DEVICE FOR DELIVERING ANTIDOTES

Inlet

Loop

Filter

14

Pump

16

Sensor

18

Battery

22

Controller

Operating Inputs

10

20

Outlet

Alarms & Data Output

28

29

Remote Central Control System

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Abstract

A device capable of delivering precise amounts of one or more antidotes to treat a victim exposed to biological and chemical agents (biochem agents), and also preferably sensing the presence of biochem agents. The delivery device includes a plurality of reservoirs containing antidotes, a manifold to which the reservoirs are fluidically and removably coupled, an outlet on the manifold, a device for selectively releasing at least one of the antidotes from the reservoirs into the manifold, a device for sensing flow of the at least one released antidote, and a device for stopping flow of the at least one released antidote in response to specified amounts of the at least one released antidote having passed through the flow sensing device.
DEVICE FOR DELIVERING ANTIDOTES

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This is a division patent application of co-pending U.S. patent application Ser. No. 10/709,782, filed May 27, 2004, which claims the benefit of U.S. Provisional Application No. 60/473,383, filed May 27, 2003. This patent application is also a continuation-in-part patent application of co-pending U.S. patent application Ser. No. 10/784,614, filed Feb. 23, 2004, which claims the benefit of U.S. Provisional Application No. 60/449,099, filed Feb. 24, 2003. The contents of these prior applications are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention generally relates to fluid handling devices, their uses and operation. More particularly, this invention relates to a fluid handling device for treating a person exposed to biological and chemical agents.

[0003] The threat of biological and chemical (biochem) attack from terrorists and rogue states has increased in recent years. Biochem threats particularly put military personnel, law enforcement, emergency response, first responders, and postal workers at risk. While not all biochem agents have antidotes, a significant percentage do. For example, antidotes and treatments exist for sarin, VX, tabun, soman, cyanide, lewisite (β-chlorovinylidichloroarsine), anthrax, brucellosis, bubonic plague, Q fever, and botulism.

[0004] Biochemical and chemical compounds can be detected through the use of absorption. For example, film materials capable of selectively absorbing certain compounds find use in humidity, pH, glucose, bacteria, blood, cellular, pollution, poisons, gas and biotoxin sensors and detectors. However, many biochem agents that might be used in an attack require immediate treatment to save the victim’s life, with the medical response time making the difference between complete recovery and a permanent handicap or death. Making treatment available in the field and in time to be effectively used is desirable but difficult. Treatment on a remote battlefield, especially when fast-acting chemical agents are involved, can be particularly difficult since many affected personnel may be incapacitated. Commercial or military products or systems do not exist that can provide immediate and effective defense against an actual biochem attack.

[0005] In view of the above, it would be desirable if a portable rapid-response device were available as a first defense for individuals against chemical and biological terrorist attacks. Such a device would preferably be capable of detecting the type and amount of biochem agent. Such a device would also be preferably capable of selecting one or more appropriate antidotes, and precisely delivering appropriate amounts and concentrations of antidote(s) to the victim. Finally, it would be advantageous if the number of separate components required to perform these functions could be minimized while maintaining or improving the precision by which these functions are performed.

BRIEF SUMMARY OF THE INVENTION

[0006] The present invention provides a device capable of delivering precise amounts of one or more antidotes to treat a victim exposed to biological and chemical agents (biochem agents), and also preferably sensing the presence of biochem agents.

[0007] According to a first aspect of the invention, the delivery device includes a plurality of reservoirs containing antidotes, a manifold to which the reservoirs are fluidically and removably coupled, an outlet on the manifold, means for selectively releasing at least one of the antidotes from the reservoirs into the manifold, means for sensing flow of the at least one released antidote, and means for stopping flow of the at least one released antidote in response to specified amounts of the at least one released antidote having passed through the flow sensing means.

[0008] According to a preferred aspect of the invention, the delivery device is preferably used in combination with a device capable of detecting biochem agents. Preferred detecting devices include a freestanding tube portion comprising an internal passage containing a substance selective to a chemical or biological agent so that matter accumulates within the freestanding tube portion when a fluid drawn through the tube portion contains the agent. When vibrated at resonance, the resonant frequency of the tube portion is indicative of the accumulation of matter and thereby the presence of the agent to which the substance is selective. The delivery device then preferably delivers precise amounts of one or more appropriate antidotes to treat the victim in response to the identified biochem agents.

[0009] In view of the above, a method performed by the detecting device involves detecting a chemical or biological agent by flowing a fluidic sample through a freestanding tube portion having an internal passage containing a substance selective to a chemical or biological agent so that matter accumulates within the freestanding tube portion, vibrating the tube portion at a resonant frequency thereof that varies with the combined density of the freestanding tube portion and contents of the internal passage, sensing movement of the freestanding tube portion to produce an output signal based on the resonant frequency of the freestanding tube portion and indicative of accumulation of the reaction product, and identifying the agent in the fluidic sample based on the accumulation of the reaction product in the freestanding tube portion.

[0010] In a preferred embodiment of the invention, the flow sensing means and the detecting device makes use of a micro-machined resonating tube of a type disclosed in U.S. Pat. No. 6,477,901 to Tadigadapa et al. According to Tadigadapa et al., a resonating tube is operated on the basis of the Coriolis effect to sense mass flow and density of a flowing fluid. In the present invention, a resonating tube of the detecting device is adapted to sense a change in the mass of the tube as a result of the matter that accumulates as a result of the presence of a chemical or biological agent drawn through the tube.

[0011] The delivery device and the detecting device are capable of being miniaturized and combined in a sufficiently small package to permit carrying by a person. As such, the devices are capable of being essential components of a portable rapid-response unit suitable for use as the first defense for individuals against chemical and biological attack. When used together, the detecting and delivery devices are capable of detecting the type and amount of biochem agent present, and then selecting and precisely delivering appropriate amounts and concentrations of the appropriate antidote(s) to the victim.
Other objects and advantages of this invention will be better appreciated from the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic of a device capable of detecting a chemical or biological agent in accordance with a preferred aspect of this invention.

FIG. 2 is a schematic of a device capable of delivering an antidote for a chemical or biological agent in accordance with another preferred aspect of this invention.

FIG. 3 is a schematic of a multi-antidote manifold in accordance with the invention.

FIGS. 4 and 5 represent a micromachined resonating tube suitable for use in the devices of FIGS. 1 and 2.

DETAILED DESCRIPTION OF THE INVENTION

With reference to FIGS. 1 and 2, two devices 10 and 50 are shown that, separately or in combination, are capable of detecting a chemical or biological (biochem) agent and delivering an antidote or other appropriate treatment for the biochem agent, respectively. The devices 10 and 50 are preferably miniaturized units that are sufficiently small and lightweight to be combined in a single unit that can be carried by a person, especially those susceptible to attack with a biochem agent. Each device 10 and 50 makes use of a flow sensor 18 and 58, respectively, of a type that makes miniaturization of the devices 10 and 50 possible. In preferred embodiments of the invention, each flow sensor 18 and 58 contains one or more micromachined resonating tubes capable of measuring certain properties of a fluid using Coriolis force principles. A preferred flow sensor of this type is taught in U.S. Pat. No. 6,477,901 to Tadigadapa et al., incorporated herein by reference.

A flow sensor 30 in accordance with Tadigadapa et al. and suitable for use in or as the flow sensors 18 and 58 is represented in FIGS. 4 and 5. Briefly, the sensor 30 is depicted as having a single micromachined resonating tube 32 fabricated on a substrate 36, though any number of resonating tubes 32 could be fabricated on the substrate 36 and/or on any additional number of substrates. According to Tadigadapa et al., the flow sensor 30 represented in FIGS. 4 and 5 can be used to measure the flow rate of a fluid flowing through a freestanding portion 34 of its tube 32 by sensing the degree to which the freestanding portion 34 deflects (twists) when vibrated, and can be used to measure the density of the fluid by sensing changes in the resonant frequency of the freestanding portion 34. When packaged in a vacuum, the sensor 30 is capable of producing a high Q signal. Furthermore, the resonating tube 32 can be miniaturized by micromachining techniques to hold just a few nanoliters of fluid (1 to 1000 mL). As such, the resonating tube 32 represented in FIGS. 4 and 5 is ideally suited for use with the small, lightweight devices 10 and 50 of FIGS. 1 and 2, and the devices 10 and 50 will be described as using sensors 18 and 58 that make use of such tubes 32. However, it is foreseeable that other miniaturized fluid-handling devices could be developed by which biochem agents can be detected and the appropriate antidote(s) delivered in accordance with this invention.

The device 10 depicted in FIG. 1 is adapted for detecting the presence of a biochem agent, and preferably the type and concentration of the agent in a fluid being sampled. The fluid may be any liquid or gas through which a biochem may be delivered, such as air, water, biological fluids, as well as fluids in which a biochem agent may be detected in a victim, such as the victim’s blood or urine. The detecting device 10 is represented as including an inlet 12, a filter 14, a pump 16 that operates to draw the fluid into the device 10, the above-noted flow sensor 18, and an outlet 20 through which the fluid exits the device 10. The pump 16 is a suitable miniaturized fan or pump capable of moving the fluid intended for analysis. Alternatively, some applications may allow the fluid to be injected into the device 10 with a syringe or pipette (not shown). The filter 14 upstream of the pump 16 and sensor 18 is desirable and may be necessary to protect the sensor 18 from clogging or to assist in separating elements of the fluid, for example, separating white from red blood cells. Accordingly, the type of filter 14 employed by the device 10 will depend on the type of fluid being analyzed.

As discussed above, the sensor 18 preferably employs one or more micromachined resonating tubes 32 of the type disclosed in Tadigadapa et al. As used herein, micromachining is a technique for forming very small elements by bulk etching a substrate (e.g., a silicon wafer), or by surface thin-film etching, the latter of which generally involves depositing a thin film (e.g., polysilicon or metal) on a sacrificial layer (e.g., oxide layer) on a substrate surface and then selectively removing portions of the sacrificial layer to free the deposited thin film. Accordingly, suitable materials for the tube 32 include glass (e.g., quartz and Pyrex), ceramic, metal or a semiconductor, including micromachined silicon, germanium, SiGe and GaAs. FIGS. 4 and 5 show a suitable configuration for the tube 32 having a pair of legs and an interconnecting cross-member, yielding essentially a U-shaped freestanding tube portion 34 suspended above the surface of the substrate 36. While a U-shaped freestanding tube portion 34 is shown, other shapes—both simpler and more complex—are within the scope of this invention. The tube portion 34 defines a continuous fluid passage 38 between an inlet and outlet 40 located on the opposite surface of the substrate 36. As previously noted, micromachining technologies employed to fabricate the tube 32 enable the size of the tube 32 and its passage 38 to be extremely small, such as lengths of about 0.5 mm and cross-sectional areas of about 100 μm², enabling the device 10 to process very small quantities of fluid.

The freestanding tube portion 34 is preferably driven at resonance, with the resonant frequency being determined in part by its mechanical design (shape, size, construction and materials). Suitable frequencies are in the range of 1 kHz to over 100 kHz, depending on the particular fluid being analyzed. Under most circumstances, frequencies above 10 kHz, including ultrasonic frequencies (those in excess of 20 kHz), will be preferred. The amplitude of vibration is preferably adjusted through means used to vibrate the tube portion 34. For this purpose, FIG. 4 shows an electrode 42 located beneath the tube portion 34 on the surface of the substrate 36. In the embodiment shown, the tube 32 serves as an electrode (e.g., is formed of doped silicon) that is capacitively coupled to the electrode 42, enabling the electrode 42 to electrostatically drive the tube portion 34. However, it is foreseeable that the tube 32 could be formed of a nonconductive material, and a separate electrode formed on the tube portion 34 opposite the electrode 42 for vibrating the tube portion 34 electrostatically. Furthermore, the tube portion 34 could be driven capacitively, piezoelectrically, piezoresistively, acoustically, ultrasonically, magnetically, optically, or by another actuation technique. Also shown in FIGS. 4 and 5 are sensing
elements 44 for providing feedback to enable the vibration frequency and amplitude to be controlled with appropriate circuitry of a controller 24, which may be located on the substrate 36 or on a separate substrate. While capacitive sensing is preferred, the sensing elements 44 could sense the proximity and motion of the tube portion 34 in any other suitable manner.

[0022] FIG. 5 schematically represents the micromachined tube 32 as being enclosed by a cap 46 bonded or otherwise attached to the substrate 36. In a preferred embodiment, the bond between the cap 46 and substrate 36 is hermetic, and the resulting enclosure formed between the substrate 36 and cap 46 is evacuated to enable the tube portion 34 to be driven efficiently at high V values without damping. A suitable material for the cap 46 is silicon, allowing silicon-to-silicon bonding techniques to be used, though other cap materials and bonding techniques are possible and within the scope of the invention.

[0023] In Tadigadapa et al., monitoring the frequency of vibration of the tube portion 34 while a fluid flows through the passage 38 enables the density and mass flow rate of the fluid to be measured. As fluid flows through the tube portion 34 while the tube portion 34 is vibrated at resonance, the tube portion 34 twists under the influence of the Coriolis effect. As explained in Tadigadapa et al., the degree to which the tube portion 34 twists (deflects) when vibrated can be correlated to the mass flow rate of the fluid flowing through the tube portion 34 on the basis of the change in the amplitude of a secondary resonant vibration mode. The density of the fluid is proportional to the natural frequency of the fluid-filled vibrating tube portion 34, such that controlling the vibration of the tube portion 34 to maintain a frequency at or near its resonant frequency will result in the vibration frequency changing if the density of the fluid flowing through the tube portion 34 changes.

[0024] In contrast to Tadigadapa et al., the detecting device 10 of FIG. 1 is not particularly concerned with the mass flow rate of a fluid through the tube portion 34, but instead is interested in a change in mass that will occur over time during operation of the device 10 if the fluid being sampled contains a biochem agent. For this purpose, one or more interior wall surfaces of the tube portion 34 are coated or filled with a substance that absorbs, chemically reacts with, biologically reacts with, or otherwise causes the accumulation of matter when a specified biochem agent is present in the fluid flowing through the tube 32. Such a substance is depicted in FIG. 2 as a film 48, hereinafter the accumulation film 48, though it is to be understood that the film 48 could be a porous material that substantially fills the passage 38, and the term “accumulation” is intended to encompass absorption, reactions, and any other mechanism that causes matter (e.g., the biochem agent, a reaction product thereof, etc.), to accumulate within the tube portion 34. As accumulation takes place, the mass of the resonant tube portion 34 also changes, generally increasing though possibly decreasing, depending on the relative densities of the fluid, the biochem agent, and the matter that accumulates in the tube portion 34. The mass change causes a resonant frequency change in the tube portion 34, enabling the sensor 18 to operate as a microscale that can be selective to a given chemical or biological agent. The sensor 18 can be fabricated to contain any number of tubes 32, each dedicated to sensing the presence of a different biochem agent through the use of different substances for the films 48 within the tubes 32. In this manner, a change sensed in the resonant frequency of a particular tube 32 can be immediately recognized by the device 10 as indicating the presence in the sampled fluid of the agent for which the film 48 within the tube 32 is selective. The rate at which the resonant frequency of a tube 32 changes is also potentially of interest as indicating the concentration of the agent in the sampled fluid. For this purpose, the controller 24 can include clock circuitry against which changes in resonant frequency (corresponding to accumulation of matter within the tube 32 and therefore the presence of agents in the sampled fluid) can be monitored.

[0025] The detecting device 19 has application for detecting the presence of a wide variety of biochemical agents, including chemical warfare agents (mustard gas, cyanide, lewisite, nerve agents, etc.) and biological warfare agents (anthrax, botulism, Brucellosis, plague, Q-fever, etc.). The device 10 can also be employed to detect a variety of other potentially harmful agents, including a variety of bacteria and viruses, dust, soot, organic solvents, drugs, explosive elements, poisons, gases, biotoxins, tainted food, water and air pollution, as well as the presence and/or properties of other chemicals, compounds, and particles of potential interest, such as humidity, pH, glucose, blood and its components, antibodies, cells, enzymes, DNA, proteins, white blood cells, urine and its components, etc. If bacteria detection is desired, the device 10 may require the capability of accumulating and incubating enough cells in the tube 32 for detection. However, since the tube 32 can be fabricated to have a volume of only several nanoliters, it offers the advantage of being able to detect the presence of a bacteria with only a few cells.

[0026] Liquid and gaseous deposition techniques can be employed to deposit the film 48, such as by injecting the absorbent or chemically/biologically reactive material into the tube 32 and allowing the material to dry to form the accumulation film 48. The performance of the tube 32 formed by silicon micromachining can be enhanced with several fabrication and design techniques. For example, single or multiple layers can be deposited or formed on the inner surfaces of the tube passage 38 to provide a surface that is more chemically reactive than the material of which the tube 32 is formed, for example, silicon or silicon oxide. For example, a metal such as gold can be deposited and then coated with a film 48 formed by a layer of thiolated single-stranded DNA to detect complementary DNA strands. Furthermore, platinum has been shown to attract proteins. Metal suicides can be deposited to improve adhesion of platinum and other reactive metals to a silicon tube 32. Furthermore, one or more polymer layers can be applied before application of a reaction-promoting layer (if present) and the film 48 to promote adhesion of these layers to tube surfaces formed of silicon, silicon oxide, silicon nitride, metal, metal silicide, etc.

[0027] The sensitivity of the tube portion 34 to mass change generally increases as the thickness of the film 48 increases relative to the tube wall thickness. Therefore, a relatively thick film 48 and/or relatively thin tube walls are generally desirable. For the latter, the tube 32 can be isotropically thinned with a plasma or wet etch after release of the tube portion 34 during the fabrication process. Nano-technology can also be used for the fabrication of the tube 32 to further increase the sensitivity of the sensor 30.

[0028] Since the densities of materials vary with temperature, temperature control is often used to manufacture highly accurate density meters of the prior art, such as thermoelectrically-controlled resonant temperature systems. Because the densities of the tube material, coatings, and analyzed
fluids are all subject to change with temperature, the controller 24 may include a temperature control element (not shown) to sense the temperature of the flow sensor 18 and thereby achieve higher accuracy of chemical and biological detection with the device 10. Temperature control can also be used to improve the performance and reduce the damage to biologic compounds. As represented in FIG. 1, the controller 24 preferably controls the pump 16, the sensor 18 and its resonant tube portion 34, and any temperature or other compensating devices. Furthermore, these devices are shown as being powered by an on-board battery 22 or other power storage device. Suitable devices for this purpose are known and therefore will not be discussed in any detail here.

[0029] As noted above, the sensor 18 can comprise arrays of the flow sensor 30 depicted in FIGS. 4 and 5, which in turn may comprise any number of resonating tubes 32. By providing multiple tubes 32 with different absorbent/reactive films 48, the device 10 is capable of detecting many different chemicals, cells and/or biotoxins. Multiple sensors 18 and digital logic with memory can be employed to reduce the incidence of false positive chemical identifications occurring. Operating inputs 26 to the controller 24 and alarms and data output 28 from the controller 24 enable the device 10 in be used as a stand-alone unit carried by an individual for personal protection from biochem agents, or used as a unit for wireless communication with a remote control system 29. In the latter embodiment, the device 10 can perform widely dispersed environmental monitoring or be used as a medical implant to check on internal chemical activity within the individual. As such, the device 10 is capable of continuous monitoring of air and water surrounding an individual carrying the device 10, or can be implanted in an individual to continuously monitor urine, blood, or other bodily fluids, or placed in various other environments to monitor the presence of agents within air systems, water systems, industrial chemicals, etc.

[0030] Because of the miniaturized sensor 18, the detecting device 10 can be small, portable and relatively inexpensive, especially when fabricated by micromachining technology to yield what is known as a microelectromechanical system (MEMS). It is foreseeable that the cost of the device 10 can be sufficiently low to render the device 10 disposable. Alternatively, the sensor 18 can be recycled after the film 48 becomes saturated. For example, heat and/or an aggressive detergent or solvent could be flushed through the tube 32 to strip the inner walls of the film 48 and the matter that has accumulated within the tube 32 as a result of absorption and/or reaction with a biochem agent. After cleaning, the inner walls of the tube 32 can be recoated if needed or desired. In view of the above, device size, batch fabrication and recycling can all contribute to reducing the cost of sensing biochem agents with the device 10.

[0031] In an investigation, water was injected into a flow sensor of the type represented in FIGS. 4 and 5. In response, the resonant frequency of the tube dropped from about 11 KHz to about 8.6 KHz. After removing the water with compressed air, the frequency initially increased to about 10.95 KHz and then gradually continued to rise, indicating that a film of water remained on the inside of the tube. In view of this observation, it was evident that the sensor was capable of sensing the presence of a very fine film that had accumulated within the tube after flow had been discontinued and the bulk of the water removed. Heating the tube and pulling a vacuum inside the tube eventually restored the resonant frequency of the tube to the original 11 KHz. Similar sensitivities to the accumulation of other materials have also been observed, such as when testing oils. From these observations, it was concluded that the inner surfaces of a resonating tube could be manufactured to intentionally and selectively absorb agents (e.g., biochem agents) to enable the device to operate as a sensor or microscale for such agents.

[0032] As previously noted, the delivery device 50 represented in FIG. 2 is adapted for delivering an antidote or other appropriate treatment to an individual, such as through a needle (not shown) or other device capable of delivering an antidote in an appropriate manner. Notable examples include a subdermal patch or intramuscularly (IM) or intravenously (IV) delivery through an IM/IV line, though other delivery methods are possible, e.g., intra-arterially, subcutaneously, intraperitoneally or intrathecally. The delivery device 50 is particularly well suited for use in combination with the detecting device 10 of FIG. 1, though the devices 10 and 50 could also be used separately and independently. In combination, the devices 10 and 50 are capable of being part of a single unit that can be carried by a person to sense chemical and biological warfare agents and deliver an appropriate antidote, preferably from an inventory of multiple drugs contained in the device 50.

[0033] The delivery device 50 is represented in FIG. 2 as including a reservoir 52 suitable for containing one or more antidotes, a valve 54, a pump 56, the previously-described flow sensor 58, and an outlet 60 through which the antidote exits the device 50 and is delivered to the individual. While the reservoir 52 and pump 56 are represented as separate components, their functions could be combined in a single component, such as by fabricating the reservoir 52 of one or more elastomeric bladders that contain the antidotes under pressure. As with the detecting device 10 of FIG. 1, the delivery device 50 includes a controller 64 that communicates with the flow sensor 58 to control the operation of its resonating tube 32. The controller 64 also preferably communicates with the valve 54 and pump 56 to allow flow through the device 50 to be initiated when treatment is required in response to detection of a harmful agent, and stopped when sufficient antidote has been delivered for the type and amount of agent detected. Also similar to the detecting device 10, the delivery device 50 is equipped with a battery 62 for powering the valve 54, pump 56, flow sensor 58 and controller 64. Furthermore, operating inputs 66 to the controller 64 and alarms and data output 68 from the controller 64 enable the operation of the device 50 to be observed and controlled by the user.

[0034] As discussed above, the sensor 18 preferably employs one or more micromachined resonating tubes 32 of the type disclosed in Tadigadapa et al. Resonating tube flow sensors of the type disclosed by Tadigadapa et al. are preferred in view of their very small size and ability to precisely measure extremely small amounts of fluids, in contrast to prior art Coriolis-type flow sensors. For example, if the flow sensor 58 of FIG. 2 employs a resonating tube of the type shown in FIGS. 4 and 5, flow rate measurement accuracies of under +/-1% can be achieved, in contrast to conventional infusion pumps whose accuracies can range from about +/-5% for volumetric pumps down to +/-3% for syringe pumps. While the high cost and the high flow rate requirements for prior art Coriolis-type flow sensors have restricted their use in the drug delivery arena, the flow sensor of Tadigadapa et al. is able to sense the extremely low flow rates (e.g., less than 0.5 ml/hr) that can be necessary when admin-
istering an antidote. Another advantage is that use of an electrostatic drive and capacitive sensing (as represented in FIGS. 4 and 5) minimizes the power requirements of the sensor 58. Accordingly, the flow sensor taught by Tagidapada et al. is ideal for achieving the high dosage accuracy, reliability, small size, biocompatibility, drug compatibility, and low power requirements needed for the device 50.

[0035] The reservoir 52 schematically depicted in FIG. 2 can be adapted to contain any number of antidotes or treatments for delivery to the individual. Furthermore, the amounts of these antidotes carried by the device 50 can be very small and concentrated, and therefore very potent, in view of the accuracy of the flow sensor 58. FIG. 3 depicts a manifold system 70 to which a number of cartridges 72 are mounted to provide a multi-antidote infusion system that combines the reservoir 52, valve 54, and sensor 58 of FIG. 2 in a single assembly. The manifold 70 comprises a fluid manifold 74 and an electrical "manifold" or power bus 76, to which each cartridge 72 is fluidically and electrically connected through connectors 78 and 80, respectively. The manifold system 70 can be fabricated to carry a sensor 58 and valve 54 dedicated to each cartridge 72. Since the manifold system 70 is modular, the sizes of the cartridges 72 can vary to accommodate different dosing requirements. The power bus 76 provides power to the sensors 58 and valves 54, relays input and output signals between the controller 64 (not shown) and the sensors 58, and relays input signals from the controller 64 to the valves 54.

[0036] While capable of being configured to have any number of cartridges 72, the manifold system 70 depicted in FIG. 3 is notably equipped with sufficient cartridges 72 to treat the following eleven biochem agents that have antidotes and pose a serious threat in the hands of terrorists and rogue states: sarin, VX, tabun, soman, cyanide, Lewisite (β-chlorovinyldichloroarsine), anthrax, brucellosis, bubonic plague, Q fever, and botulism. The manifold system 70 is shown as being equipped with eight cartridges 72 that can contain atropine and 2-PAM-CI for nerve agents, botulism antitoxin, tetracycline, and doxycycline for the initial treatment of anthrax, brucellosis, Q-fever and the plague, BAL or dimericpol for lewisite and sodium nitrite followed by sodium thiosulphate for cyanide poisoning. Subsets of these drug combinations or alternate drugs could also be utilized in the manifold system 70.

[0037] Delivery of one or more antidotes can be initiated with the controller 64 either through manual input by the user, a radio signal from a remote central location (e.g., the control system 59 of FIG. 1), or in response to one or more detecting devices (e.g., the detecting device 10 of FIG. 1) carried on the person or placed in the local vicinity. The programmability of the device 50 can include, but is not limited to, which antidote or combinations of antidotes should be delivered, the dosage, and the timing of the delivery (e.g. continuous or intermittent) for a variety of treatment regimes. In addition, because antidote dose requirements for many chemical agents are body weight dependent, the programmability of the device 50 also preferably allows the user to preprogram his or her body weight into the device 50 to improve self-treatment and safety.

[0038] In addition to the above, the device 50 can be configured to offer other advantages and functions. For example, the ability to measure antidote density can be used to prevent delivery of the wrong antidote or those that are spoiled or contain air bubbles or inclusions. Other functionalities that can be combined with the device 50 include indicating the location of the individual (e.g., through GPS (global positioning system)), broadcasting an alert signal to a remote center or others equipped with similar delivery devices 50 if delivery of an antidote is commenced in response to an attack, monitoring of the individual's biological functions (e.g., heart beat), sending such biological information to a remote center or another individual, etc. Along with the device 50 (including its valve 54, pump 56, sensor 58, and injection device), such additional components can be fabricated by micromachining to yield a fully integrated system that is small, low-power, rugged and biocompatible at high production volumes.

[0039] In use, after being notified of the presence of a biochem agent (such as by detection with the detecting device 10), the user can place a needle connected to the device 50 in his or her body and then activate the device 50 to allow the device 50 to deliver the appropriate antidote combination and dosage based on the type and concentration of agent sensed. Alternatively, in high risk situations such as a battlefield or suspected contaminated area, a needle or catheter can be pre-inserted so that the device 50 can inject the appropriate antidote combination and dosage without any (or minimal) direct input or action from the user. In one particular example, a remote central detection system (e.g., making use of the detecting device 10) can be linked through a wireless radio network with one or more of the delivery devices 50. When an alert from the central detection system is received, each device 50 automatically selects the appropriate antidote(s) and delivers the antidote(s) at the appropriate dose and delivery timing to the individual wearing the device 50. In another example, each device 50 has a keypad (not shown) to interact with the controller 64. When instructed that exposure to a chemical or biological agent has occurred (e.g., verbally, through a remote central detection system, with the detecting device 10, etc.), the user can punch in the appropriate code to cause the device 50 to select and deliver the correct antidote. In a third example, the detecting device 10 and the delivery device 50 are contained in a single portable unit, so that the unit contains all of the components necessary to sense and automatically respond to a chemical or biological threat.

[0040] In view of the above, the biochem detecting device 10 and antidote delivery device 50 can be combined into a single unit as a first defense for individuals against a chemical and/or biological attack. In combination, the detecting device 10 and delivery device 50 provide for the automatic detection of the type and amount of biochem agent present, selection of an appropriate antidote combination from multiple reservoirs, preparation and mixing of the appropriate antidotes at the correct concentration, and delivery of such antidote(s) with great accuracy. As such, the invention provides a small, portable, rapid-response bio-protector that can be carried as standard equipment by a soldier or other at-risk personnel for rapid treatment during an attack without the intervention of a medical professional. If the treatment is carried out automatically, the invention has the further advantage of being capable of precise dose control and repeated, timed injections as may be necessary.

[0041] While the invention has been described in terms of certain embodiments, it is apparent that other forms could be adopted by one skilled in the art. Therefore, the scope of the invention is to be limited only by the following claims.

1. A device for containing and delivering a plurality of antidotes, the device comprising:
a plurality of reservoirs containing the antidotes;
a manifold to which the reservoirs are fluidically and
removably coupled;
an outlet on the manifold;
means for selectively releasing at least one of the antidotes
from the reservoirs into the manifold;
means for sensing flow of the at least one released antidote;
and
means for stopping flow of the at least one released antidote
in response to specified amounts of the at least one
released antidote having passed through the flow sensing
means.

2. The device according to claim 1, wherein the releasing
means is operable to simultaneously release more than one
antidote from the reservoirs.

3. The device according to claim 2, wherein the flow sensing
means comprises separate flow sensors individually associated
with the reservoirs, and each of the flow sensors senses flow of a corresponding one of the antidotes from a corresponding one of the reservoirs.

4. The device according to claim 2, further comprising
means for mixing the more than one antidote.

5. The device according to claim 1, wherein the reservoirs
are cartridges releasably mounted to the manifold.

6. The device according to claim 1, further comprising
means for delivering the at least one released antidote from
the outlet of the manifold and into the body of a person.

7. The device according to claim 1, wherein the flow sensing
means also measures the density of the at least one
released antidote.

8. The device according to claim 1, wherein the flow sensing
means comprises:
a tube comprising a freestanding tube portion through
which the at least one released antidote flows;
means for vibrating the freestanding tube portion of the
tube at a resonant frequency thereof that varies with the
density of the at least one released antidote flowing
through it, the Coriolis effect causing the freestanding
tube portion to twist while being vibrated at resonance,
the freestanding tube portion exhibiting a degree of
twist that varies with the mass flow rate of the at least
one released antidote flowing therethrough; and
means for sensing movement of the freestanding tube
portion of the tube, the movement-sensing means producing
a first output signal based on the resonant frequency of
the freestanding tube portion and a second output signal
based on the degree of twist of the freestanding tube
portion.

9. The device according to claim 8, the device further
comprising means for measuring elapsed time during which
the at least one released antidote has flowed through the flow
sensing means.

10. The device according to claim 8, wherein flow stopping
means is operable to stop the flow of the at least one released
antidote into the manifold in response to either of the first and
second output signals from the movement-sensing means.

11. The device according to claim 1, further comprising:
means for detecting the presence of a biochem agent in a
fluidic sample; and
means for electrically connecting the detecting means to
the releasing means.

12. The device according to claim 11, wherein the fluidic
sample is air, water, blood or urine.

13. The device according to claim 11, wherein the detecting
means comprises:
a freestanding tube portion through which the fluidic
sample flows, the freestanding tube portion comprising
an internal passage containing a substance selective to
the agent so that matter accumulates within the freestanding
tube portion;
means for vibrating the freestanding tube portion at a resonant
frequency thereof that varies with a combined density
of the freestanding tube portion and contents of the
internal passage; and
means for sensing movement of the freestanding tube
portion and producing an output signal based on the resonant
frequency of the freestanding tube portion, the output
signal being indicative of accumulation of the matter
and thereby presence of the agent in the fluidic sample.

14. The device according to claim 11, wherein the detecting
means is operable to identify which of the antidotes is
capable of counteracting the biochem agent.

15. The device according to claim 1, wherein the device is
sufficiently small and lightweight to be carried by a person.

16. The device according to claim 1, further comprising
means for sending a signal indicating the location of the
device.

17. The device according to claim 1, further comprising
means for broadcasting an alert signal to a remote location if
delivery of the at least released one antidote is commenced.

18. The device according to claim 1, further comprising
means for monitoring biological functions of a person, iden-
tifying biological information based on the biological func-
tions, and sending the biological information to a remote
location.

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