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(54) **METHOD OF HEATING AND HEATING APPARATUS**

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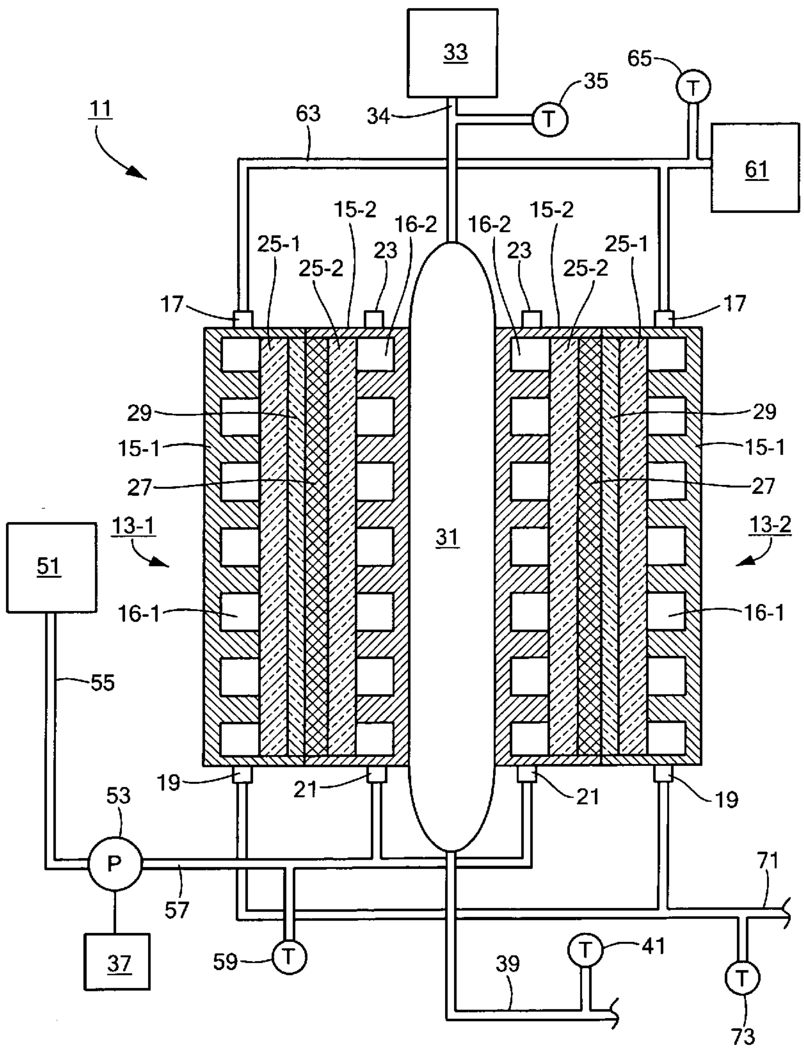
(57) **ABSTRACT**

Method of heating and heating apparatus. According to one embodiment, the heating apparatus is designed for warming infusion fluids and includes a pair of catalytic heaters positioned around a cartridge containing the infusion fluid. Each catalytic heater includes a pair of frames jointly defining a cavity. One of the frames per heater is positioned proximate to the cartridge and includes an input port for receiving a liquid solution of methanol. The other frame per heater is positioned distal to the cartridge and includes an input port for receiving oxygen gas and an output port for exhaust gases. A first fluid diffusion medium is positioned within the methanol frame, and a second fluid diffusion medium is positioned within the oxygen frame. Sandwiched between the two diffusion media are a pervaporation membrane facing the first diffusion medium and a porous metal catalyst facing the second diffusion medium. Methanol in liquid form is supplied to the pervaporation membrane, which then transports the methanol in vapor form to the catalyst, where combustion occurs. Heat from the combustion reaction is then conducted through the heater to the cartridge containing the infusion fluid.



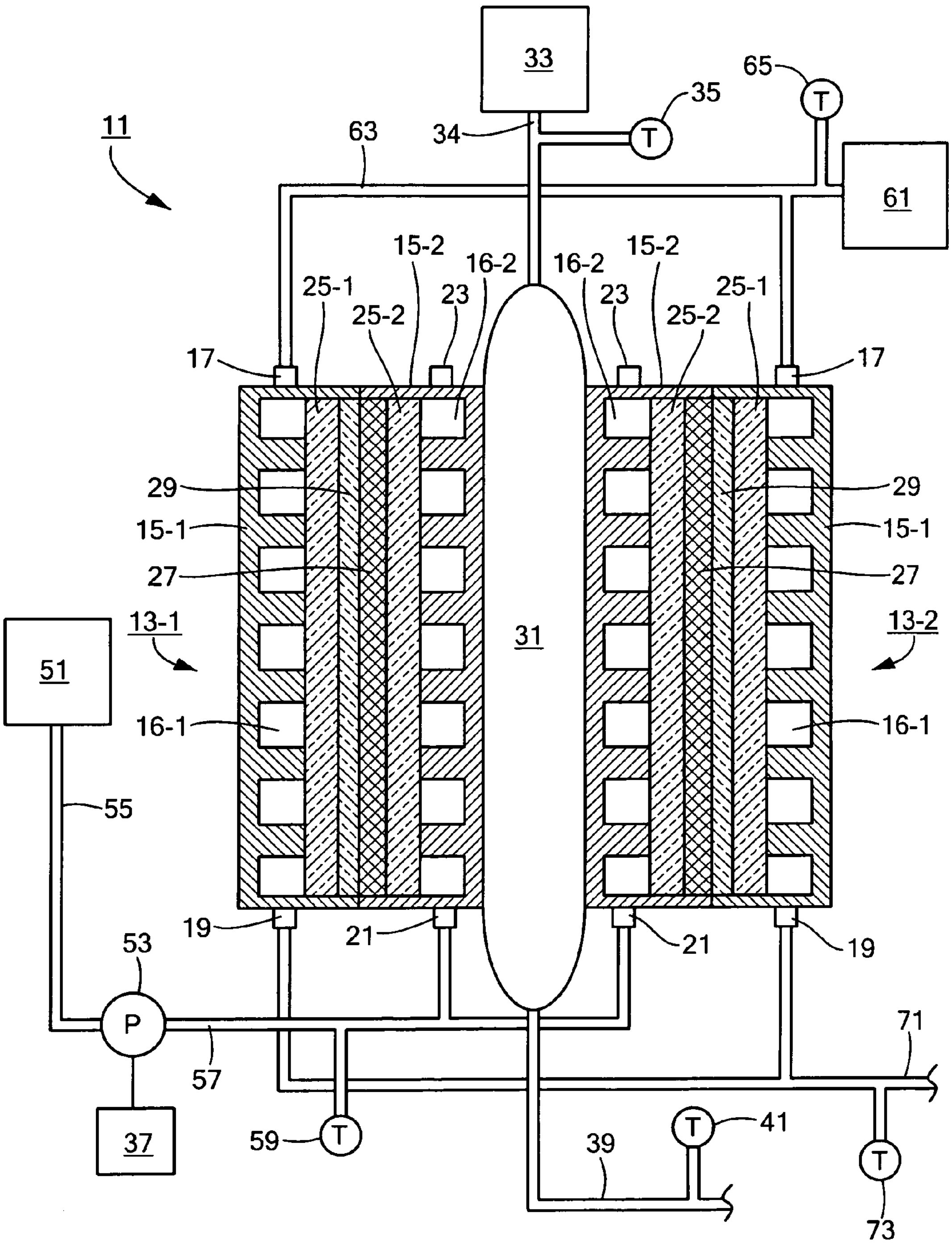

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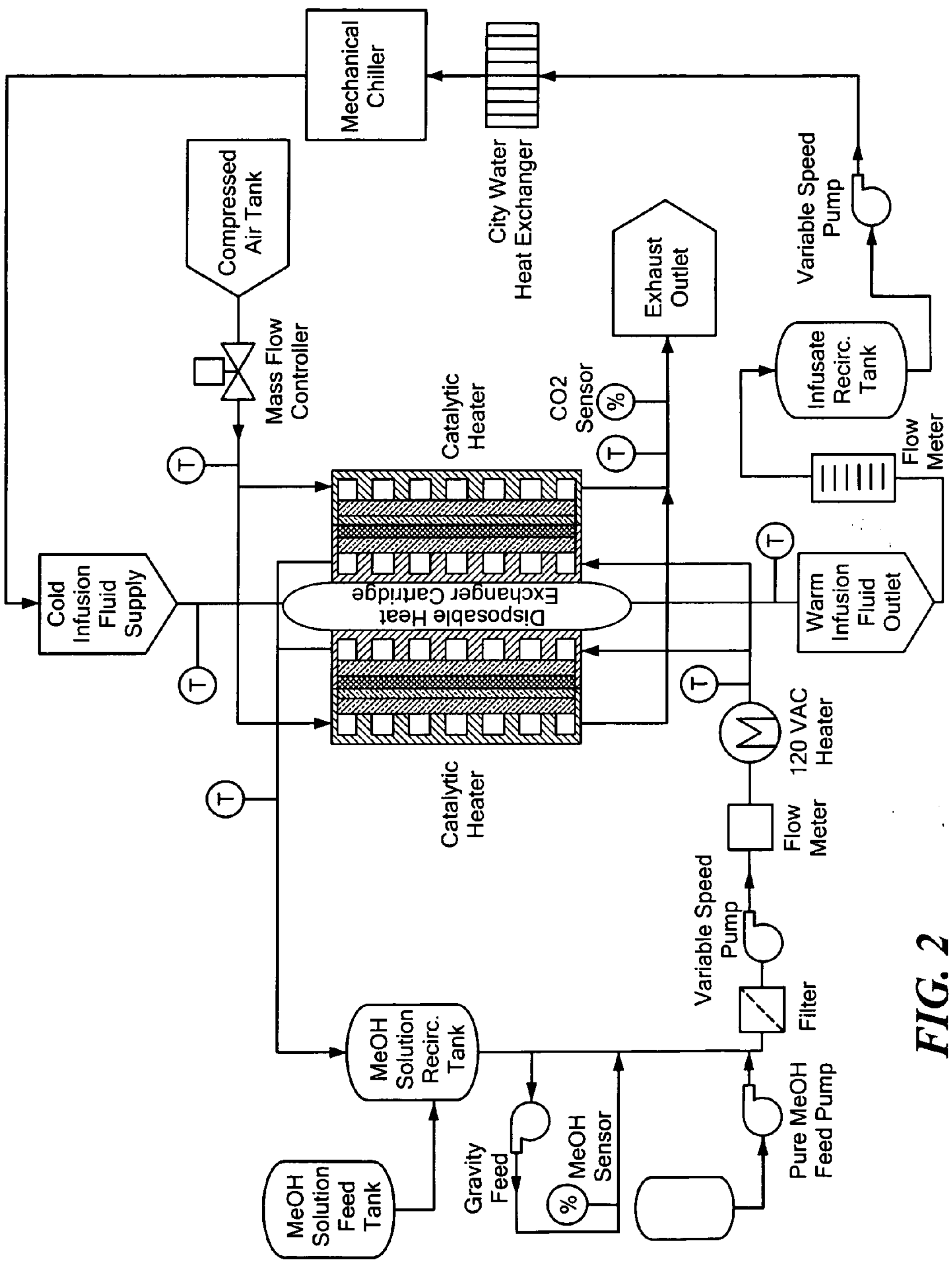
FIG. 1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City Water Heat Exchanger
Compressed Air Tank
Mass Flow Controller
Exhaust Outlet
Variable Speed Pump
Infusate Recirc. Tank
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Catalytic Heater
Cold Infusion Fluid Supply
Disposable Heat Exchanger Cartridge
Warm Infusion Fluid Outlet
120 VAC Heater
Flow Meter
Variable Speed Pump
Filter
MeOH Solution Recirc. Tank
MeOH Solution Feed Tank
Gravity Feed
MeOH Sensor
Pure MeOH Feed Pump

FIG. 2

METHOD OF HEATING AND HEATING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit under 35 U.S.C. 119(e) of U.S. Provisional Patent Application No. 61/278,273, filed Oct. 5, 2009, the disclosure of which is incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of SBIR Phase I Contract Nos. 1R43GM083360-01A1 awarded by NIH/NIGMS.

BACKGROUND OF THE INVENTION

[0003] The present invention relates generally to methods of heating and heating apparatuses and relates more particularly to methods of heating and heating apparatuses suitable for warming intravenous fluids or the like.

[0004] Excessive hemorrhaging, hypothermia and shock are among the emergency conditions that often demand timely infusion of fluids, such as whole blood, crystalloid or packed red cells. Unfortunately, the infusion of large volumes of such fluids, which are often below body-temperature, contributes to hypothermia in these trauma patients. The on-site treatment of trauma victims with warmed intravenous fluids (infusate) during the critical first hour after the onset of a medical emergency (the so-called "Golden Hour") requires effective portable heating equipment. However, to-date, such equipment is not yet available. Consequently, medical emergencies in remote areas or during disasters, such as hurricanes or terrorist attacks, often result in the "Golden Hour" passing without appropriate trauma treatment of these victims.

[0005] An early research effort to develop a portable infusion heater was that of Belmont Instrument Corporation. In 1992, Belmont Instrument Corporation demonstrated an inductive magnetic heating-based prototype. Two efforts to develop a portable infusion warmer were awarded in 2006 to CUBE Technology and Catalytic Devices International under U.S. Army SBIR Topic A06-157, "Liquid-Fueled Catalytic Heater for Infusion Fluids." However, none of these three efforts got beyond the Phase I, proof of concept level of effort.

[0006] The use of flameless heater packs by military personnel in the field to warm infusion fluids has been evaluated (see Modesto, "Avoiding hypothermia in trauma: use of the flameless heater pack, meal ready to eat, as a field-expedient means of warming crystalloid fluid," Mil. Med., 165:903-4 (2000)). These heater packs are similar to those used to heat meals-ready-to-eat (MRE) rations. Such flameless packs can only provide a limited quantity of heat at an uncontrolled temperature and are not reusable. This approach was found to be worthwhile only in cases where there is no access to proper medical heating equipment.

[0007] Existing infusion warmers generally have insufficient battery capacity to power the electrical resistance heating mechanisms. A recent study by Dubick evaluated the suitability of four commercially-available fluid heating devices for use in military forward surgical and combat areas (see Dubick, "Evaluation of commercially available fluid-warming devices for use in forward surgical and combat areas," Mil. Med., 170(1):76-82 (2005)). These forward surgical and combat areas are quite similar to the numerous remote, rural locations that exist across the United States and to the conditions that would exist in the event of a natural or terrorist disaster. The study included two floor model warmers and two portable units. The Level 1 Model 1000 (Smiths Medical, Dublin, Ohio) and FMS 2000 (Belmont Instruments, Billerica, Mass.) were evaluated for hospital use and were found to be suitable for Department of Defense (DoD) forward surgical units. Of the two portable units tested, the THERMAL ANGEL heater (Estill Medical Technologies, Dallas, Tex.) was found to be better suited for use in the most-forward echelons of care because it is lightweight and battery-powered. The RANGER heater (Arizant Healthcare, Eden Prairie, Minn.) was a more efficient fluid warmer than the THERMAL ANGEL heater, but it required external electrical power. The THERMAL ANGEL heater, the most portable of the four units tested, and the only unit not requiring external power, uses electrical resistance heaters powered by a 3.0 kg battery pack. This device was designed for heating 1-3 units of blood (450 mL/unit) from 20° to 38° C. In the aforementioned Dubick study, the ability of the THERMAL ANGEL unit to warm refrigerated fluids to body temperature was very limited. This was particularly true with the crystalloid volume expander Lactated Ringer's solution, which could not be warmed to a minimum infusion temperature of 32° C. at a flow rate of 150 mL/min.

[0008] The rechargeable battery used by the THERMAL ANGEL heater is a 12-V battery that stores 7.2 Amp·h (Estill Medical Technologies, TA-BCE Battery Product Information), resulting in a stored energy content of 86.4 Whr. Dividing by the battery mass gives a specific energy of 28.8 Wh/kg. Estill Medical Technologies specifies that the battery charge will last through the heating of approximately one to three units of blood from 20° to 38° C. The ability to heat only one to three units of blood before battery recharge or replacement severely limits the field use of the product, particularly in disaster situations where large numbers of patients must be treated.

[0009] Difficulties in battery supply logistics and charge cycle management have led to the examination of alternative power sources, including fuel cells and solar panels (see Defense Update, "Portable electrical power: battery supplies and logistics lessons learned in Operation Iraqi Freedom 2003," Defense Update: International Online Defense Magazine, 2004(1), http://www.defense-update.com/features/du-1-04/batteries-lessons-iraq.htm (Jun. 13, 2006)). Fuel cells have generally not come into use in civilian applications, due to their present high initial costs. A solar panel alternative is generally impractical for civilian pre-hospital emergency medicine applications, due to the large solar panel area required and the probability of insufficient solar irradiance to power the device.

SUMMARY OF THE INVENTION

[0010] It is an object of the present invention to provide a novel heating method.

[0011] It is another object of the present invention to provide a novel heating method that overcomes at least some of the shortcomings discussed above in connection with existing heating methods.

[0012] Therefore, according to one aspect of the invention, there is provided a method of heating a material to be warmed, said method comprising the steps of (a) providing a porous metal catalyst suitable for catalyzing the combustion of a gaseous fuel in the presence of oxygen; (b) supplying the porous metal catalyst with the gaseous fuel and with oxygen, whereby the gaseous fuel is combusted and heat is generated; and (c) transferring the heat generated to the material to be warmed.

[0013] It is still another object of the present invention to provide a novel heating apparatus.

[0014] Therefore, according to another aspect of the invention, there is provided an apparatus for heating a material, said apparatus comprising (a) a porous metal catalyst suitable for catalyzing combustion of a gaseous fuel in the presence of oxygen; (b) a pervaporation membrane, the pervaporation membrane having an input face and an output face, the output face being in sufficient proximity to the porous metal catalyst to supply the porous metal catalyst with fuel in vapor form; (c) means for supplying the input face of the pervaporation membrane with a fluid fuel, whereby the fluid fuel travels from the input face of the pervaporation membrane to the output face of the pervaporation membrane and is emitted from the output face of the pervaporation membrane in vapor form; (d) means for supplying the porous metal catalyst with oxygen; and (e) means for transferring heat generated by combustion of the gaseous fuel to a material to be warmed.

[0015] According to still another aspect of the invention, there is provided an apparatus for heating a material, said apparatus comprising: (a) a catalytic heater, said catalytic heater comprising (i) a housing, the housing defining a cavity and having a fuel input port for receiving a fuel, an oxygen input port for receiving oxygen gas, and an exhaust outlet port for discharging exhaust gases, (ii) a first fluid diffusion medium disposed in said cavity and in fluid communication with said fuel input port, (iii) a second fluid diffusion medium disposed in said cavity and in fluid communication with said oxygen input port and said exhaust outlet port, (iv) a porous metal catalyst suitable for catalyzing combustion of a gaseous fuel in the presence of oxygen, said porous metal catalyst being disposed between said first and second fluid diffusion media and in contact with said second fluid diffusion medium, (v) a pervaporation membrane for supplying the porous metal catalyst with fuel in vapor form, the pervaporation membrane having an input face and an output face, the input face being in contact with the first fluid diffusion medium, the output face being in contact with the porous metal catalyst; (b) means for supplying the catalytic heater with a fuel; and (c) means for supplying the catalytic heater with oxygen gas.

[0016] Additional objects, as well as aspects, features and advantages, of the present invention will be set forth in part in the description which follows, and in part will be obvious from the description or may be learned by practice of the invention. In the description, reference is made to the accompanying drawings which form a part thereof and in which is shown by way of illustration various embodiments for practicing the invention. The embodiments will be described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural changes may be made without departing from the scope of the invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is best defined by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The accompanying drawings, which are hereby incorporated into and constitute a part of this specification, illustrate various embodiments of the invention and, together with the description, serve to explain the principles of the invention. In the drawings wherein like reference numerals represent like parts:

[0018] FIG. **1** is a simplified schematic diagram of a first embodiment of a heating apparatus constructed according to the teachings of the present invention, certain components of the apparatus being shown in cross-section; and

[0019] FIG. **2** is a simplified schematic diagram of a second embodiment of a heating apparatus constructed according to the teachings of the present invention, certain components of the apparatus being shown in cross-section, said heating apparatus being used as an experimental set-up for the examples discussed below.

DETAILED DESCRIPTION OF THE INVENTION

[0020] A major innovation of this invention is the development of a reusable, portable heater/warmer for infusion fluids that uses a non-flammable liquid fuel to provide heating capacity in a portable device for the full range of trauma treatment. The infusion warmer could also be non-portable. A preferred non-flammable liquid fuel comprises an alcohol mixed with water, and in particular a 15-24% methanol solution. Alternately, a hydrocarbon, alcohol, or other flammable or non-flammable liquid or gaseous fuels could be employed including mixtures and, especially, mixtures with water. Gaseous fuels could include hydrocarbons, hydrogen, or a mixture of fuel gases. An objective of this invention is to provide a liquid-fueled catalytic heater that can warm a large number of units of infusate at a flow rate of up to 500 mL/min using one fuel cartridge. Another objective is to warm 20 units of infusate using one cartridge of methanol (or other hydrocarbon) fuel (possibly in aqueous solution). This will allow either treating 20 patients with 1 unit each or treating one patient with 20 units of infusate. 20 units of blood are sufficient to cover all but the most extreme single cases and are sufficient to meet the infusion needs for 92% of trauma patients (see Novikov et al., "Fluid and Blood Therapy in Trauma," Trauma Anesthesia, Cambridge University Press, New York, N.Y., pp. 101-20 (2008)). By changing the fuel cartridge, additional patients can be treated by the system (or more than 20 units of fluid can be given to a single patient).

[0021] A specific technical innovation in this invention is the use of a pervaporation membrane to supply methanol fuel vapor at a controlled rate to a catalytic oxidation chamber, wherein the methanol vapor reacts with oxygen from air to produce heat which is transferred to flowing infusate. In addition to ambient air, oxygen-containing gas (10-90%) or high purity oxygen gas (90-100%) could also be employed. The catalyst used in the catalytic oxidation chamber can comprise an unsupported porous metal or a porous metal deposited on an oxygen-inert support particulate sinter or metal. The porous metal catalyst can comprise a noble metal, such as a platinum group member, or a non-noble metal, such as a transition metal member. A preferred embodiment of this invention includes integration of the fuel supply, catalytic oxidation cell and heat transfer device, as well as selection of operating parameters to provide safe, efficient, controlled heating of infusion liquids. In addition to the heat transfer device being a heat exchanger, a heat pipe could be used. The infusion fluid being warmed could include one or more of crystalloid, saline, whole blood, plasma, packed red cells, platelets, artificial blood, or other biological liquids. Other non-biological liquids could be heated; gases and solid materials, including gels or semi-solids, could also be heated.

[0022] A "dry heat" version of this invention was demonstrated, where heat is catalytically produced by the methanol-fueled device, and passes through first a metal (aluminum) and then a plastic (an AZIRANT RANGER heat transfer cassette) surface to reach the infusion fluid. A major advantage of this dry heat method is that there is no chance of contaminating the infusion fluid with the liquid fuel. A disadvantage of this method is the potential for cooling of the heated infusion fluid after it leaves the heater and as it passes down an intravenous (IV) line to the patient's catheter.

[0023] A water-heated version could also be produced using this technology, where the heat that is catalytically produced by the methanol-fueled device is released to a sterile water supply. Such a sterile water supply would then pass through a direct contact heat exchanger to heat the infusion liquid. A major advantage of this water-heated version is that a long, tube-in-tube direct contact heat exchanger can be used, delivering the heated infusate to close proximity of the patient's catheter. A major disadvantage is the potential for contamination of the heated infusate should there be a defect (e.g. a water-to-infusate leak) in the long, tube-in-tube direct contact heat exchanger.

[0024] Rather than heating a liquid, heat from the reaction chamber could be transferred to a gas or gas mixture including one or more of the following: air, nitrogen, oxygen, anesthetic, analgesic and/or inert gases.

[0025] A preferred embodiment of this technology involves a portable infusion heater that can initially be used in the field, at the site of a medical problem. Subsequently, the methanol-fueled device would travel with the patient during transport (by ambulance or Med-Flight) to a hospital, then during the patient's assessment in an emergency department. Warm transfusions could be maintained as the patient is transported to a diagnostics area and could continue during that diagnostic assessment to find the source(s) of any bleeding. Warm infusion fluids can continue to be supplied during the patient's transport to an operating room and during an operation. During an extended, complicated operation, transitioning to a conventional, 120 VAC utility-powered fluid heater would be possible. This continuum of infusion represents a great improvement over conventional, electrically-powered heaters, where infusion of warmed fluids is often interrupted, e.g. during transport to the operating room.

[0026] In order to ensure compliance with applicable health and safety requirements, a small catalytic converter could be added to treat the effluent exhaust. Such a converter could significantly reduce aerobic methanol vapor concentrations. Testing of this catalytic converter technology was successfully conducted and showed essentially complete removal of methanol in the effluent exhaust. The catalytic converter may or may not need electric heat in order to provide acceptable methanol destruction efficiency. Although platinum was used, various catalysts, including non-noble metal catalysts (e.g. nickel), are available to provide suitable reactivity.

[0027] A hybrid heating arrangement could also be possible, involving a combination of electric heat and methanol-sourced heat. The electric heat (as a supplement or boost) could be provided by either batteries (in a portable application) or from a utility's 120 VAC wall connection (for a stationary application). A capacitor could be included for shaping peak power demand of the device.

[0028] Either the warm exhaust gas leaving the heater and/or the warm liquid fuel leaving the heater could be passed either directly or indirectly to another process, including a heat transfer device. Heat from the heater and/or this heat transfer device could be used in a patient heating process or in other thermal management devices.

[0029] Heat from the catalytic reaction chamber could also be transferred to a solid, gel, or semi-solid, for use warming a patient or other possible use.

[0030] In addition to heating infusate fluids, a methanol-fueled device as herein described could produce heat for many existing, medical devices that are cord-powered off of 120 VAC power, including: bed heating pads, bed heating mattresses, adhesive-backed heating pads for attachment to patients, heated blankets that are positioned on top of patients, warming clothing, etc. Heat from a methanol-fueled device can warm, either directly or indirectly, either water or air for such purposes. Warmed liquids or gases from the device can be used to inflate the patient warming system. Other methanol-heated medical devices would also be possible, including other form factors and configurations.

[0031] Referring now to FIG. **1**, there is shown a simplified schematic view of a first embodiment of a heater apparatus constructed according to the teachings of the present invention, said heater apparatus being represented generally by reference numeral **11**.

[0032] Apparatus **11** comprises a pair of catalytic heaters **13-1** and **13-2**. Heaters **13-1** and **13-2** are essentially identical to one another, except that heater **13-2** is a mirror image of heater **13-1**. Therefore, it is to be understood that, apart from its mirror-image orientation, the discussion below of heater **13-1** is applicable to heater **13-2**. Heater **13-1** comprises a pair of frames **15-1** and **15-2**. Each of frames **15-1** and **15-2** is preferably made of a heat-conductive material, such as aluminum or a like metal. Frames **15-1** and **15-2** are joinable to one another (by means not shown). The interior of frame **15-1** defines a flow field **16-1**, and the interior of frame **15-2** defines a flow field **16-2**, with frames **15-1** and **15-2** jointly defining a cavity in fluid communication with flow fields **16-1** and **16-2**. Frame **15-1** further includes an inlet port **17** and an outlet port **19**, both of which are in fluid communication with flow field **16-1**, and frame **15-2** further includes an inlet port **21** and an outlet port **23**, both of which are in fluid communication with flow field **16-2**.

[0033] Heater **13-1** further comprises a pair of fluid diffusion media **25-1** and **25-2**. Media **25-1** and **25-2** may be identical to one another and may be fluid diffusion media of the type used, for example, in electrochemical cells. Media **25-1** is positioned within frame **15-1** against flow field **16-1**, and media **25-2** is positioned within frame **15-2** against flow field **16-2**.

[0034] Heater **13-1** further comprises a pervaporation membrane **27** and a porous metal catalyst **29** sandwiched between media **25-1** and **25-2**, with pervaporation membrane **27** having opposing faces in intimate contact with catalyst **29** and media **25-2**, respectively, and with porous metal catalyst **29** having opposing faces in intimate contact with pervaporation membrane **27** and media **25-1**, respectively. Pervaporation membrane **27** may be a permselective membrane or a microporous membrane.

[0035] Apparatus **11** further comprises an infusion fluid receptacle **31**, which may be used to hold a quantity of fluid to be warmed by heaters **13-1** and **13-2**. Receptacle **31** may be, for example, a plastic bag having a serpentine shape, with one side of receptacle **31** in intimate contact with heater **13-1** and the opposing side of receptacle **13** in intimate contact with heater **13-2**. Receptacle **31** may receive fluid to be warmed from a fluid source **33** conducted through a length of tubing **34**. A temperature sensor **35** connected to a controller **37** (by means not shown) may be used to monitor the temperature of fluid prior to its being warmed. After being warmed in receptacle **31**, the fluid may be conducted to a patient (not shown) through a length of tubing **39**. A temperature sensor **41** connected to controller **37** (by means not shown) may be used to monitor the temperature of fluid that has been warmed in receptacle **31**.

[0036] Apparatus **11** further comprises a fuel cartridge **51**, which may contain a quantity of a methanol solution or the like. Cartridge **51** is fluidly connected to a fluid pump **53** through a length of tubing **55**. Pump **53** is electrically connected to controller **37** and is fluidly connected to inlet ports **21** of heaters **13-1** and **13-2** through a length of tubing **57**. A temperature sensor **59** connected to controller **37** (by means not shown) may be used to monitor the temperature of fluid that is being pumped to inlet ports **21**.

[0037] Apparatus **11** further comprises a fan **61** for blowing ambient air into inlet ports **17** through a length of tubing **63**. Fan **61** may be connected to controller **37** (by means not shown). A temperature sensor **65** connected to controller **37** (by means not shown) may be used to monitor the temperature of air that is being supplied to inlet ports **17**.

[0038] Apparatus **11** further comprises a length of tubing **71** connected to outlet ports **19** for removing the exhaust and other fluids from heaters **13-1** and **13-2**. A temperature sensor **73** connected to controller **37** (by means not shown) may be used to monitor the temperature of the exhaust fluids.

[0039] Apparatus **11** has small auxiliary power requirements for pump **53**, fan **61** and controller **37**. These power requirements are minimized so that they can be supplied by a long-lasting, small battery (not shown).

[0040] In use, methanol solution is pumped from cartridge **51** into flow fields **16-2**, and ambient air is blown into flow fields **16-1**. The methanol solution diffuses through media **25-2** and is then conducted in vapor phase to porous catalyst **29**, where it then reacts with oxygen to generate carbon dioxide and heat. The generated heat is transferred through frames **15-1** and **15-2** to receptacle **31** and, in turn, to the fluid contained within receptacle **31**. After being warmed, this fluid is then administered to the patient. The carbon dioxide and other excess fluids remaining in flow field **16-1** are discharged through outlets **19**. As can be appreciated, by monitoring the temperatures of the various fluids, controller **37** may be used to adjust the rate at which fluids are pumped into heaters **13-1** and **13-2**.

[0041] The following examples are illustrative only and do not in any way limit the present invention:

Example 1

[0042] The steady-state equipment arrangement shown in FIG. **2** was used for laboratory testing of the prototype hardware. The 120 VAC methanol heater was provided to reduce the required time to startup the test stand and in case insufficient heat was supplied by the apparatus of this invention. The methanol sensor loop and pure methanol feed pump subsystem were provided to maintain a constant methanol concentration (6 M) in the circulating liquid. The small (1 liter) methanol solution recirculation tank was provided to reduce the volume of circulating methanol, and thus speed the transient responsiveness of the prototype. The large (5 liter) methanol feed tank was designed to provide fresh solution to make up for methanol solution consumption in the recirculation loop. A compressed air tank and mass flow controller were used in the permselective membrane, methanol-fueled heater apparatus; it is also possible that a prototype would use a variable speed fan or blower for controlling the air supply. To allow facile documentation of heating performance of the laboratory apparatus, an infusion fluid recirculation loop was used, including both a city water heat exchanger for initial cooling, and an electrically-powered mechanical chiller to return the recirculated infusate to the desired temperature (e.g. 5° C.). Type K thermocouples were used to monitor inlet and discharge temperatures; a carbon dioxide sensor measured the air-side exhaust effluent. Flow meters were also provided on the recirculated infusate loop and the recirculated methanol solution loop.

[0043] The prototype included two 203 sq. cm methanol-fueled cells that transferred heat from the methanol stream to the infusate (water) stream. The two cells made a sandwich with an Arizant Ranger Model 24365 High Flow I.V. Blood/Fluid Warming Set (the disposable heat exchanger in FIG. **2**). Each cell was assembled with the following materials:

[0044] Membrane: General Electric PVDF (Polyvinylidene Fluoride) Transfer Membrane, Part No. 1214429, Model No. PV2HY00010, 220 nm pore size. Other membranes have been and could be used. For example, a permselective membrane could be used that possessed a pore size ranging from 0 to 800 mm, or preferably a pore size of 100 to 300 mm. The permselective membrane could be comprised of a solid ion-conductive polymer electrolyte membrane, a fluorocarbon-based polymer, a hydrocarbon-based polymer, or other material.

[0045] Air-side support: Wetproofed Toray H-060 with platinum catalyst, similar to state-of-the-art direct methanol fuel cell (DMFC) supports. Although platinum was used, various catalysts are available to provide suitable reactivity. Although Toray H-060 was used, other support materials could be selected, providing they were stable under the conditions in the catalytic oxidizing chamber.

[0046] Methanol-side support: Toray H-060, untreated. Although Toray H-060 was used, other support materials could be selected, providing they were stable under the conditions in the fuel-side chamber.

Results from operating the prototype with the electric heat turned off included the following:

[0047] 100 cc/min. infusate recirculation rate, 5° C. inlet temperature, 52° C. outlet temperature (in excess of the desired outlet temperature of 40° C.)

[0048] 8,000 scc/min inlet air flow rate, 24.6° C. inlet temperature, 50.7° C. outlet (exhaust) temperature, exhausting 10.4% V/V carbon dioxide, or an equivalent of 770 mA/sq. cm carbon dioxide production

[0049] 285 cc/min 6 M methanol recirculation rate, 46.4° C. inlet temperature, 51.2° C. outlet temperature

[0050] This operating point demonstrates a heat production rate (temperature rise) of 47° C., which is in excess of the desired 35° C. temperature rise, without use of any electric heat.

Example 2

[0051] Additional tests reached the design goal of a temperature rise of 35° C.+/−1° C. with infusion recirculation rates of 100 and 500 cc/min using crystalloid (normal saline) solution rather than water. Due to the limited size of the prototype, caused by the fixed size of the commercially-obtained disposable heat exchanger that the system was designed around, the 500 cc/min test required a limited amount of supplemental electrical heating to reach the desired temperature rise. (The 100 cc/min test was conducted with the electric heat disabled.) Based on related direct methanol fuel cell experience, it is possible to produce a suitable system design and to adjust the air and methanol solution circulation rates to produce the desired temperature rise of 35° C. at an infusate flow rate of 500 cc/min without the use of supplemental electrical heat.

[0052] The embodiments of the present invention described above are intended to be merely exemplary and those skilled in the art shall be able to make numerous variations and modifications to it without departing from the spirit of the present invention. All such variations and modifications are intended to be within the scope of the present invention as defined in the appended claims.

What is claimed is:

1. A method of heating a material to be warmed, said method comprising the steps of:
- (a) providing a porous metal catalyst suitable for catalyzing the combustion of a gaseous fuel in the presence of oxygen;
- (b) supplying the porous metal catalyst with the gaseous fuel and with oxygen, whereby the gaseous fuel is combusted and heat is generated; and
- (c) transferring the heat generated to the material to be warmed.

2. The method as claimed in claim **1** wherein the porous metal catalyst comprises an unsupported porous metal.

3. The method as claimed in claim **1** wherein the porous metal catalyst comprises a porous metal deposited on an oxygen-inert support particulate sinter or metal.

4. The method as claimed in claim **1** wherein the porous metal catalyst comprises a noble metal.

5. The method as claimed in claim **5** wherein the noble metal comprises a platinum group member.

6. The method as claimed in claim **1** wherein the porous metal catalyst comprises a non-noble metal.

7. The method as claimed in claim **6** wherein the non-noble metal comprises a transition metal member.

8. The method as claimed in claim **1** wherein said supplying step comprises providing a pervaporation membrane, said pervaporation membrane having an input face and an output face, the output face being in proximity to the porous metal catalyst, and supplying the input face of said pervaporation membrane with a fluid fuel, whereby the pervaporation membrane transports the fluid fuel from said input face to said output face in vapor form so that the fluid fuel exits said pervaporation membrane at said output face as the gaseous fuel.

9. The method as claimed in claim **8** wherein said pervaporation membrane has a pore size ranging from 0 to 400 nm.

10. The method as claimed in claim **9** wherein said pervaporation membrane has a pore size ranging from 100 to 300 nm.

11. The method as claimed in claim **8** wherein said pervaporation membrane comprises a solid ion-conductive polymer electrolyte membrane.

12. The method as claimed in claim **8** wherein said pervaporation membrane comprises a fluorocarbon-based polymer.

13. The method as claimed in claim **8** wherein said pervaporation membrane comprises a hydrocarbon-based polymer.

14. The method as claimed in claim **8** wherein the fluid fuel is supplied to the pervaporation membrane in liquid form.

15. The method as claimed in claim **8** wherein the fluid fuel is supplied to the pervaporation membrane in gaseous form.

16. The method as claimed in claim **1** wherein the gaseous fuel comprises a hydrocarbon.

17. The method as claimed in claim **1** wherein the gaseous fuel comprises an alcohol.

18. The method as claimed in claim **17** wherein the gaseous fuel comprises methanol.

19. The method as claimed in claim **1** wherein the oxygen supplied to the porous metal catalyst is supplied as ambient air.

20. The method as claimed in claim **1** wherein the oxygen supplied to the porous metal catalyst is supplied as a high purity oxygen gas.

21. The method as claimed in claim **1** wherein said transferring step comprises using a heat exchanger to transfer heat to the material to be warmed.

22. The method as claimed in claim **1** wherein said transferring step comprises using a heat pipe to transfer heat to the material to be warmed.

23. The method as claimed in claim **1** wherein the material to be warmed comprises at least one gas.

24. The method as claimed in claim **23** wherein the at least one gas comprises at least one gas selected from the group consisting of air, nitrogen, oxygen, an anesthetic gas, an analgesic gas, and an inert gas.

25. The method as claimed in claim **1** wherein the material to be warmed comprises at least one liquid.

26. The method as claimed in claim **25** wherein the at least one liquid is selected from the group consisting of water, glycols, and oils.

27. The method as claimed in claim **25** wherein the at least one liquid comprises an infusion fluid.

28. The method as claimed in claim **27** wherein the infusion fluid is selected at least one fluid selected from the group consisting of crystalloid, saline, whole blood, plasma, packed red cells, platelets, and artificial blood.

29. The method as claimed in claim **1** wherein the material to be warmed is selected from the group consisting of a warming mattress, a warming pad, a warming blanket, a warming clothing, and a thermal management device.

30. The method as claimed in claim **1** wherein the material to be warmed is selected from the group consisting of a solid, a gel, and a semi-solid.

31. An apparatus for heating a material, said apparatus comprising:
- (a) a porous metal catalyst suitable for catalyzing combustion of a gaseous fuel in the presence of oxygen;
- (b) a pervaporation membrane, the pervaporation membrane having an input face and an output face, the output

face being in sufficient proximity to the porous metal catalyst to supply the porous metal catalyst with fuel in vapor form;

(c) means for supplying the input face of the pervaporation membrane with a fluid fuel, whereby the fluid fuel travels from the input face of the pervaporation membrane to the output face of the pervaporation membrane and is emitted from the output face of the pervaporation membrane in vapor form;

(d) means for supplying the porous metal catalyst with oxygen; and

(e) means for transferring heat generated by combustion of the gaseous fuel to a material to be warmed.

32. The apparatus as claimed in claim **31** wherein the porous metal catalyst comprises an unsupported porous metal.

33. The apparatus as claimed in claim **31** wherein the porous metal catalyst comprises a porous metal deposited on an oxygen-inert support particulate sinter or metal.

34. The apparatus as claimed in claim **31** wherein the porous metal catalyst comprises a noble metal.

35. The apparatus as claimed in claim **34** wherein the noble metal comprises a platinum group member.

36. The apparatus as claimed in claim **31** wherein the porous metal catalyst comprises a non-noble metal.

37. The apparatus as claimed in claim **36** wherein the non-noble metal comprises a transition metal member.

38. The apparatus as claimed in claim **31** wherein said pervaporation membrane has a pore size ranging from 0 to 400 nm.

39. The apparatus as claimed in claim **38** wherein said pervaporation membrane has a pore size ranging from 100 to 300 nm.

40. The apparatus as claimed in claim **31** wherein said pervaporation membrane comprises a solid ion-conductive polymer electrolyte membrane.

41. The apparatus as claimed in claim **31** wherein said pervaporation membrane comprises a fluorocarbon-based polymer.

42. The apparatus as claimed in claim **31** wherein said pervaporation membrane comprises a hydrocarbon-based polymer.

43. An apparatus for heating a material, said apparatus comprising:

(a) a catalytic heater, said catalytic heater comprising:

i. a housing, the housing defining a cavity and having a fuel input port for receiving a fuel, an oxygen input port for receiving oxygen gas, and an exhaust outlet port for discharging exhaust gases,

ii. a first fluid diffusion medium disposed in said cavity and in fluid communication with said fuel input port,

iii. a second fluid diffusion medium disposed in said cavity and in fluid communication with said oxygen input port and said exhaust outlet port,

iv. a porous metal catalyst suitable for catalyzing combustion of a gaseous fuel in the presence of oxygen, said porous metal catalyst being disposed between said first and second fluid diffusion media and in contact with said second fluid diffusion medium,

v. a pervaporation membrane for supplying the porous metal catalyst with fuel in vapor form, the pervaporation membrane having an input face and an output face, the input face being in contact with the first fluid diffusion medium, the output face being in contact with the porous metal catalyst;

(b) means for supplying the catalytic heater with a fuel; and

(c) means for supplying the catalytic heater with oxygen gas.

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