18U-6-CC-SB available from Omega Engineering, Inc. of Stamford, Connecticut.

[0038] Figure 4 depicts the block 12 with thermoelectric generators (TEG) 20 covering substantially the entirety of its external surface. The TEGs 20 are Seebeck effect devices, which output a DC voltage dependent on the difference in temperature between “hot” and “cold” sides of the device 20. Each TEG 20 has a positive and negative terminal. The TEGs are all wired in series – that is, the positive terminal of each TEG 20 is connected to the negative terminal of the next TEG 20, and the positive terminal of the last TEG 20 and the negative terminal of the first TEG 20 are connected to a calibrated multimeter or other data recording device. A suitable TEG 20 for the block 12 other than the top is model TEG1-PB-12611-6.0, and a suitable TEG 20 for the top of the block 12 is model TEG1-PB-07110-25, both available from Thermal Electronics, Inc. of Lake Elsinore, California. These TEGs 20 can withstand up to 300º C.

[0039] The TEGs 20 cover substantially all of the block 12, including the top and bottom. The TEGs 20 must be held firmly against the walls of the block 12 to obtain a consistent, optimal thermal conduction. Attachment of TEGs 20 to metal surfaces is conventionally accomplished via thermally conductive adhesive, such as epoxy. However, no known epoxy remains an effective adhesive at the anticipated high operating temperatures of the calorimeter 10. Accordingly, mechanical attachment of the TEGs 20 to the block 12 is necessary. If the TEGs 20 were attached directly to the block 12, such as by screws or other mechanical fasteners, the contact pressure would change as the block 12 heated up. This would not only result in differing thermal conductivity due to changes in attachment pressure, it could damage the TEGs 20, which are relatively fragile devices. Accordingly, the TEGs 20 are preferably biased against the block 12 with a constant force, such as by a mechanical spring.

[0040] In one embodiment, TEG retention clips 22 are used to attach the TEGs 20 to the block 12. Figure 5 depicts the TEGs 20 and the retention clips 22. As depicted in Figure 6, to achieve a constant bias force pressing the TEGs 20 against the block 12, a shoulder bolt 26 and Bellville washers 28 may be used. A Bellville washer 28, also known as a conical spring washer, is a spring having a frusto-conical shape, and adapted to be used on mechanical fasteners as a washer. Figure 6 depicts a shoulder bolt 26 disposed through a through-hole in a TEG retention clip 22, and into a threaded hole in the block 12. When the shoulder bolt 26 is tightened to the point that the bolt shoulder is flush with the face of the block 12, the head of the bolt 26 extends a known distance *d* from the TEG retention clip 22. The dimensions of the retention clip 22 and shoulder bolt 26 may be selected such that when one or more Bellville washers 28 are interposed on the bolt between the retention clip 22 and the bolt head – that is, confined within the distance d – the washers 28 are compressed and generate a known force along the longitudinal axis of the bolt 26. This operates to bias the retention clip 22, and hence the TEG 20, against the block 12 with the known force. This force will remain substantially constant throughout the small range of distances *d* that may result from thermal expansion over the anticipated range of operating temperatures of the calorimeter 10. In some embodiments, a thermally conductive material 24, supplied by the TEG manufacturer, may be interposed between the TEG 20 and the block 12. In other embodiments, the hot side of the TEGs 20 directly contact the metal block 12.

[0041] In general, Seebeck effect devices exhibit an inherently non-linear relationship between temperature differential and output voltage. By maintaining a constant attachment bias, and by operating within a limited temperature range, the devices may be limited to a more linear range. Additionally, different TEG 20 devices may be utilized for different anticipated operating temperatures of the calorimeter 10, to achieve such linearity. In any event, the calorimeter 10 must be well calibrated before an exothermic reaction is triggered, to account for discrepancies.

[0042] Figures 7A, 7B, and 8 depict heat sinks 30 over the TEGs 20. The heat sinks 30 help the cold side of the TEGs 20 to maintain a constant, uniform temperature substantially cooler than that of the block 12 before, during, and after any exothermic reaction. The heat sinks 30 cover substantially all of the TEGs 20. In one embodiment, the heat sinks 30 are attached to the block 12 with compression screws. Of course, the compression screws must not go through any TEG 20, to prevent damage. In one embodiment, the heat sinks 30 are formed from aluminum, due to its good thermal conductivity and ease of machining. However, the heat sinks 30 may be formed from other material. As with any heat sink, a large surface area exposed to the air increases thermal transfer efficacy. Accordingly, the heat sinks may be formed with fins, increasing the surface area and allowing air flow between the fins. In one embodiment, the fins are oriented vertically, although this is not a requirement.

[0043] Figure 9 depicts one or more fans 32 disposed and oriented to generate convective airflow over the heat sinks 30, preferably in the direction of the fins. This helps remove heat from the cool side of the TEGs 20, creating a greater thermal differential between the hot and cold sides. In one embodiment, four 12V DC brushless fans 32 are placed beneath the calorimeter 10, and oriented so as to maximize convective airflow over and between the fins of the heat sinks 30. Such fans are commonly used in computer housings to cool electronics.

[0044] Figure 10 depicts the calorimeter 10 – including the exothermic reaction chamber 68, metal block 12, TEGs 20, heat sinks 30, and convective airflow fans 32 – disposed in a refrigerated container 34. In one embodiment container 34 has a glass (or other transparent) door 36 for observing the calorimeter 10 during an experiment. By reducing the temperature of ambient air providing the convective airflow, the cool side of the TEGs 20 is further lowered, and maintained at a constant temperature, against which changes in the temperature of the block 12 may be measured by changes in the TEG 20 output voltage.

[0045] Other methods of cooling the cold side of the TEGs 20 are contemplated. In one embodiment, water or other fluid may be sprayed on the calorimeter 10 in a low humidity environment to take advantage of evaporative cooling. In one embodiment water or other fluid may be circulated over the surface of the calorimeter 10 in tubes or pipes with high thermal conductivity. In one embodiment, the calorimeter 10 may be immersed in an ice bath or fluid that is circulated through a chiller to maintain a constant low temperature. In general, any means of cooling the cooling the cold side of the TEGs 20 may be utilized.

[0046] Figure 11 depicts the calorimeter 10 with the exothermic reaction chamber 68 (not visible) installed in the first bore 14. A sealing nut 40 is attached. A safe high voltage connector 42 protrudes from the sealing nut 40, and a gas flow tube 44 connects to the interior of the reaction chamber 68. Figure 12 is an enlarged view of the gas flow tube 44, and an electrical connector 46, which may for example receive an RF signal. Although not depicted in Figures 11 or 12, electrical connections to the heating elements 74 and thermocouples 76, as well as both ends of the series-connected TEGs 20, will exit the top of the calorimeter 10. A heat sink 30 will be fitted to the top, with provisions for these connectors to protrude through it.

[0047] Figure 13 depicts a gas flow manifold 48, which facilitates experimentation of triggering events for an exothermic reaction in the exothermic reaction chamber 68. The manifold attaches to the gas flow tube 44 (Figs. 11, 12) at nut 50. A port 52 allows a pressure meter to be attached, to monitor the pressure (vacuum) in the exothermic reaction chamber 68. A port 54 allows for attachment to a vacuum pump, to evacuate the exothermic reaction chamber 68 to 10^{-6}-10^{-7} Tor prior to introducing hydrogen gas. A gas flow valve 56 isolates the port 54 from the manifold 48 after the desired vacuum is achieved. In one embodiment, the gas flow valves 56 are electronically actuated, and hence may be controlled by software executing on a processor. In other embodiments, the valves 56 may be manually actuated.

[0048] A mass flow controller 58 permits precise amounts of gas – stored, in one embodiment, in supply gas storage chambers 60 – to pass into the exothermic reaction chamber 68, once a desired vacuum has been achieved in the chamber 68. In one embodiment, one supply gas storage chamber 60 stores "light" hydrogen gas (H), and the other stores "heavy" hydrogen gas (deuterium). Gas flow valves 56 isolate the supply gas storage chambers 60, and selectively allow gas to flow from one or the other through the mass flow controller 58 into the exothermic reaction chamber 68.

[0049] In one embodiment, after an exothermic reaction has been observed by a rise in the temperature of the block 12, as detected by the TEG 20 output, gas in the exothermic reaction chamber 68 may be sampled for analysis, such as by mass spectroscopy. For example, the presence of ^4He nuclei may indicate that a nuclear fusion reaction occurred in the exothermic reaction chamber 68. A sample gas storage chamber 62 may be evacuated to a vacuum, along with the exothermic reaction chamber 68, by opening both sample gas valves 64 during the vacuum pump operation. The sample gas valves 64 are then closed as one or more supply gases are introduced and an exothermic reaction is triggered in the exothermic reaction chamber 68. Following an indication of a reaction (i.e., thermal rise), the sample gas valves 64 may both be opened, and the pressure differential will transfer gas from the exothermic reaction chamber 68 into the sample gas storage chamber 62. At this point, both sample gas valves 64 may be closed, and the connection nut 66 loosened to remove the gas storage chamber 62, which may subsequently be attached to instrumentation such as a mass spectrometer.

[0050] In another embodiment, an entrance port to an instrument may replace the gas storage chamber 62, and the analysis of sample gas performed in "real time." Real time gas sample analysis can be used to monitor the progress of an exothermic reaction in the reaction chamber 68. The analysis may be focused on detecting an indication that a reaction is actually taking place. The analysis can also be used as feedback to control the reaction. In the embodiment depicted in Figure 13, the sample gas valves 64 are manually actuated; in other embodiments, they may be electronically actuated and controlled by software executing on a processor. By programming the processor, gas samples can be extracted at a pre-determined time interval by a pre-determined amount. The gas samples can be used to detect one or more signature gases. For example, the content of a sample can be analyzed to determine how much reactant gas, e.g., deuterium gas, has been consumed or how much resultant gas, e.g., ^4He, has been produced. In some embodiments, the amount of helium detected in the gas sample may indicate whether the reaction rate is slowing down or will slow down imminently. The reaction rate can be accelerated or moderated based on the amount of helium detected in the samples to maintain a desired reaction rate. For example, to increase the reaction rate, the mass flow controller 58 can be controlled to allow more gas supply to flow from the gas storage chambers 60 into the reaction chamber 68.

[0051] In some embodiments, instead of analyzing gas samples, other types of real time data analysis can be performed, for instance, energetic particle detection, radio frequency (RF) detection, and optical signal detection.

[0052] In some embodiments, the gas samples extracted in real time may be analyzed to detect energetic particles. In some embodiments, energetic particle detection can be carried out by placing detectors around the calorimeter 10.

[0053] In some embodiments, one or more ports may be added to facilitate RF detection. Additionally or alternatively, an optical window may be introduced on the calorimeter 10 to allow optical signals to pass through. Often, optical signals are reliable indicators of how a reaction is progressing.

[0054] In other embodiments, more than two supply gas storage chambers 60 may be provided, and/or more than one sample gas storage chamber 62 may be provided, as desired or required for a given experiment. A suitable supply/sample gas storage chamber is the HydroStik 10-liter canister available from Jameco Electronics of Belmont, California.

[0055] Figure 14 depicts the exothermic reaction chamber 68, according to one embodiment. The exothermic reaction chamber 68 includes the sealing nut 40 and gas flow tube 44. In one embodiment, one or more generally toroidal magnets 70 surround the exothermic reaction chamber 68. One feature of the exothermic reaction chamber 68 is a flange 72 on the end opposite the sealing nut 40 – that is, the end of the exothermic reaction chamber 68 that is inserted into the first bore 14 in the block 12. The flange 72 acts to retain the magnets 70 as the exothermic reaction chamber 68 is removed from the block 12. The flange also allows the end of the exothermic reaction chamber 68 to be attached and sealed by orbital welding, yielding a stronger and more robust chamber 68.

[0056] Figure 15 depicts a functional block diagram of a complete and functional calorimeter 10, according to embodiments of the present invention. The exothermic reaction chamber 68 comprises a metal container 78 plated with a layer of gold 82 and a layer of palladium 84, and contains an anode 86. A lid 88 seals the exothermic reaction chamber 68, with a gas flow pass-through 90. A Teflon block 92 insulates the anode 86 in the small region on which the metal container 78 is not plated with gold 82 and palladium 84, to prevent arcing between the anode 86 and this portion of the metal container 78 under very high voltage. In one embodiment, magnets 70 surround the exothermic reaction chamber 68. The exothermic reaction chamber 68, and the magnets 70, are disposed in a first bore 14 of the metal block 12.

[0057] A plurality of heating elements 74 are disposed in second bores 16, and operate to heat the block 12 to a predetermined temperature (e.g., 150º - 300º C). A plurality of thermocouples 76 are disposed in third bores 18, and operative to monitor the temperature of the block 12, allowing for a closed-loop control system to maintain the block 12 at a steady, predetermined temperature.

[0058] When the reaction chamber 68 is evacuated to a vacuum and the desired form of hydrogen gas is introduced in the desired quantity, such as by utilizing the manifold 48 (not depicted in Fig. 15), an exothermic reaction is triggered. In one embodiment, the trigger may comprise the application of high voltage (e.g., 5 kV) at low current between the anode 86 and metal container 78 (grounded to act as cathode). In another embodiment, the trigger may comprise the high DC voltage with an RF signal superimposed, e.g., at a resonant frequency.

[0059] Because the trigger voltage generates a very low current, very little power is input to the system by triggering the exothermic reaction. For example, in one embodiment the triggering power may be 0.1 W. Accordingly, virtually the entirety of any temperature rise of the block 12 may be attributed to an exothermic reaction in the exothermic reaction chamber 68. Such a thermal rise is detected by monitoring the output voltage of the series-connected TEGs 20 which cover substantially the entirety of the external surface of the block 12. Note that the

TEG retention clips 22 and thermal transfer material 24 (Fig. 6) are not depicted in Figure 15. The TEGs 20 are covered by heat sinks 30 to aid in cooling the cold side of the TEGs 20. In some embodiments, the cooling is further supplemented by convective airflow and/or a refrigerated ambient environment. By maintaining a large temperature differential between the hot and cold sides of the TEGs 20, any rise in temperature of the block 12 is detected and reflected in the TEG 20 output voltage.

[0060] In this manner, excess heat from an exothermic reaction in the exothermic reaction chamber 68 may be detected, quantified, and carefully measured. The occurrence of an exothermic reaction may thus be definitively proven. By utilizing the features provided by the gas flow manifold 48, numerous variations of experimental parameters may easily be explored, and the reaction product gases analyzed. The calorimeter 10 is scalable, and may be modified to operate at higher temperatures than those specified herein. Any operating temperature, voltage value, vacuum level, or other parameter specifically disclosed herein is exemplary only, and not limiting.

[0061] The present invention may, of course, be carried out in other ways than those specifically set forth herein without departing from essential characteristics of the invention. The present embodiments are to be considered in all respects as illustrative and not restrictive, and all changes coming within the meaning and equivalency range of the appended claims are intended to be embraced therein.

CLAIMS

What is claimed is:

1. A calorimeter operative to measure excess heat from an exothermic reaction, comprising:

a block of thermally conductive material;

a first bore formed in the block and operative to hold a reaction chamber;

a plurality of second bores formed in the block, each operative to hold a heating element;

a plurality of third bores formed in the block, each operative to hold a thermocouple; and

a plurality of thermoelectric generators (TEG), each having a hot side and a cold side, the hot side of each TEG being affixed to the block, the TEGs connected in series and operative to generate an output voltage in response to the temperature of the block.

2. The calorimeter of claim 1 wherein the block of thermally conductive material is a copper block.

3. The calorimeter of claim 1 wherein the plurality of second bores formed in the block are evenly spaced radially around the first bore.

4. The calorimeter of claim 1 wherein the plurality of third bores formed in the block are evenly spaced radially around the first bore.

5. The calorimeter of claim 1 wherein the TEGs comprise Seebeck Effect TEGs operative in a hot side temperature range from 120º C to 160º C.

6. The calorimeter of claim 1 further comprising a thermally conductive material interposed between each TEG and the block.

7. The calorimeter of claim 1 wherein the TEGs cover substantially the entire surface area of the block.

8. The calorimeter of claim 1 wherein each TEG is connected to the block with a TEG retention clip.

9. The calorimeter of claim 1 wherein the TEGs are biased towards the block with a predetermined force.

10. The calorimeter of claim 9 wherein the TEGs are affixed to the block with shoulder bolts and spring washers, such that the spring washers are operative to apply a predetermined force biasing the TEGs against the block when the shoulder bolts are fully advanced.

11. The calorimeter of claim 1 further comprising one or more heat sinks affixed to the cold side of the TEGs.

12. The calorimeter of claim 11 further comprising one or more fans operative to direct convective airflow over the heat sinks.

13. The calorimeter of claim 12 further comprising a refrigerated housing operative to contain the calorimeter in an environment having a predetermined ambient temperature.

14. The calorimeter of claim 1 further comprising a gas flow manifold operative to supply one or more gases to an exothermic reaction chamber, the manifold comprising:

a mass flow controller operative to control the flow of one or more supply gasses into the exothermic reaction chamber at a predetermined rate;

one or more supply gas storage chambers in gas flow relationship with the mass flow controller;

a supply gas valve interposed between with each supply gas storage chamber and the mass flow controller and operative to selectively isolate the supply gas storage chamber from the mass flow controller; and

a port in gas flow relationship with the exothermic reaction chamber and operative to connect to a vacuum pump.

15. The calorimeter of claim 14 wherein the mass flow controller and the supply gas valves are actuated electronically under the control of software executing on a processor.

16. The calorimeter of claim 14 wherein the manifold is further operative to sample gas from the exothermic reaction chamber, and further comprises a sample gas storage chamber removeably connected to the manifold and in gas flow relationship with the exothermic reaction chamber.

17. The calorimeter of claim 16 wherein the manifold further comprises a coupling configuration interposed between the sample gas storage chamber and the manifold, the coupling configuration comprising:

first and second sample gas valves; and

a coupling interposed between the first and second sample gas valves;

wherein when the first and second sample gas valves are open, gas is operative to flow from the exothermic reaction chamber into the sample gas storage chamber; and

wherein when the first and second sample gas valves are closed, the second valve and sample gas storage chamber may be removed from the manifold at the coupling.

18. The calorimeter of claim 17 wherein the first and second sample gas valves are manually actuated.

19. The calorimeter of claim 17 wherein the first and second sample gas valves are actuated electronically under the control of software executing on a processor.

20. The calorimeter of claim 1 further comprising an exothermic reaction chamber comprising:

a cylindrical chamber operative to house an exothermic reaction chamber;

one or more toroidal magnets positioned around the chamber;

a gas flow connector at one end of the chamber operative to connect to a gas flow manifold in gas flow relationship; and

a flange at the other end of the chamber operative to retain the magnets around the chamber.

21. The calorimeter of claim 16, wherein the gas is sampled in real time.

22. The calorimeter of claim 16, wherein the gas sample is analyzed for one or more signature gases.

23. The calorimeter of claim 16, wherein the gas sample is analyzed for energetic particle detection or radio frequency detection.

24. The calorimeter of claim 1, further comprising an optical window for detecting an optical signal.

ABSTRACT

A calorimeter provides a temperature-controlled environment for an exothermic reaction chamber, and precisely measures any excess heat generated by an exothermic reaction. The calorimeter features a thermally-conductive metal block, with a bore formed to hold an exothermic reaction chamber. The block also holds, in a plurality of bores, heater elements to heat the block and thermocouples to monitor the block temperature. The TEGs are biased against the block with spring washers. The TEGs are connected in series, and their collective output voltage is determined by the temperature difference between their hot side, pressed against the block, and their cold side, cooled by the heat sinks and convective airflow. The exothermic reaction may be triggered in a variety of ways, and excess heating of the block as a result of an exothermic reaction will be reflected in the TEG output voltage.

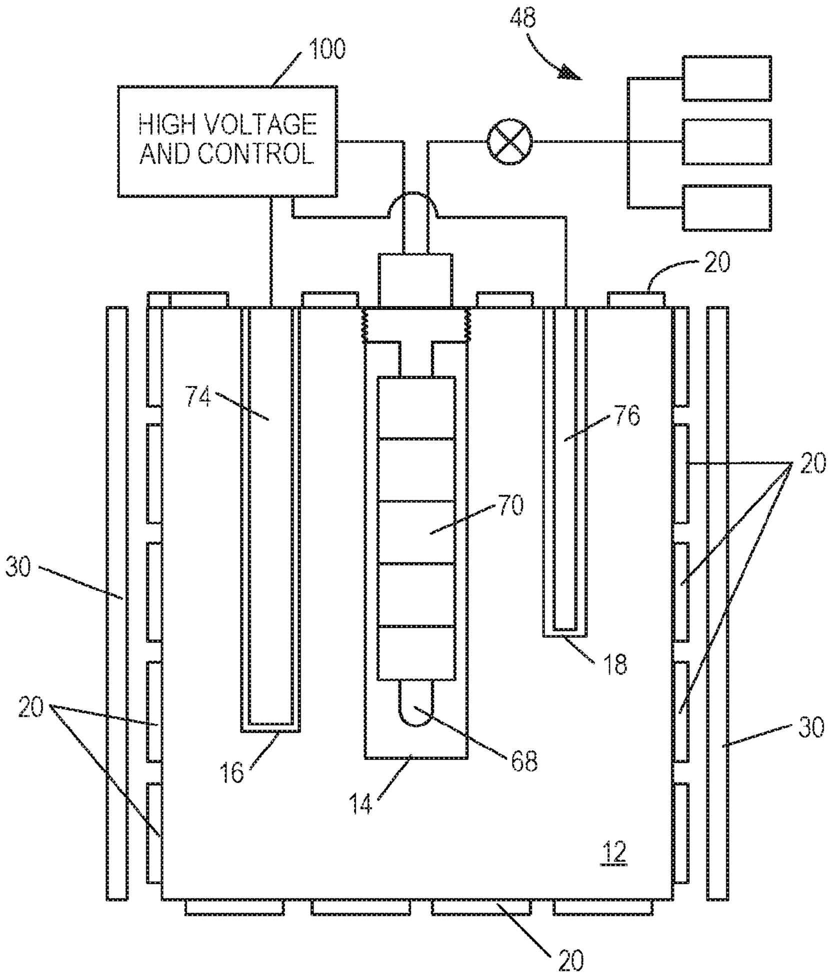
100
48
HIGH VOLTAGE
AND CONTROL
20
74
76
20
70
30
18
20
30
16
68
14
12
20

FIG. 1

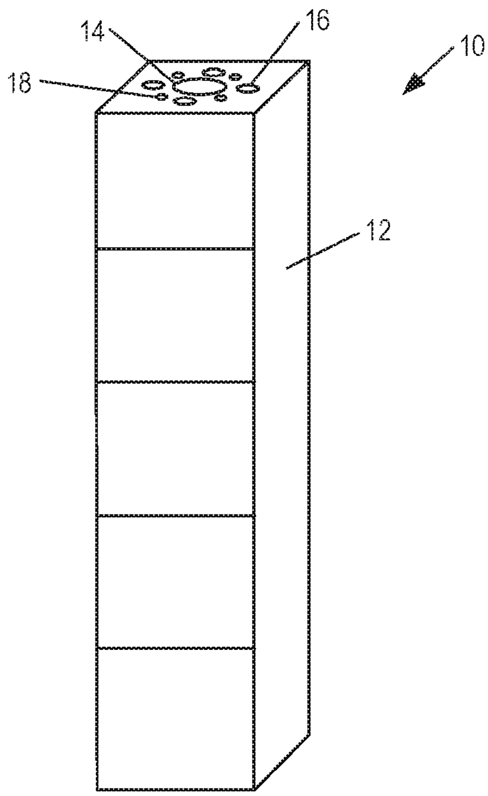

FIG. 2

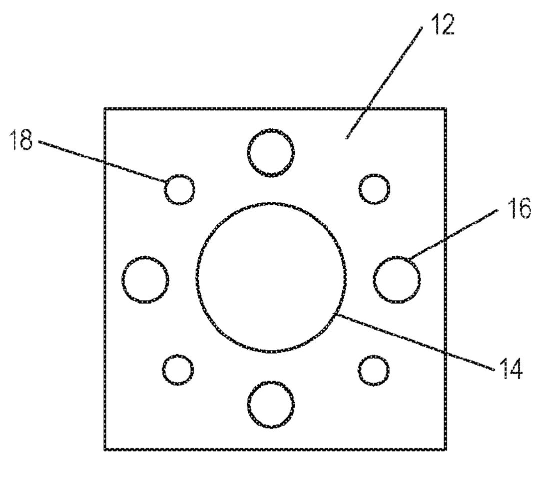

FIG. 3

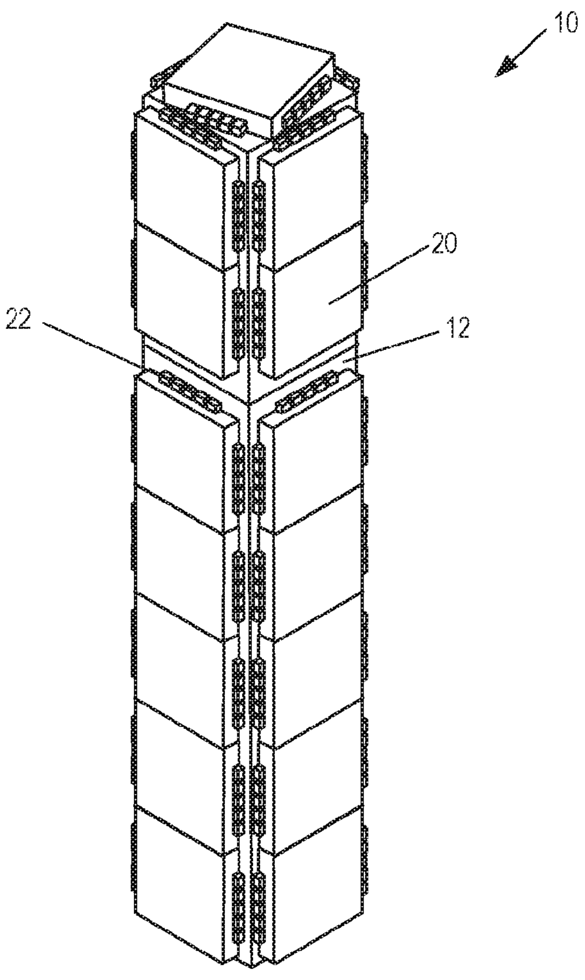

FIG. 4

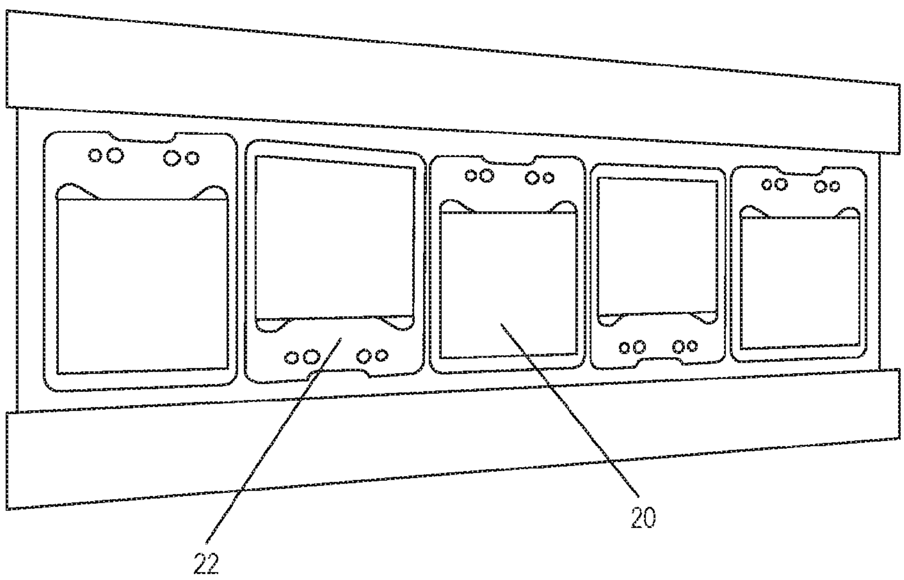

FIG. 5

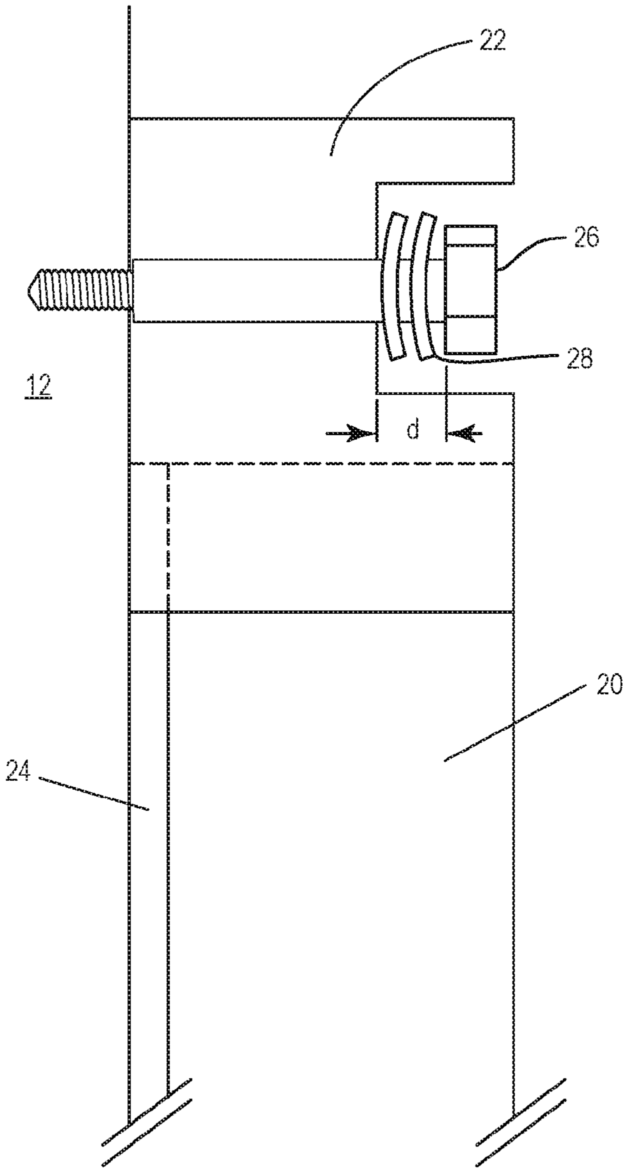

FIG. 6

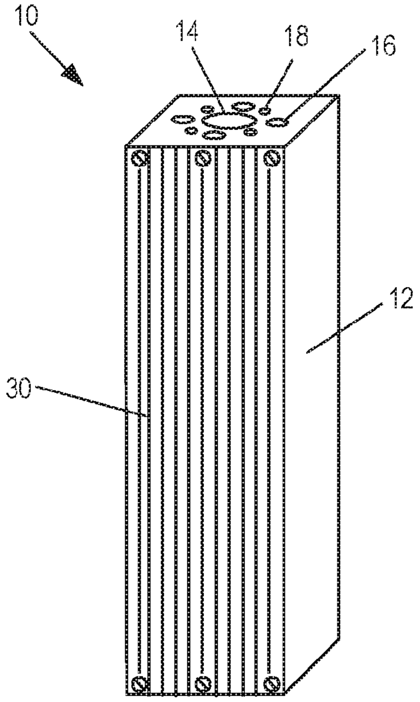

FIG. 7A

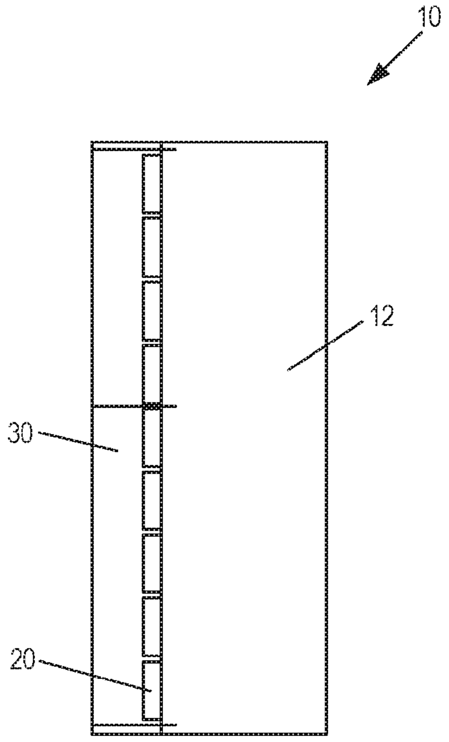

FIG. 7B

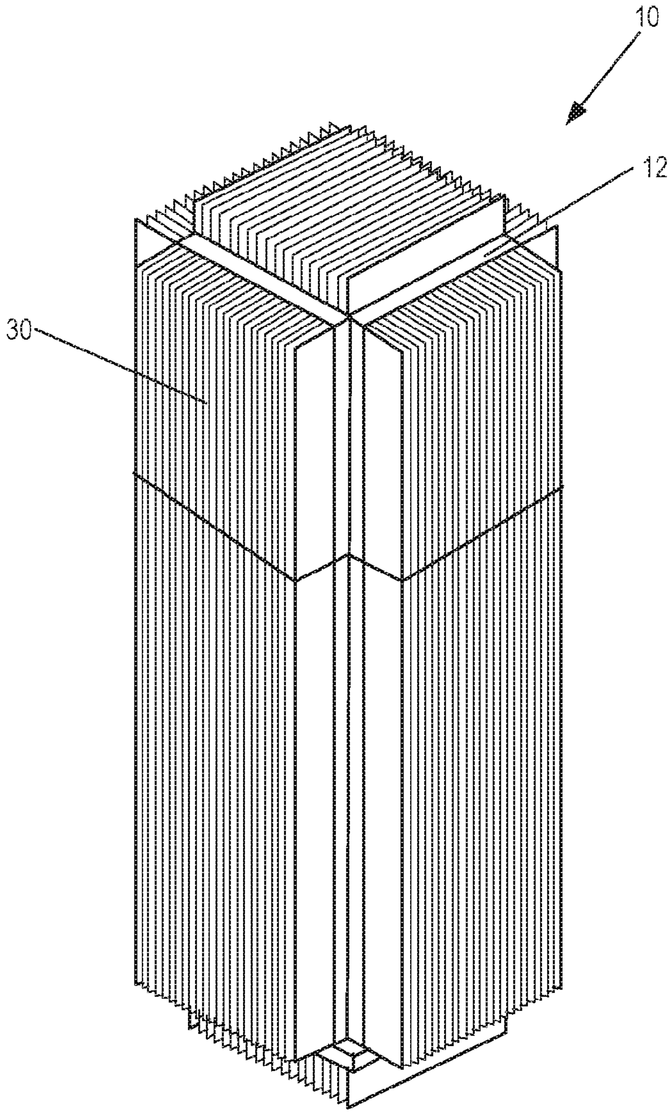

FIG. 8

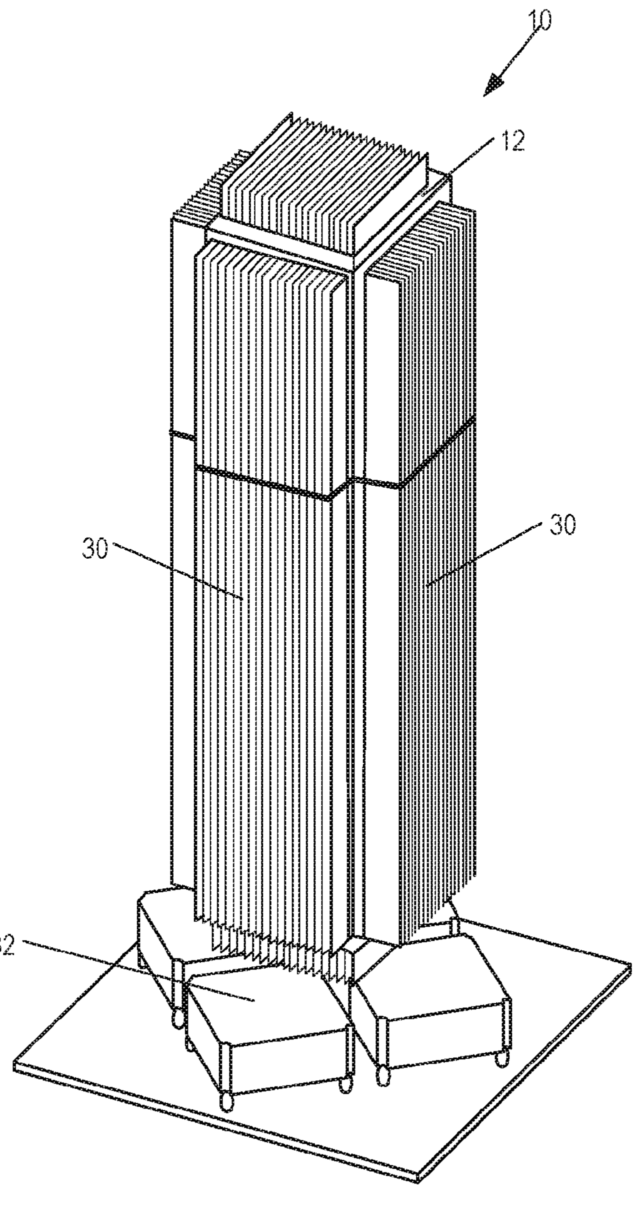

FIG. 9

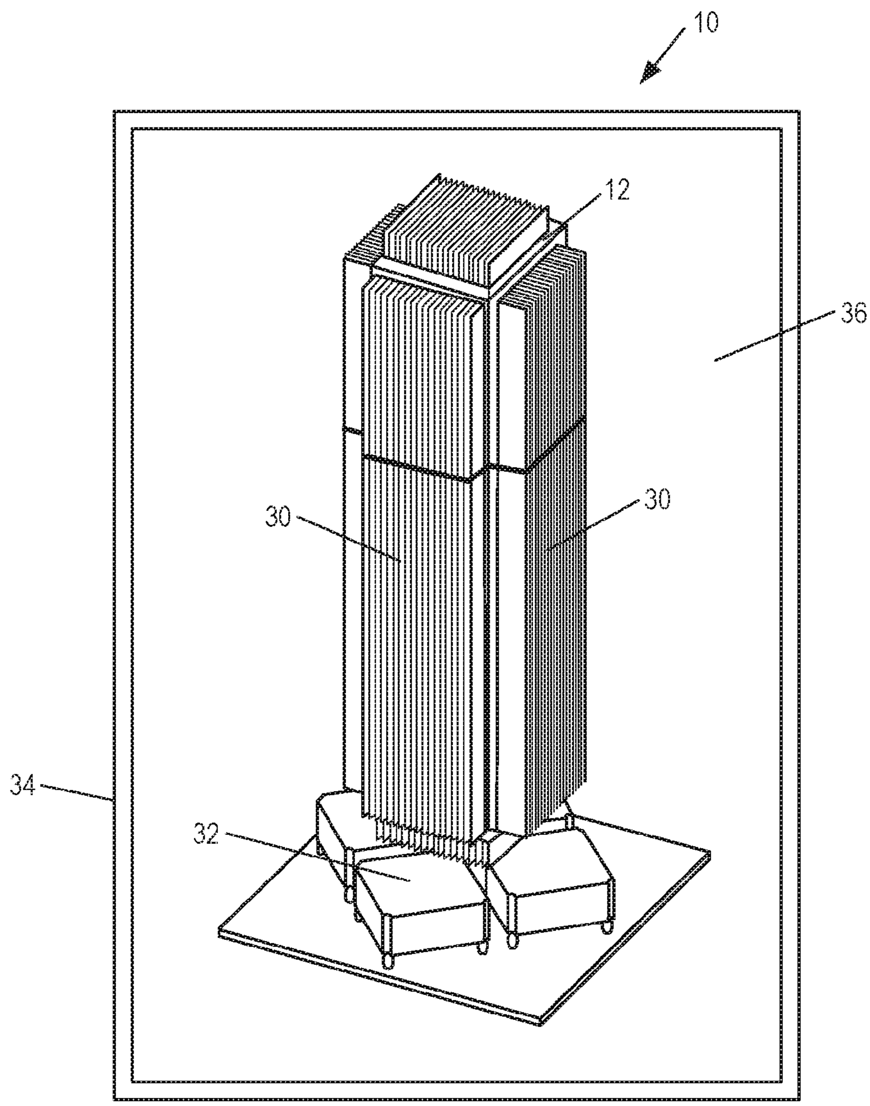

FIG. 10

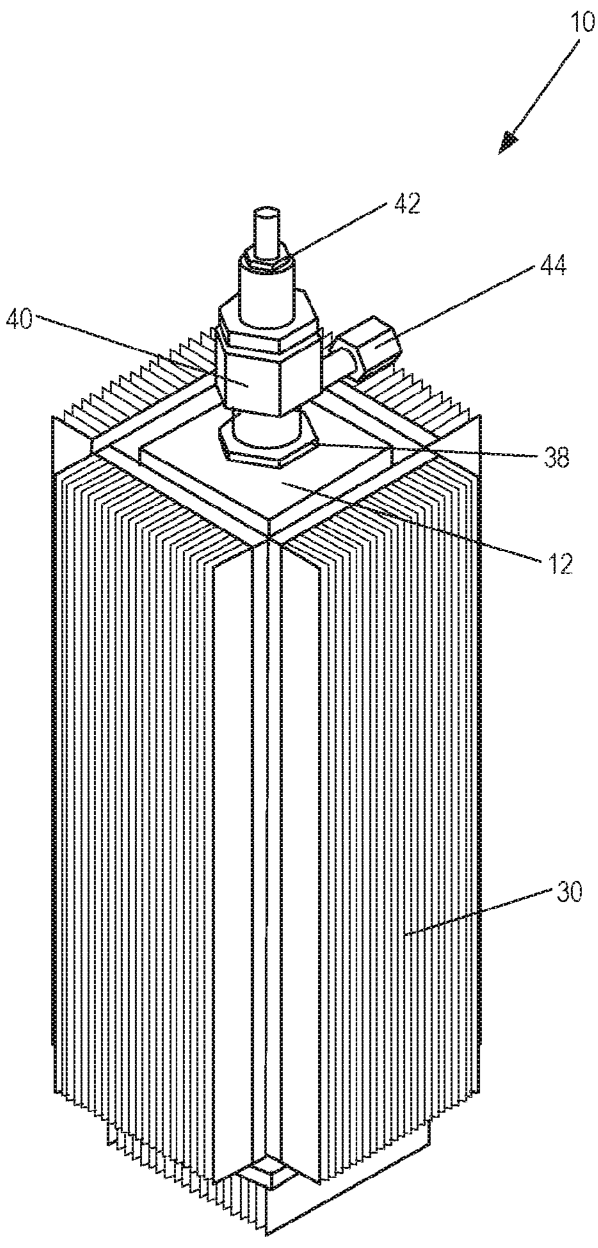

FIG. 11

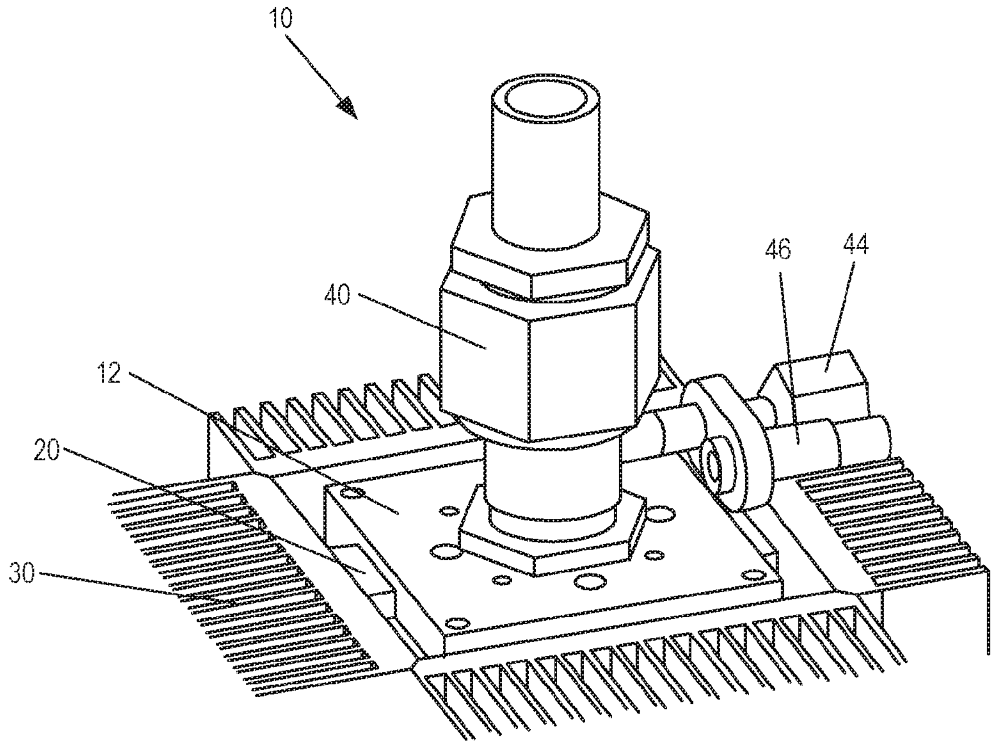

FIG. 12

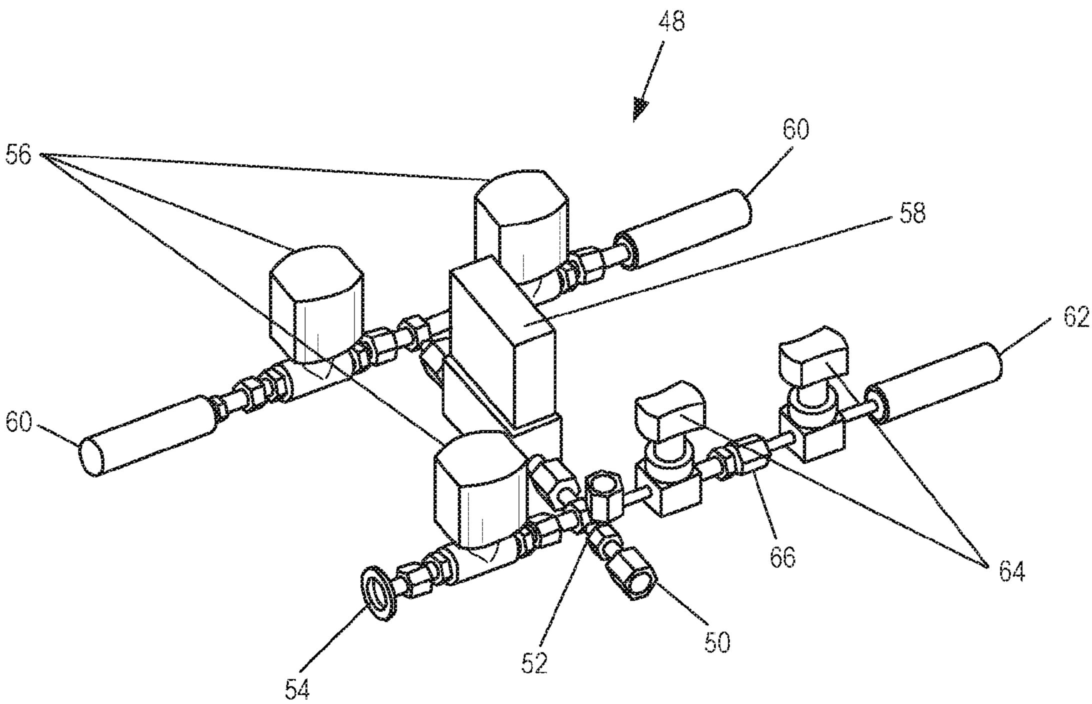

FIG. 13

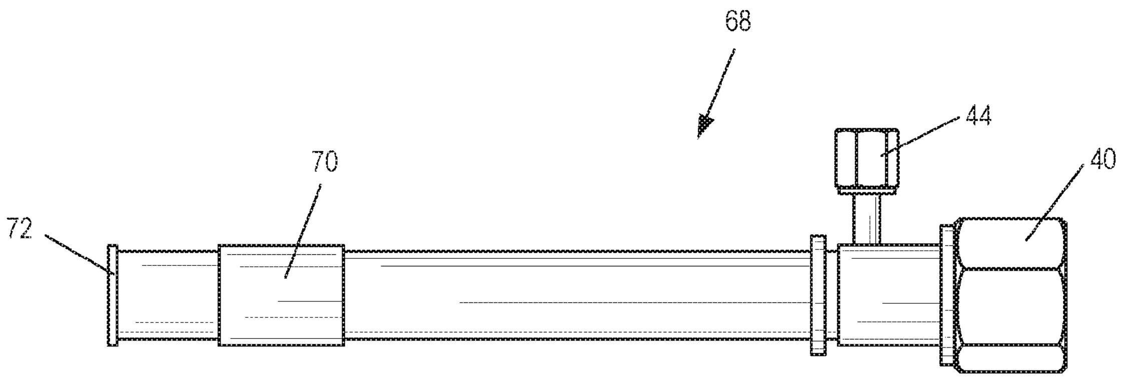

FIG. 14

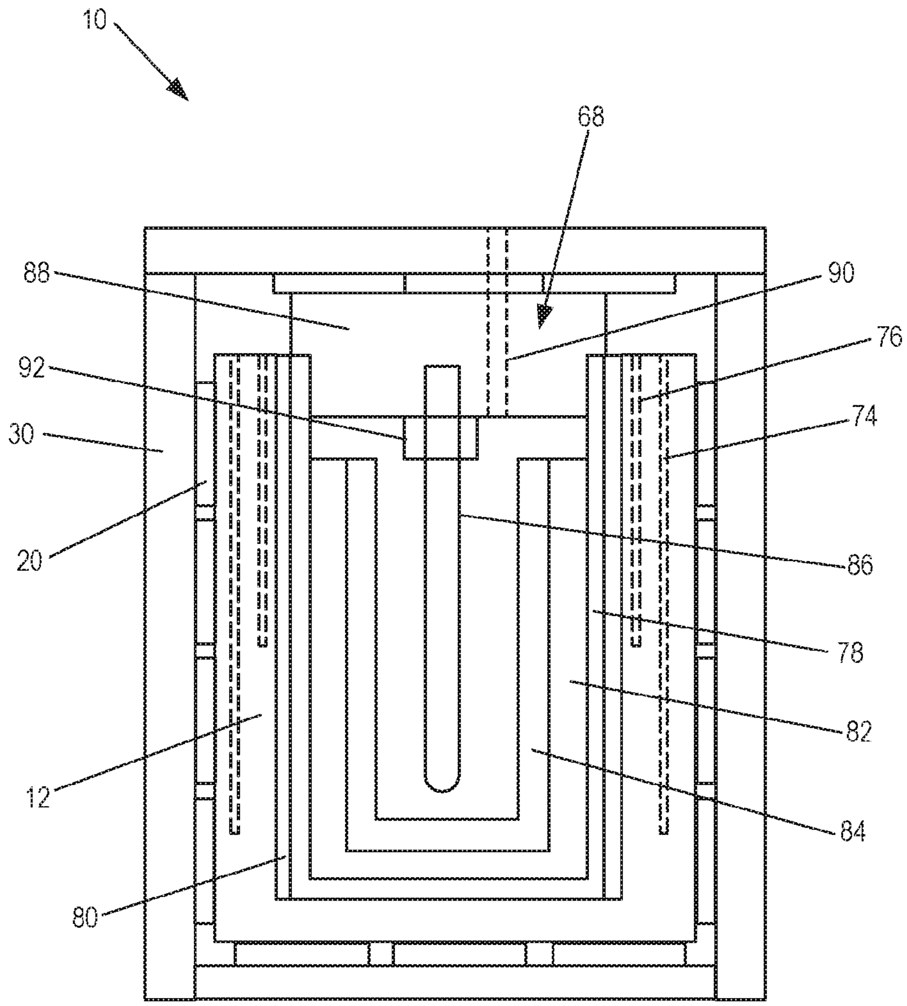

FIG. 15