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(54) AUTOMATED FILTRATION SYSTEM WITH AUTOMATED ROTARY VIAL UNCAPPING SYSTEM AND FILTER REMOVAL

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(52) **U.S. Cl.**
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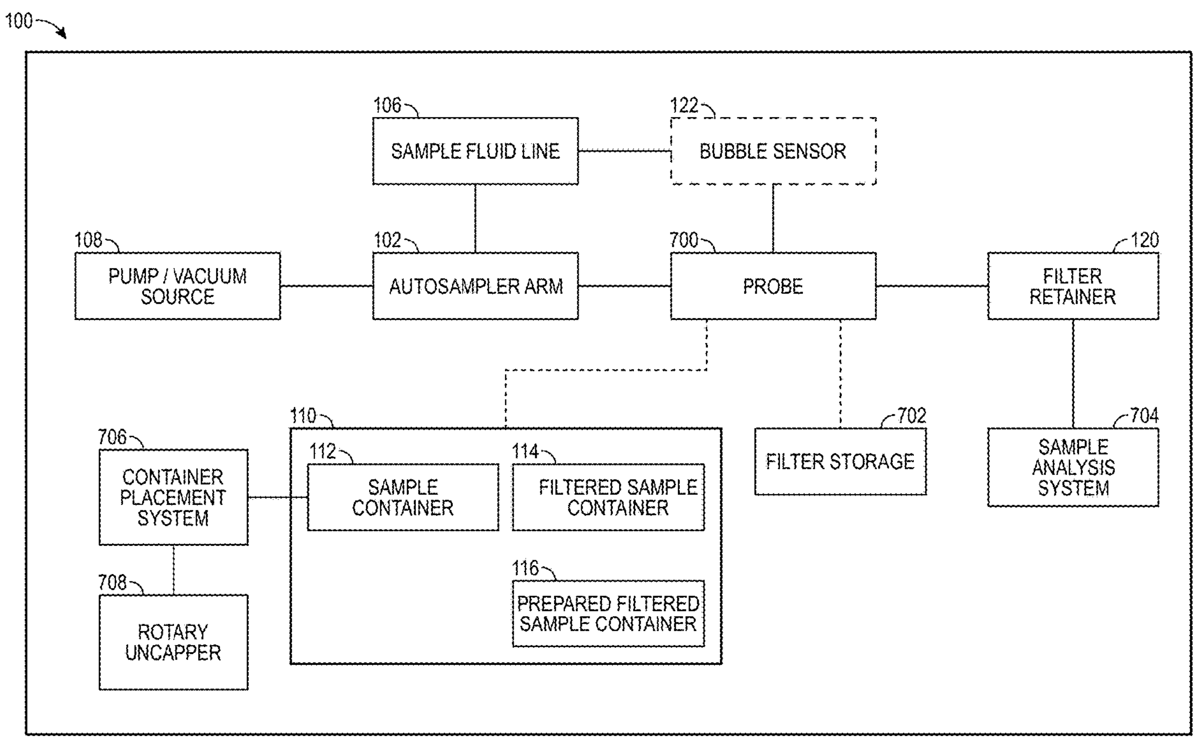
(57) **ABSTRACT**

Automated systems are described that remove a cap from a capped sample container, introduce a probe to the uncapped sample container, direct the sample through the filter to provide a filtrate, and transfer the filtrate to another uncapped sample container, a sample fluid line in fluid communication with a sample analysis system, or combinations thereof.



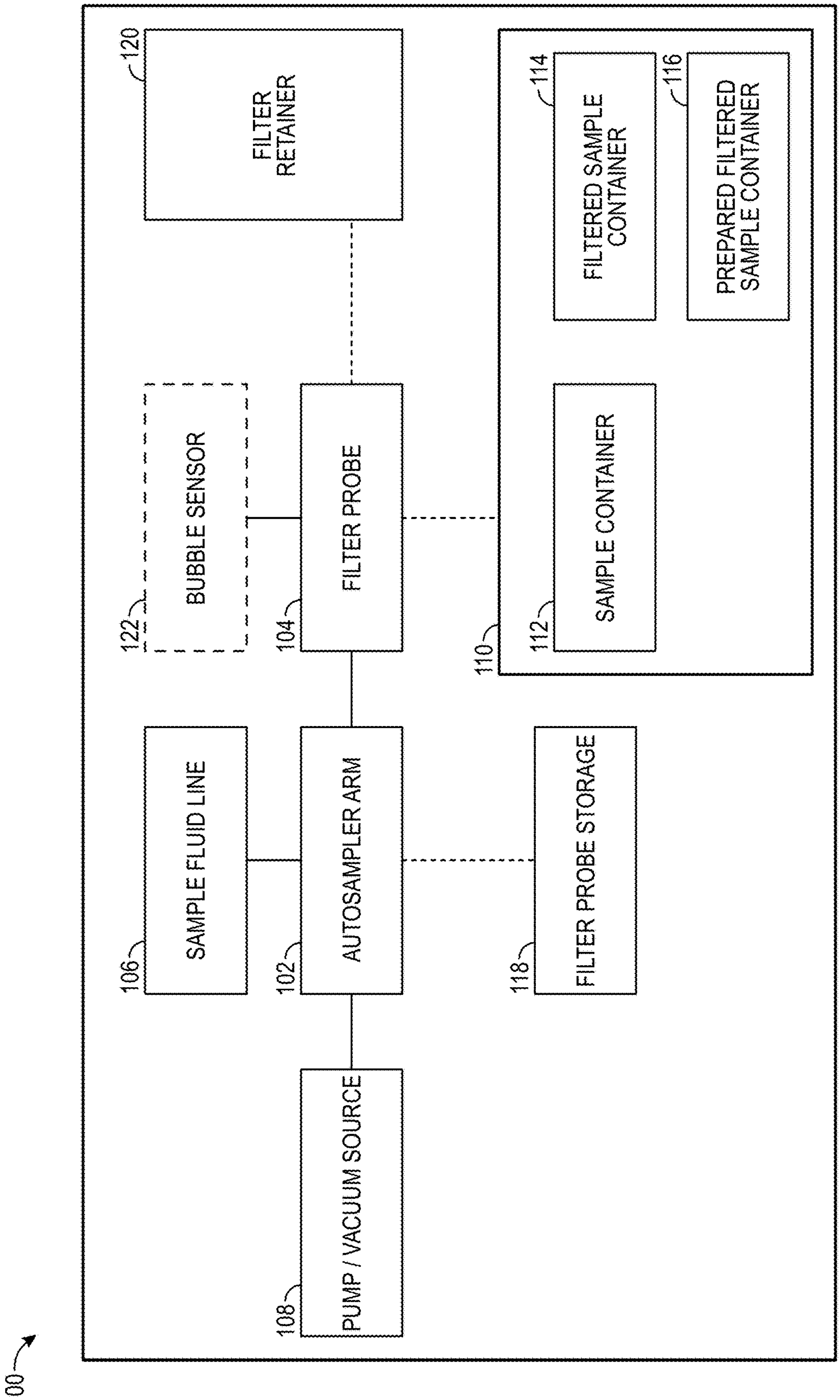

100
FILTER RETAINER
120
BUBBLE SENSOR
122
FILTER PROBE
104
SAMPLE FLUID LINE
106
AUTOSAMPLER ARM
102
PUMP / VACUUM SOURCE
108
110
SAMPLE CONTAINER
112
FILTERED SAMPLE CONTAINER
114
PREPARED FILTERED SAMPLE CONTAINER
116
FILTER PROBE STORAGE
118

FIG. 1

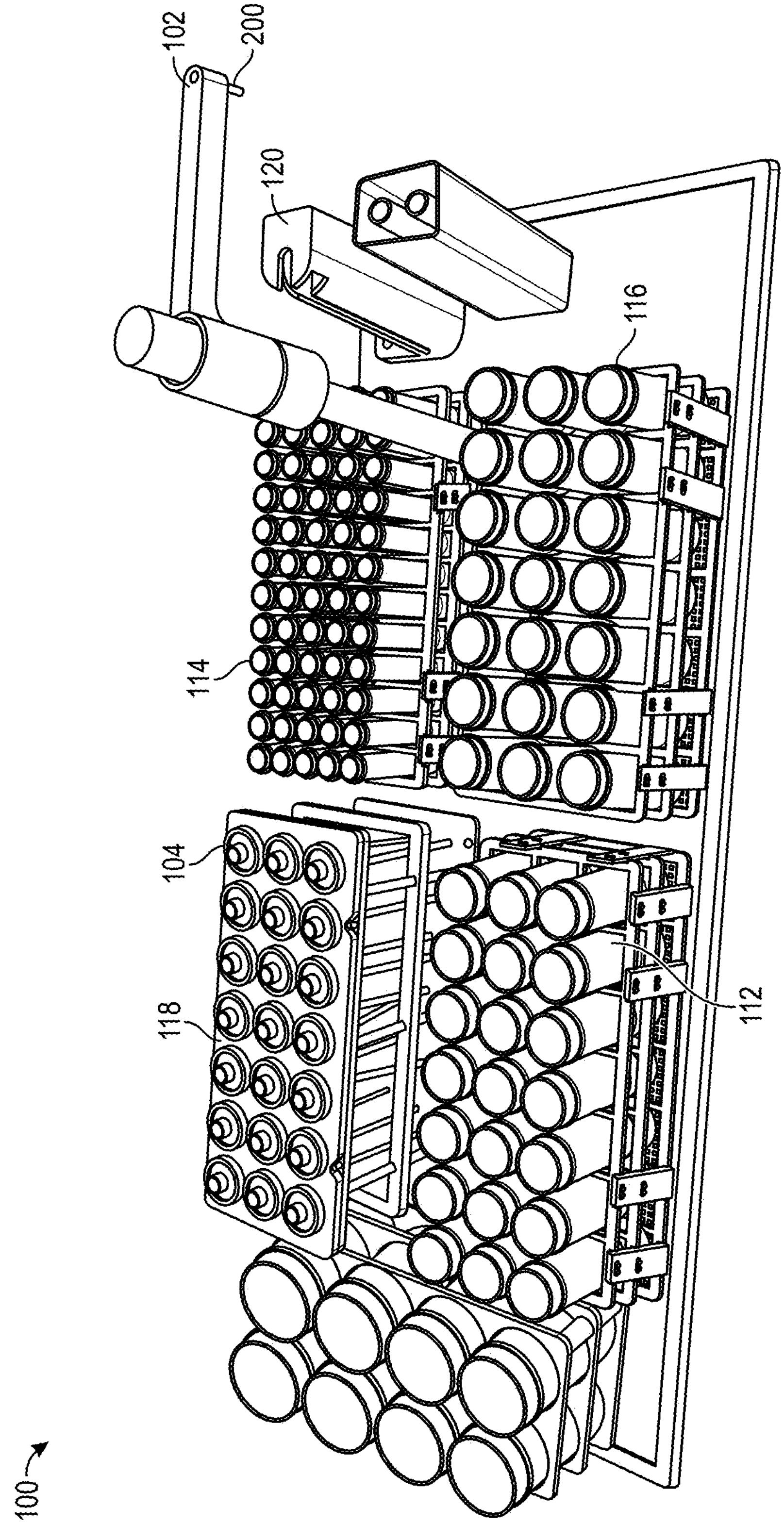


FIG. 2

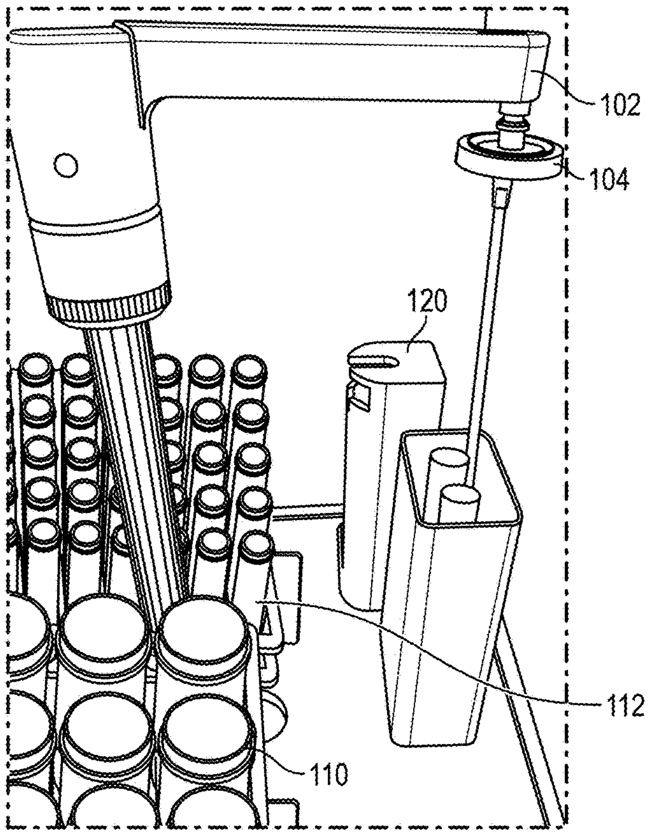


FIG. 3A

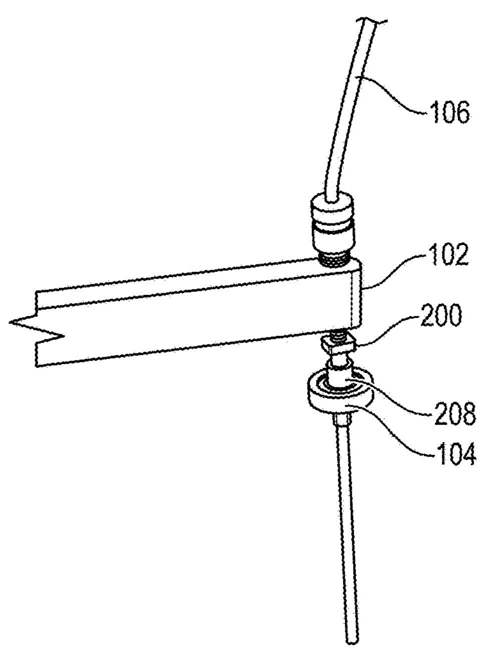


FIG. 3B

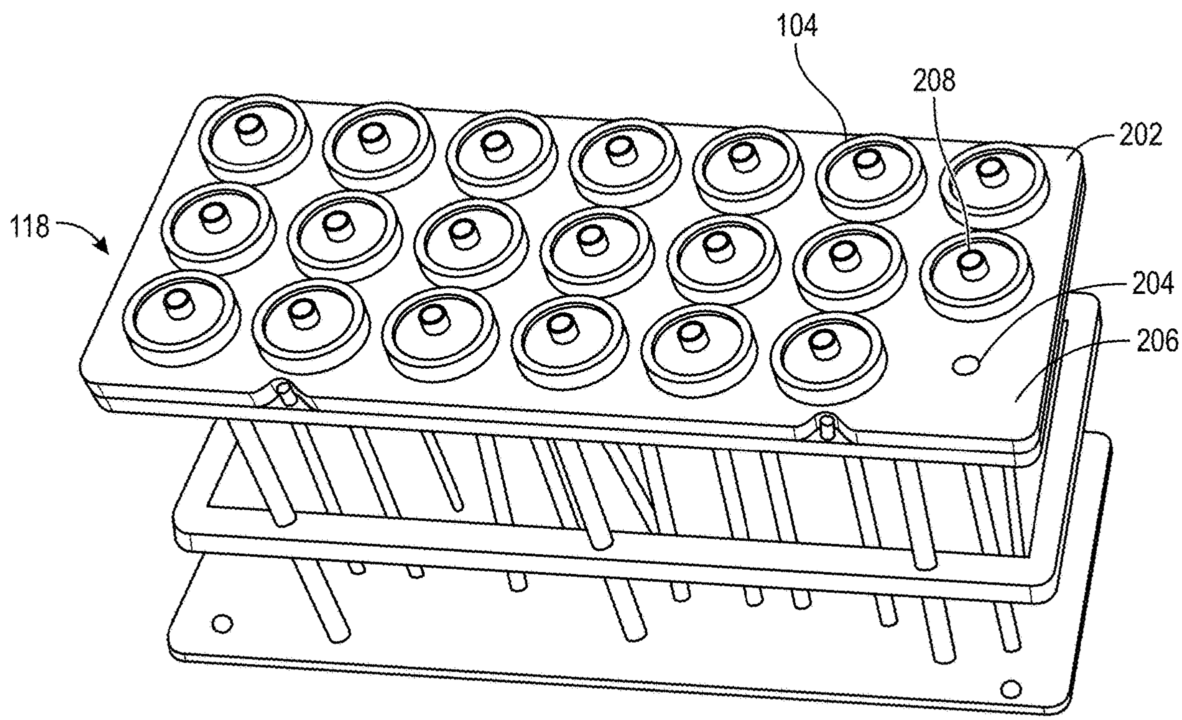


FIG. 4

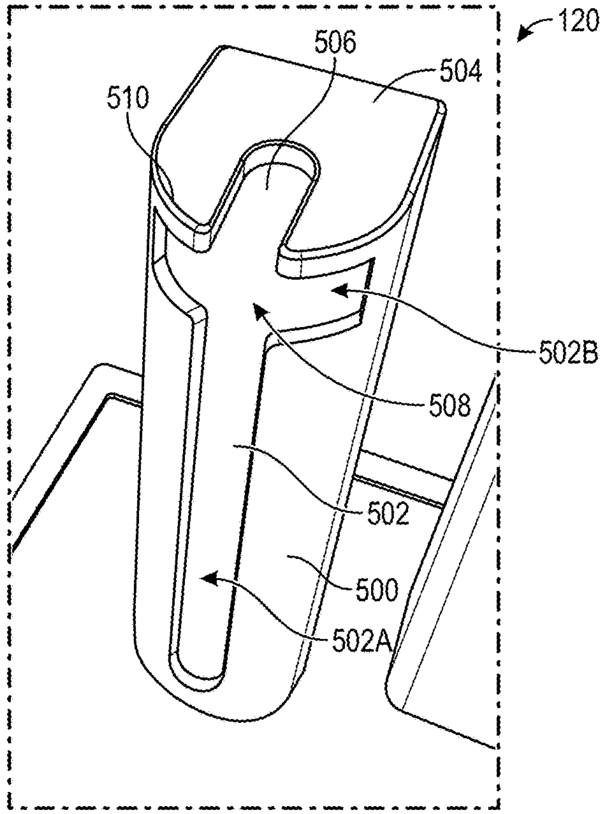

120
506
504
510
502B
508
502
500
502A

FIG. 5

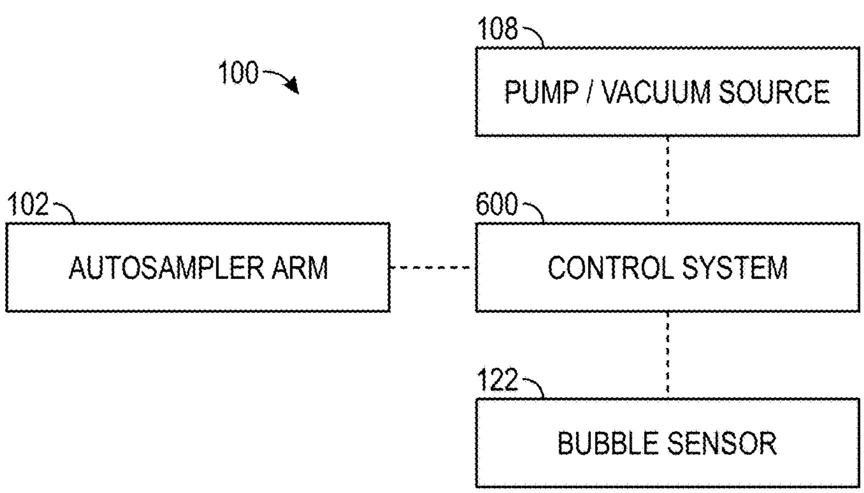

100
108
PUMP / VACUUM SOURCE
102
AUTOSAMPLER ARM
600
CONTROL SYSTEM
122
BUBBLE SENSOR

FIG. 6

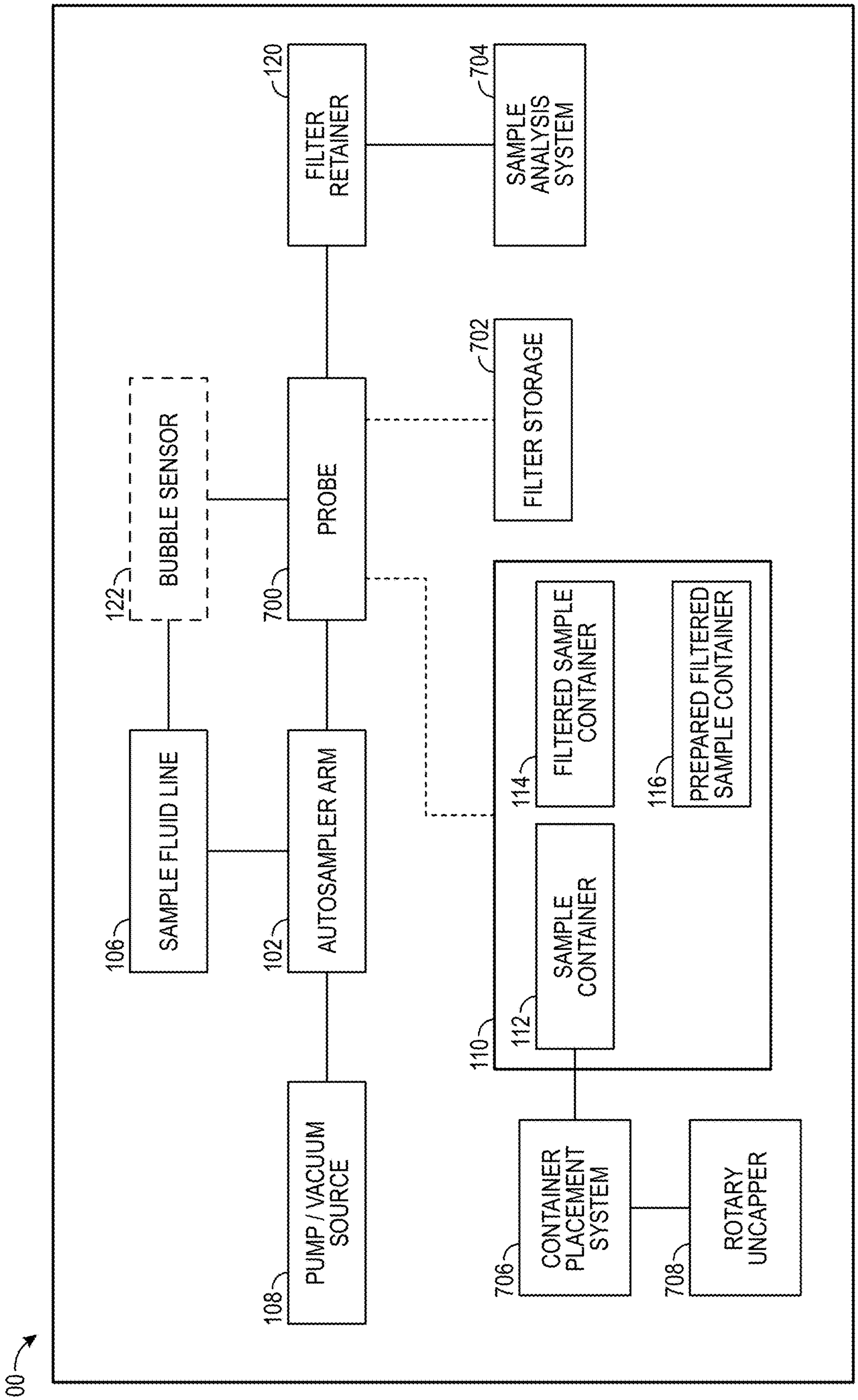

100
FILTER RETAINER
120
SAMPLE ANALYSIS SYSTEM
704
BUBBLE SENSOR
122
PROBE
700
FILTER STORAGE
702
SAMPLE FLUID LINE
106
AUTOSAMPLER ARM
102
FILTERED SAMPLE CONTAINER
114
PREPARED FILTERED SAMPLE CONTAINER
116
SAMPLE CONTAINER
112
110
PUMP / VACUUM SOURCE
108
CONTAINER PLACEMENT SYSTEM
706
ROTARY UNCAPPER
708

FIG. 7

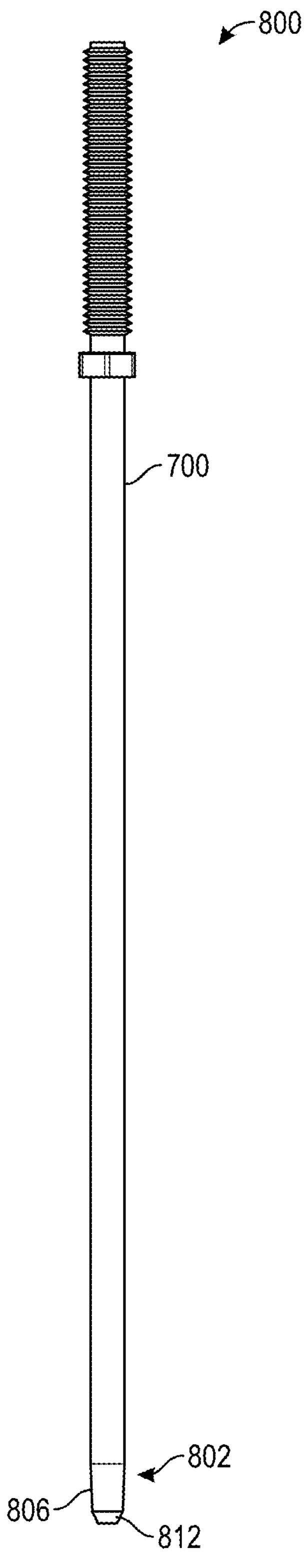


FIG. 8A

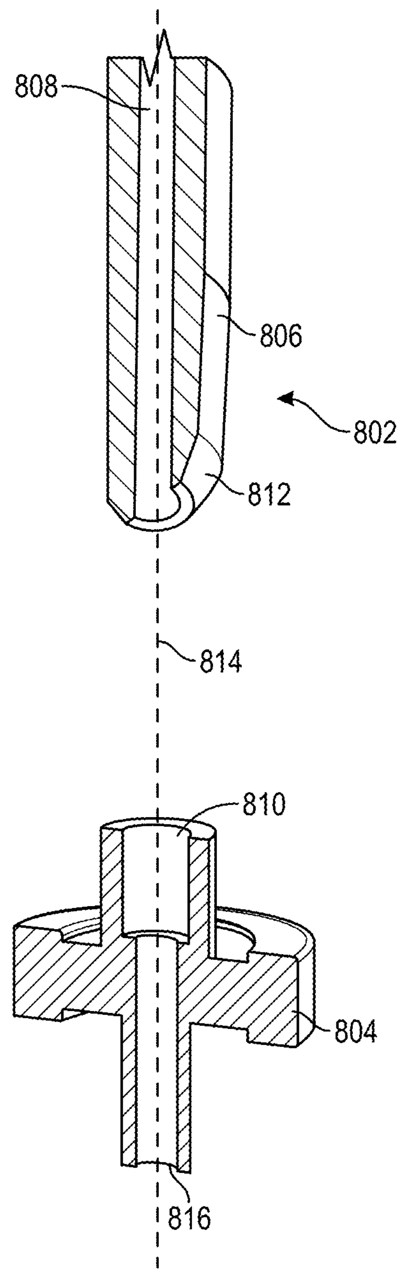


FIG. 8B

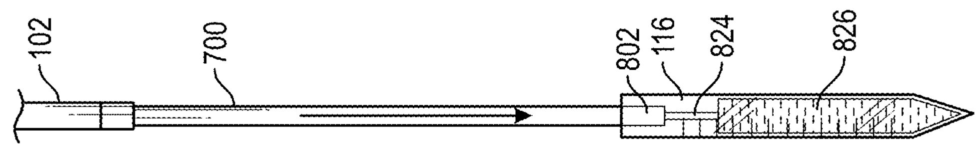


FIG. 8E

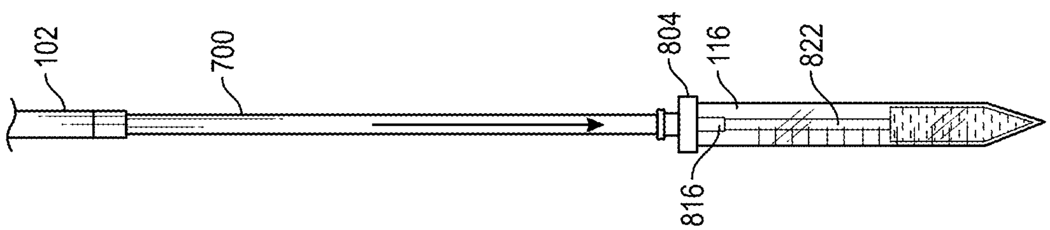


FIG. 8D

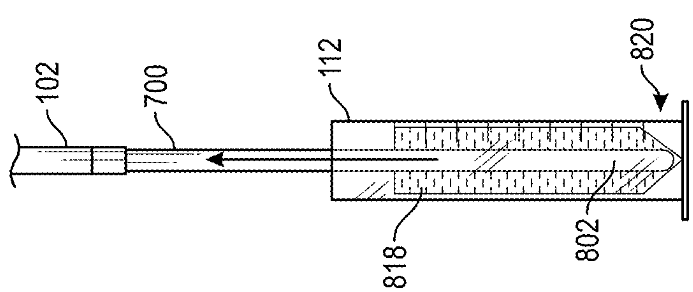


FIG. 8C

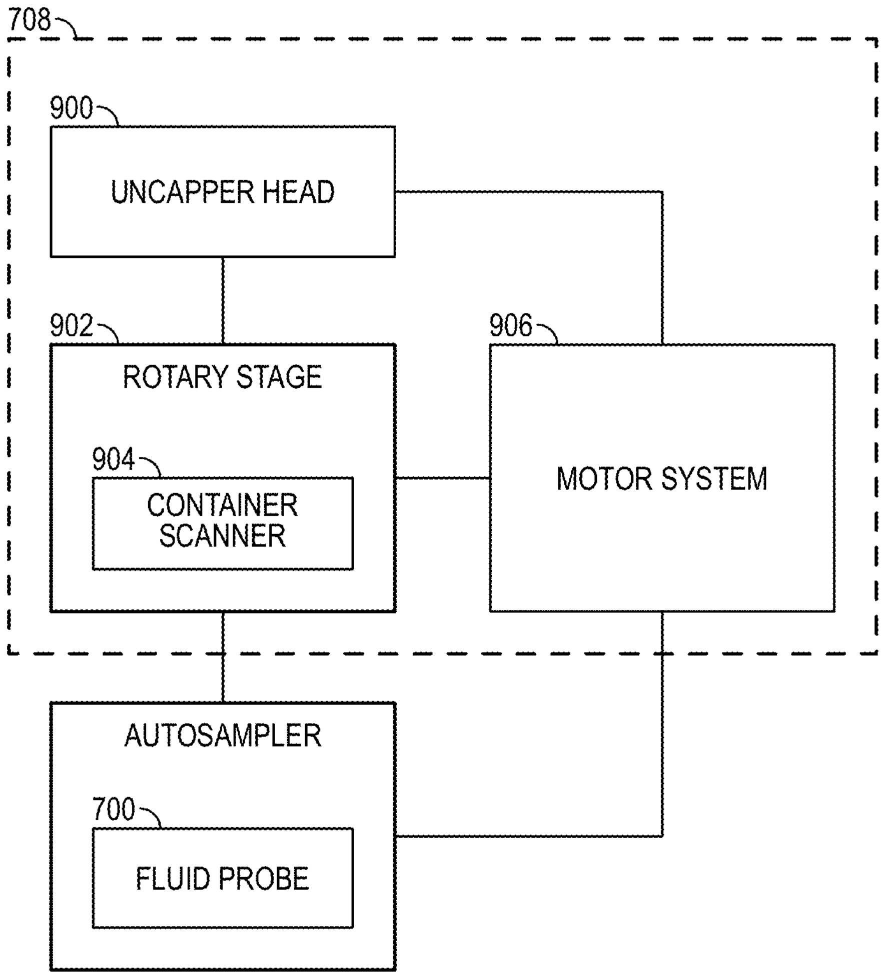

708
900
UNCAPPER HEAD
902
ROTARY STAGE
904
CONTAINER SCANNER
906
MOTOR SYSTEM
AUTOSAMPLER
700
FLUID PROBE

FIG. 9

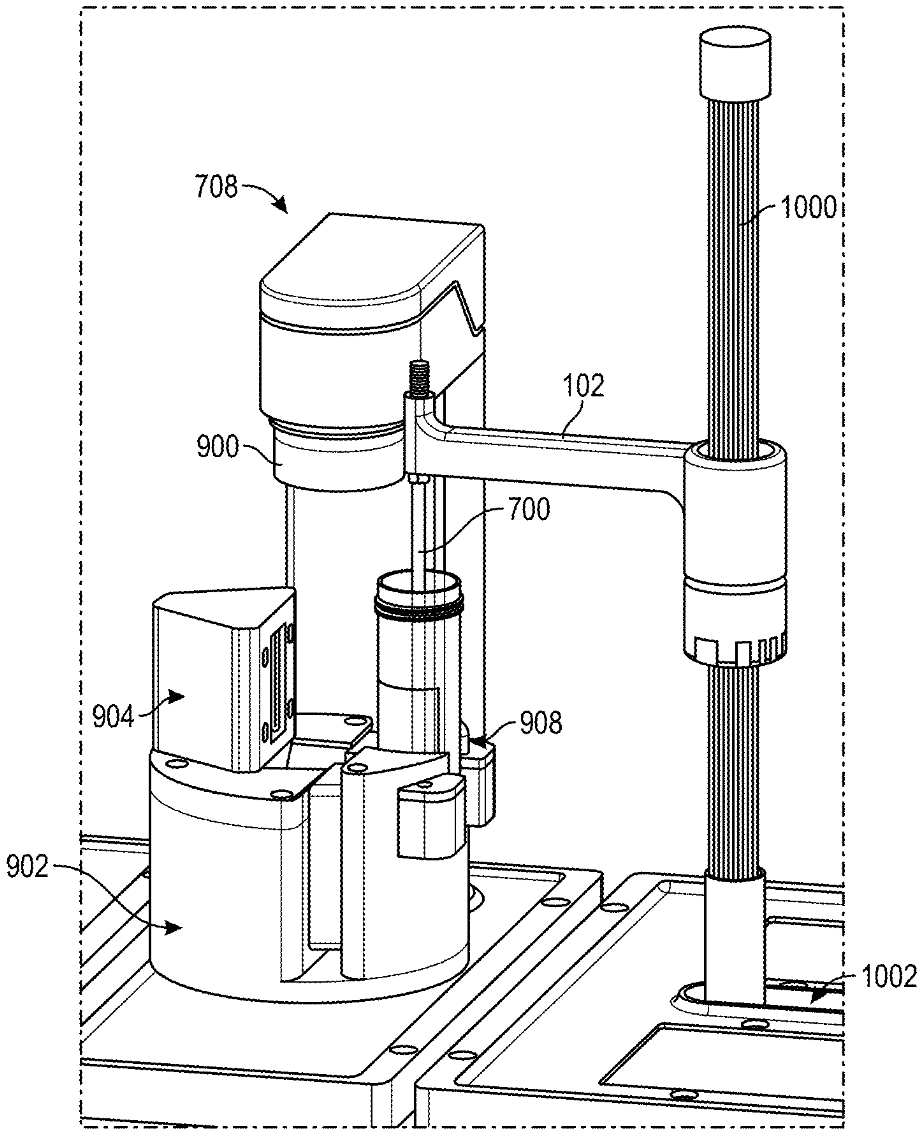


FIG. 10

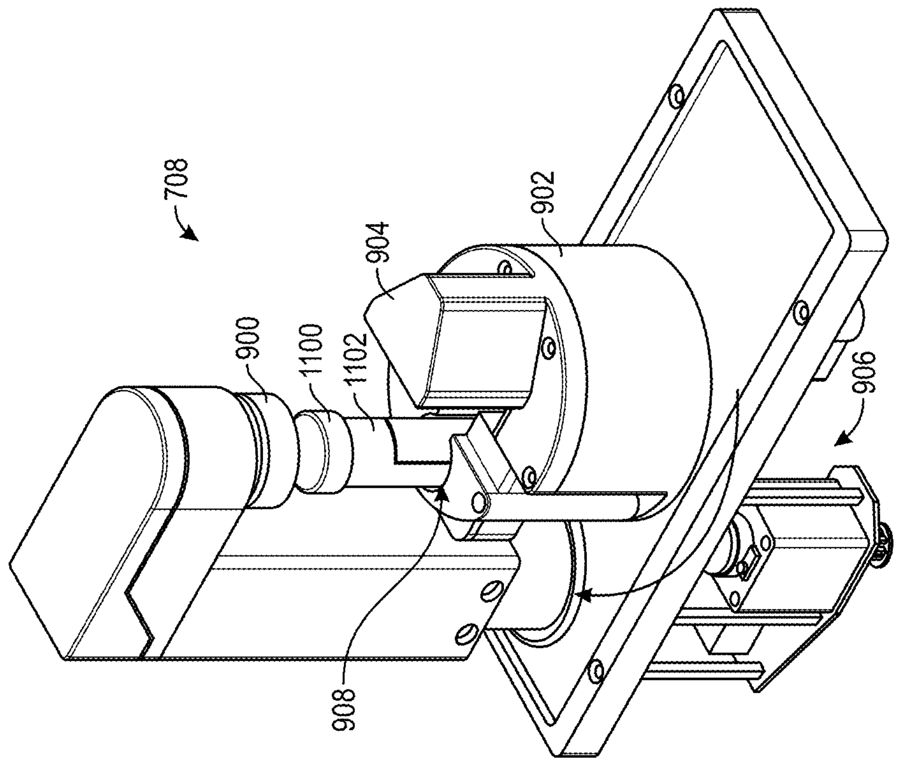


FIG. 11B

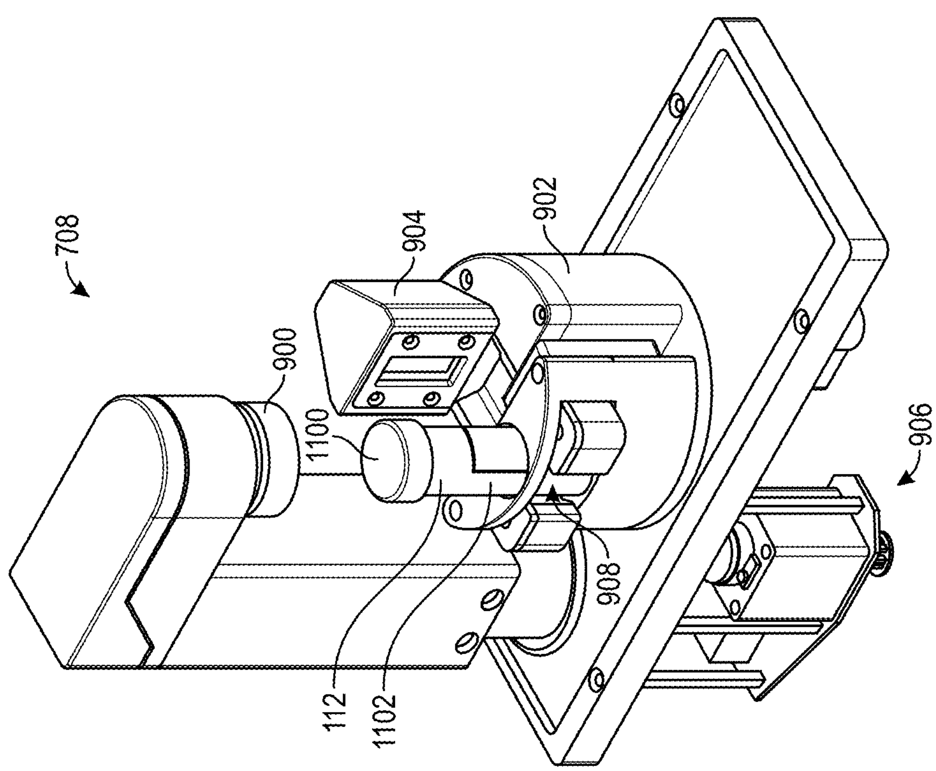


FIG. 11A

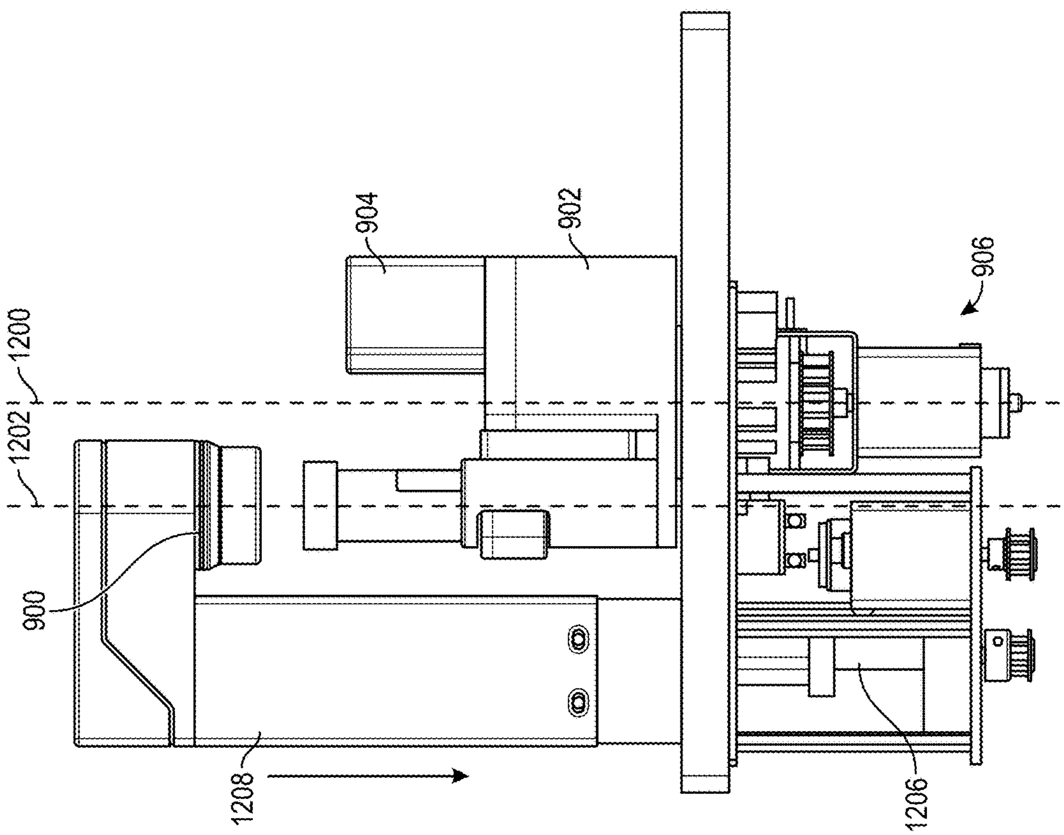


FIG. 12A

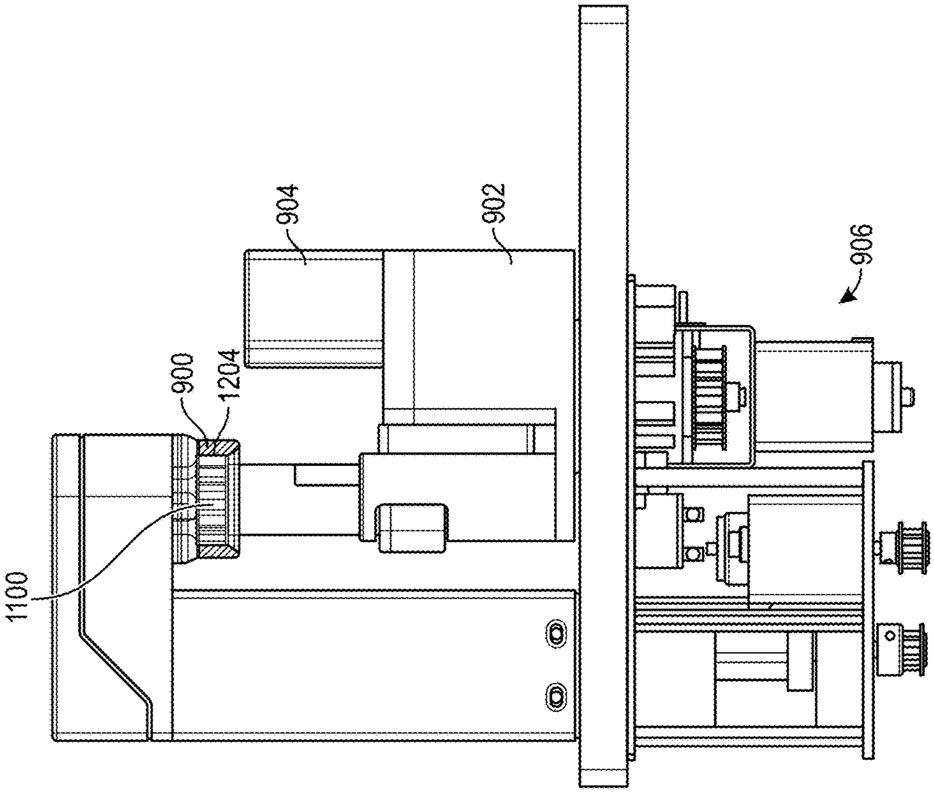


FIG. 12B

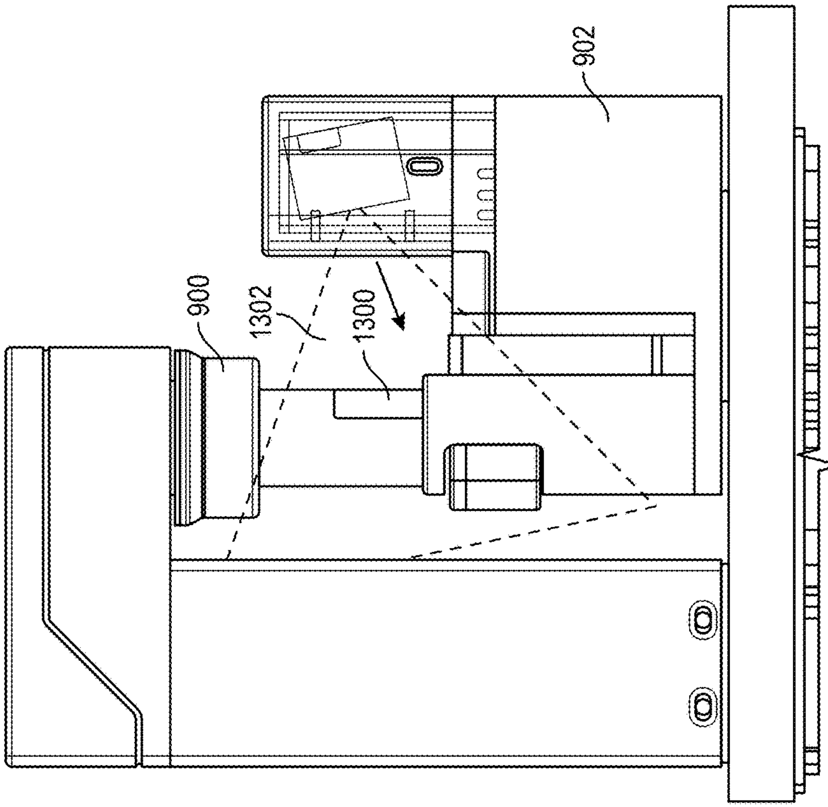


FIG. 13B

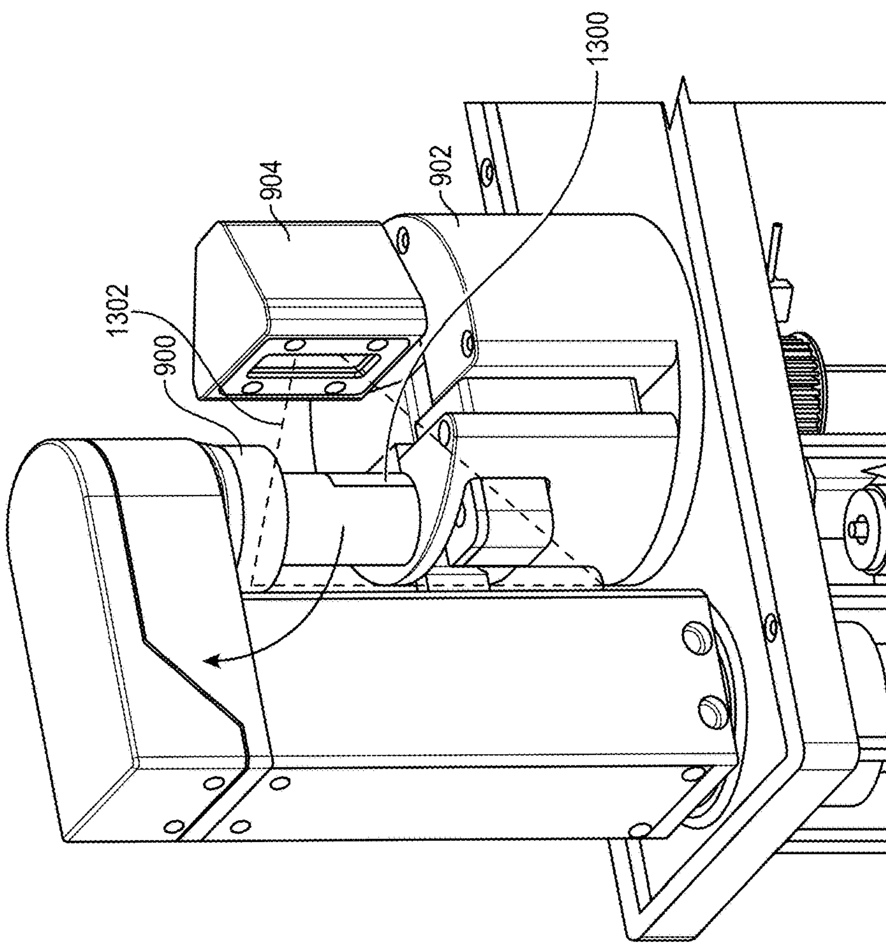


FIG. 13A

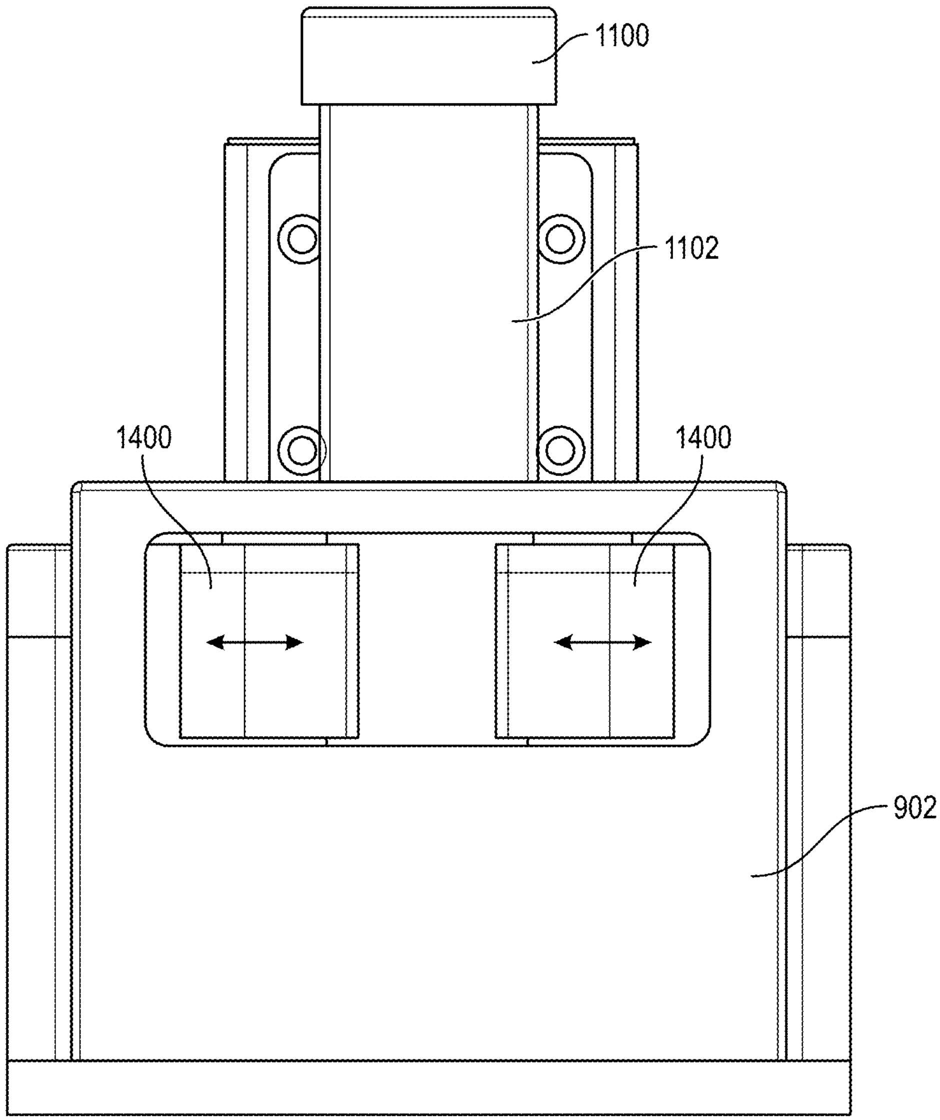


FIG. 14

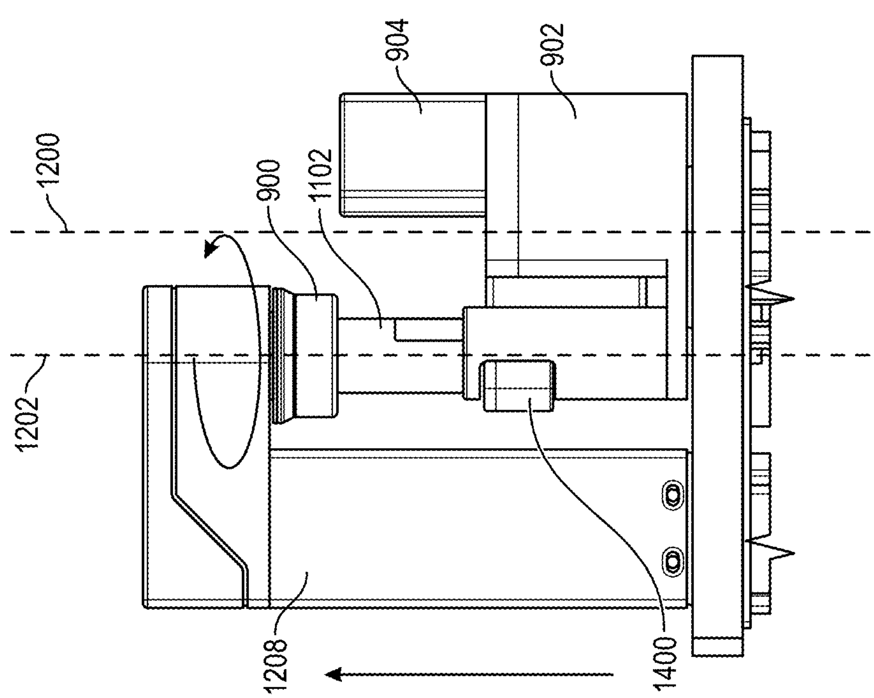


FIG. 15A

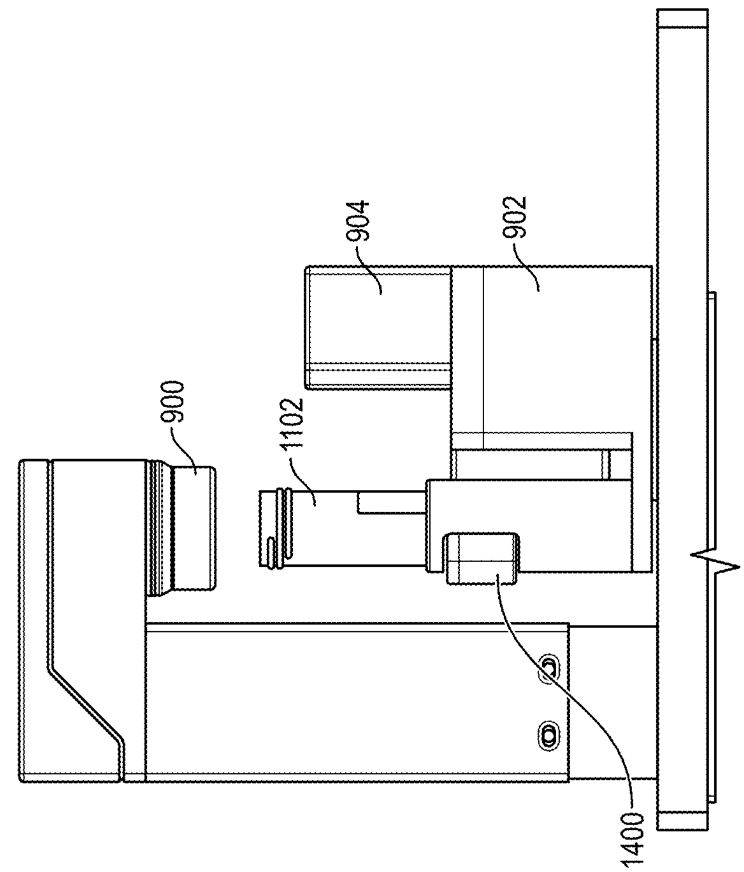


FIG. 15B

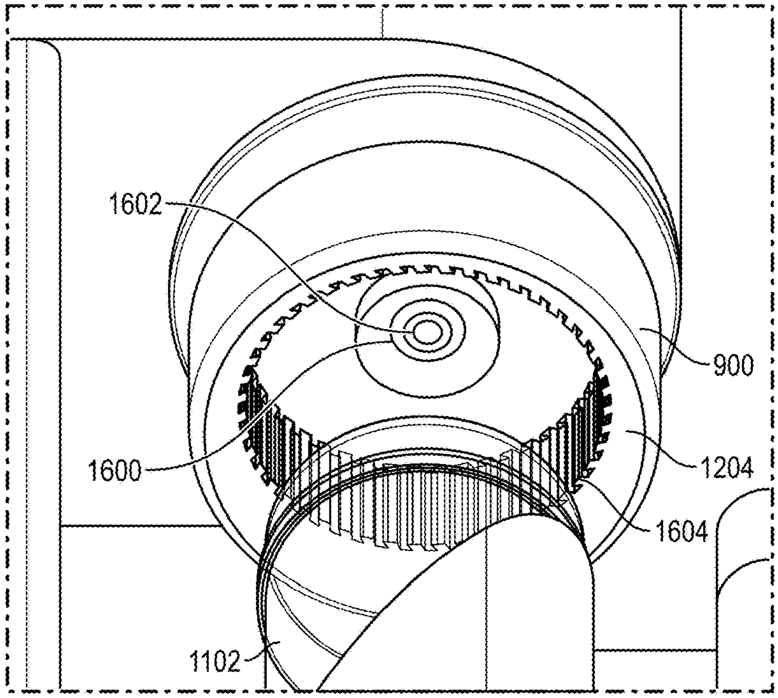


FIG. 16

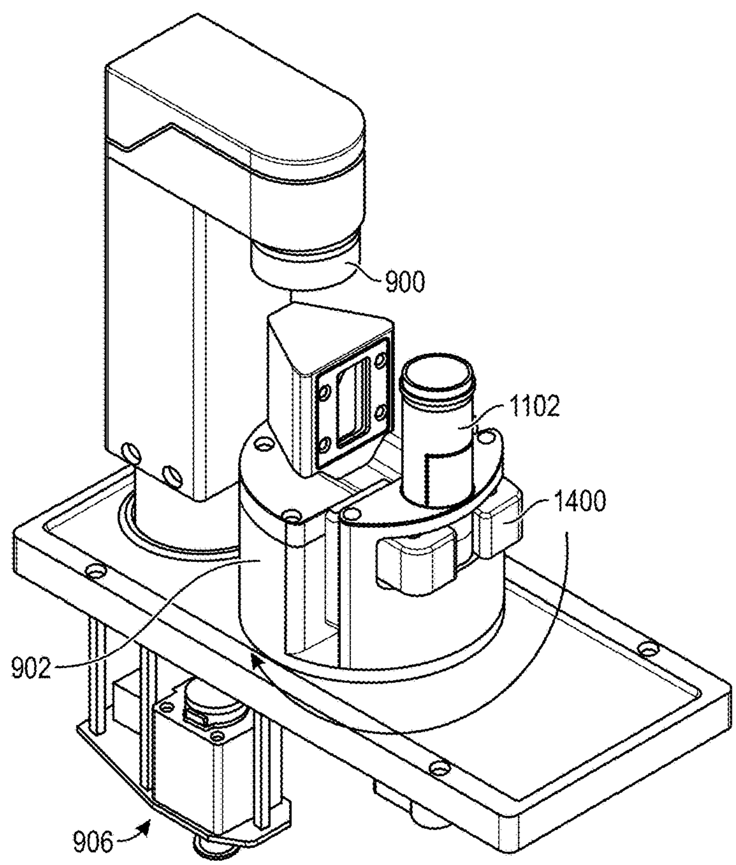


FIG. 17

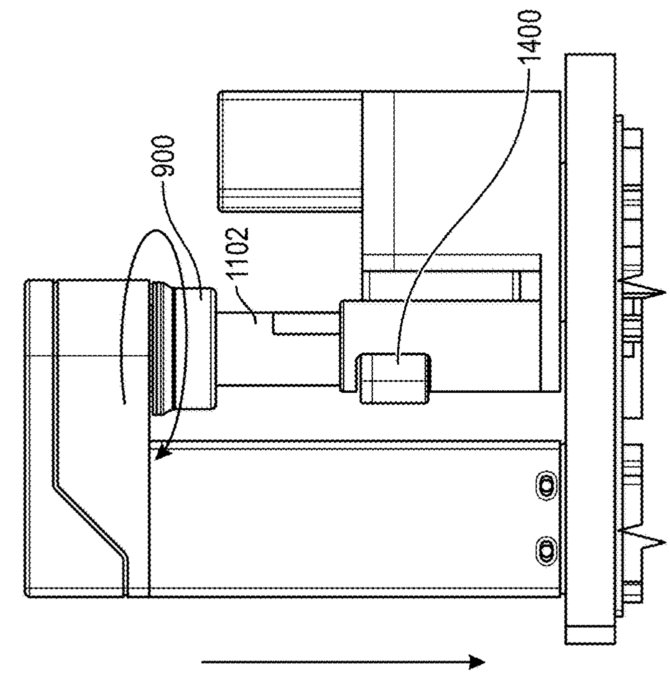


FIG. 18B

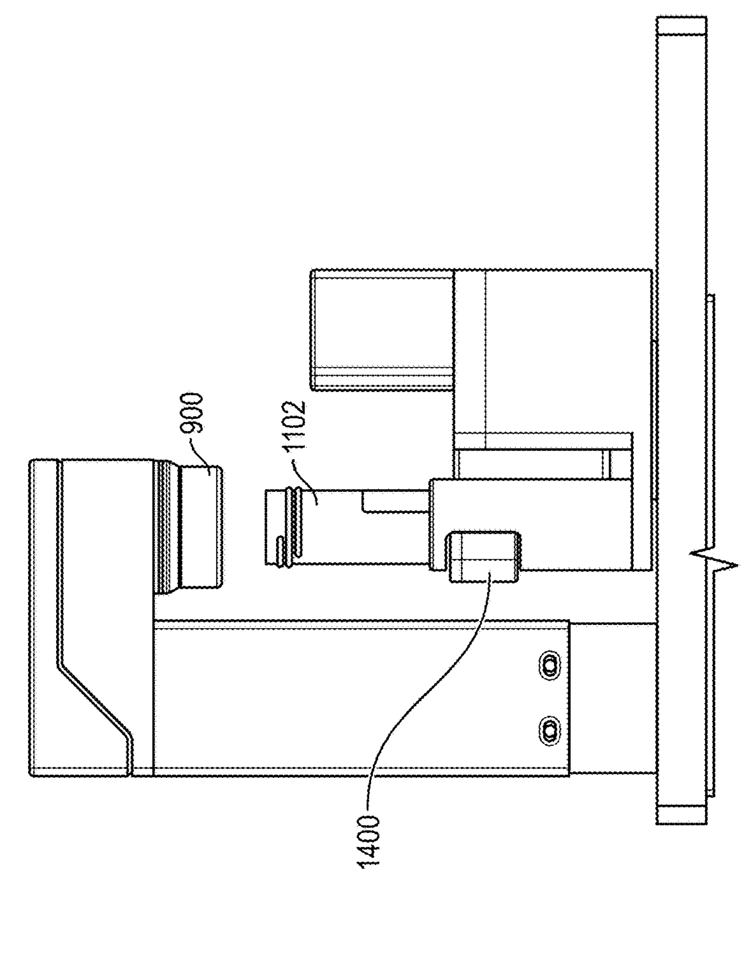


FIG. 18A

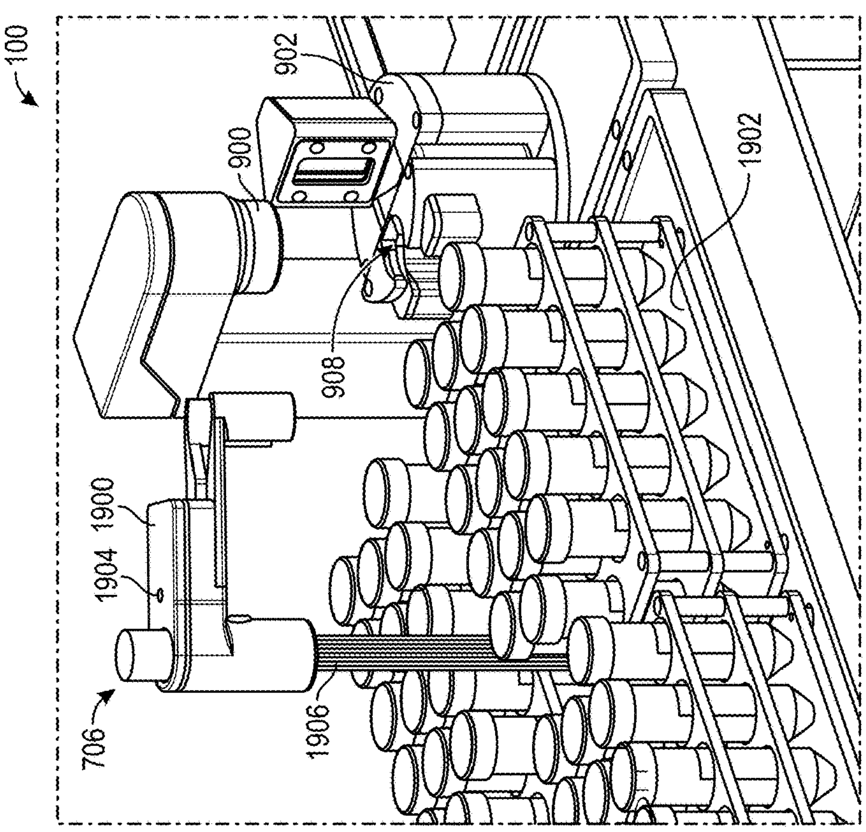


FIG. 19A

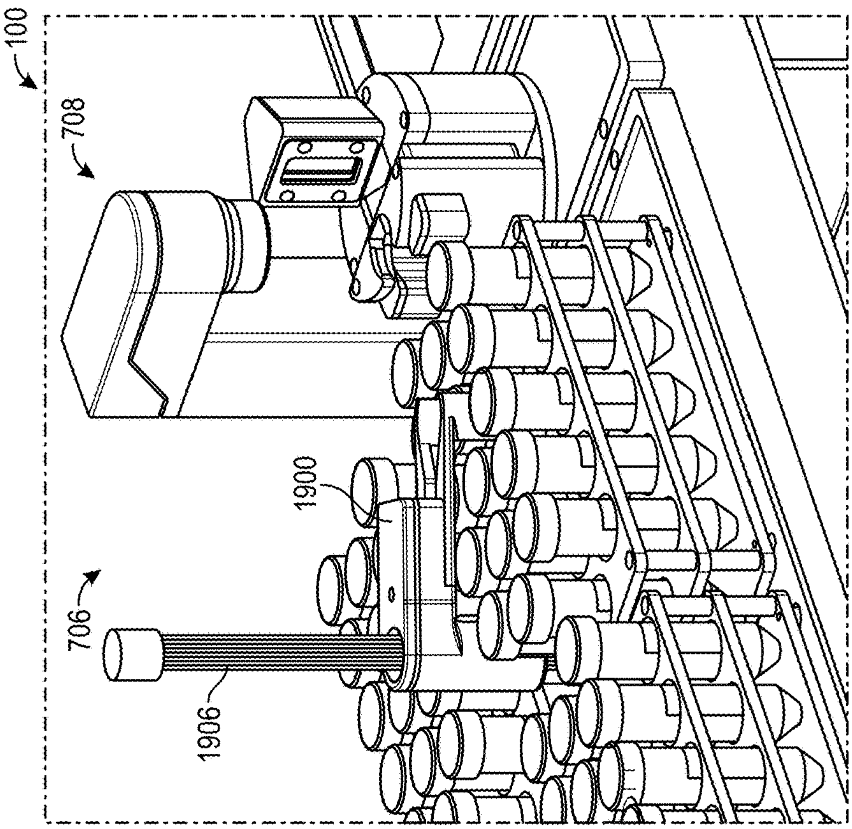


FIG. 19B

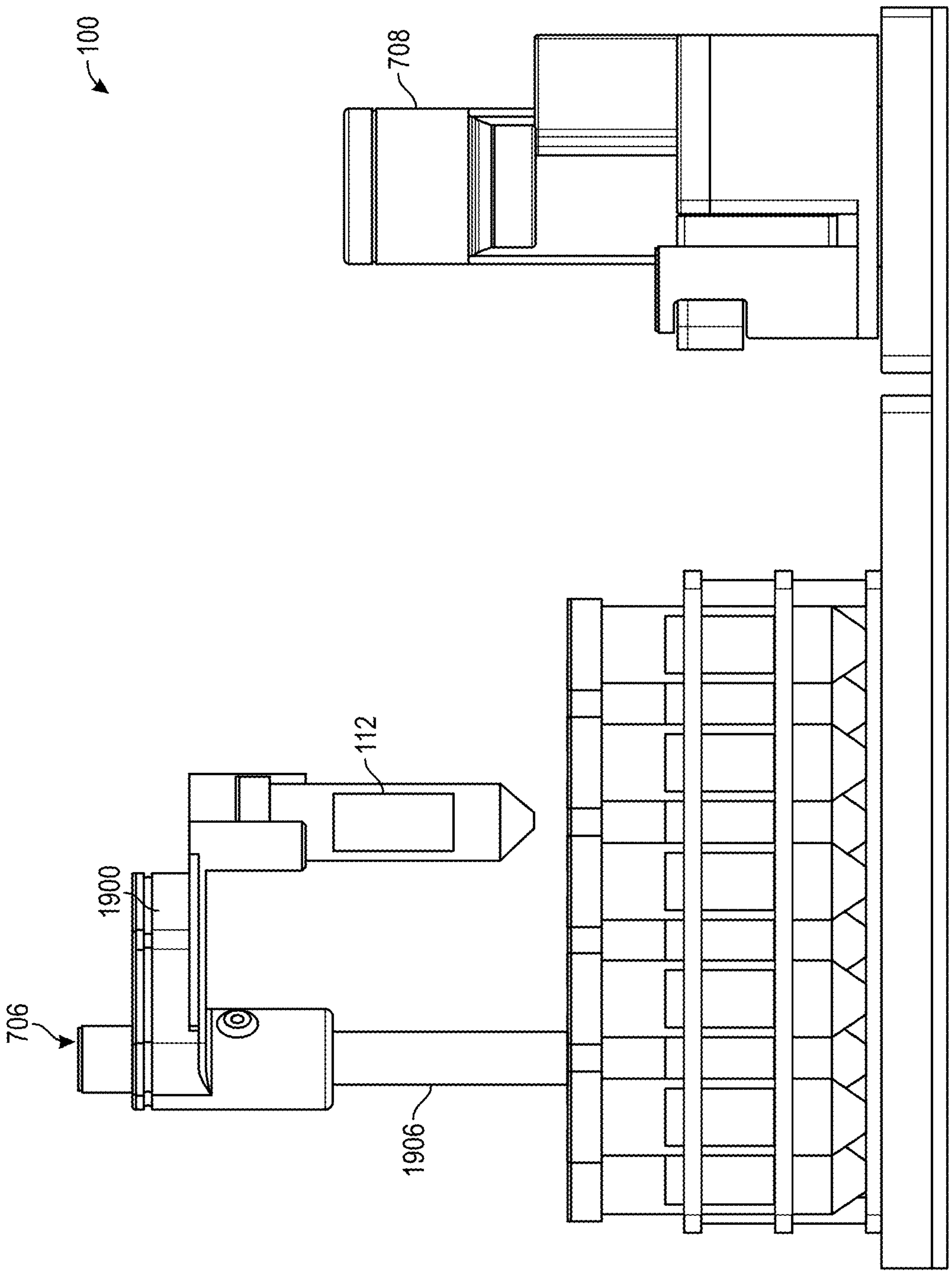


FIG. 20

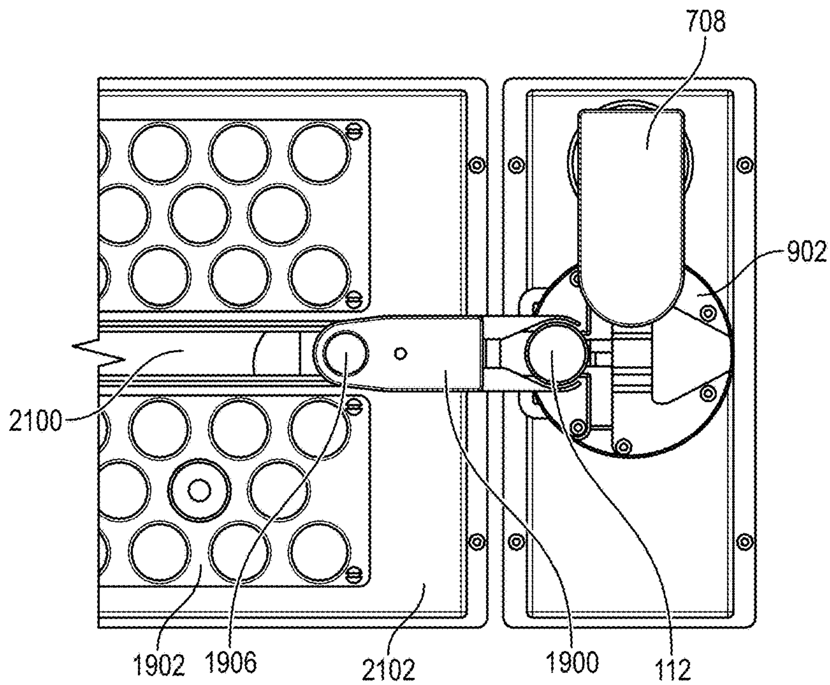


FIG. 21A

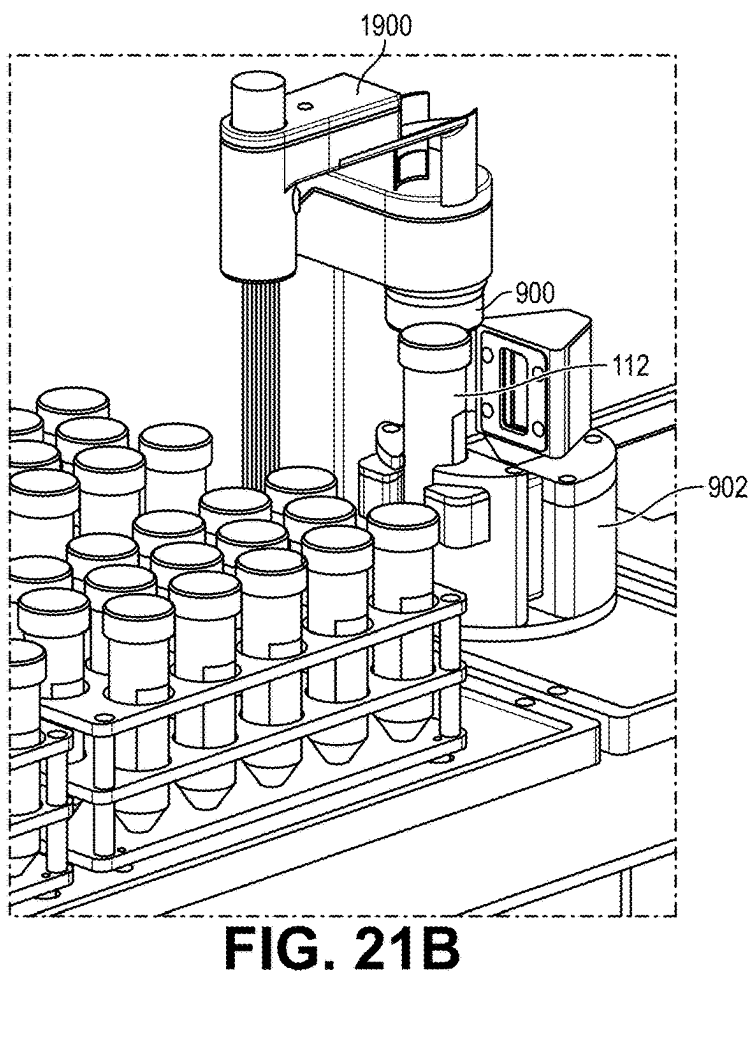


FIG. 21B

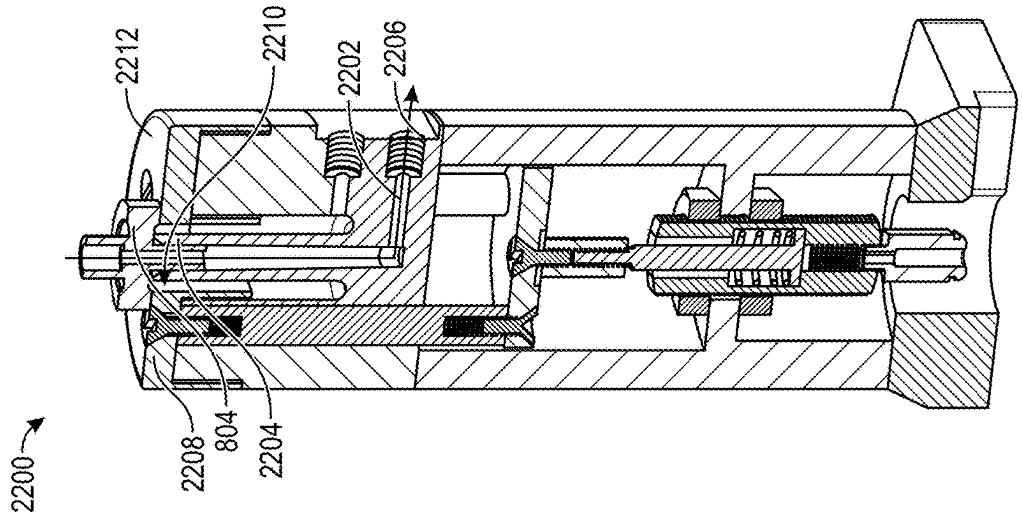


FIG. 22A

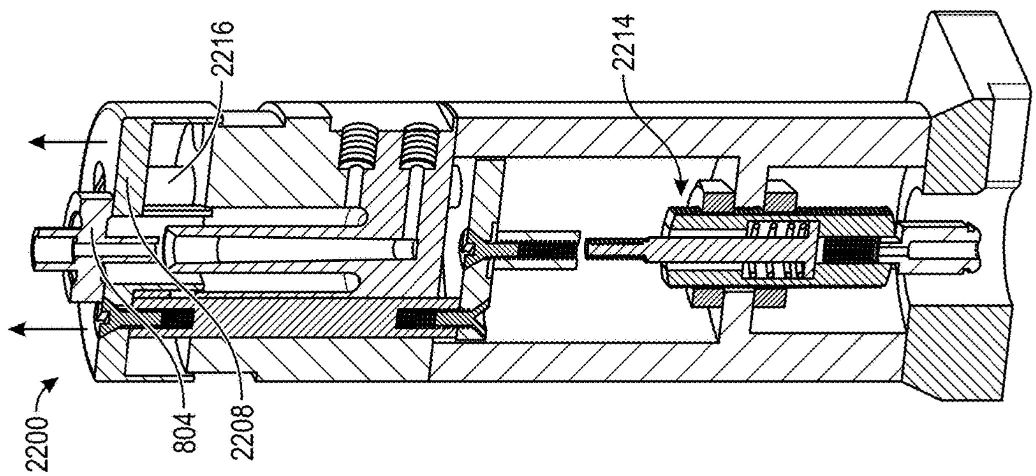


FIG. 22B

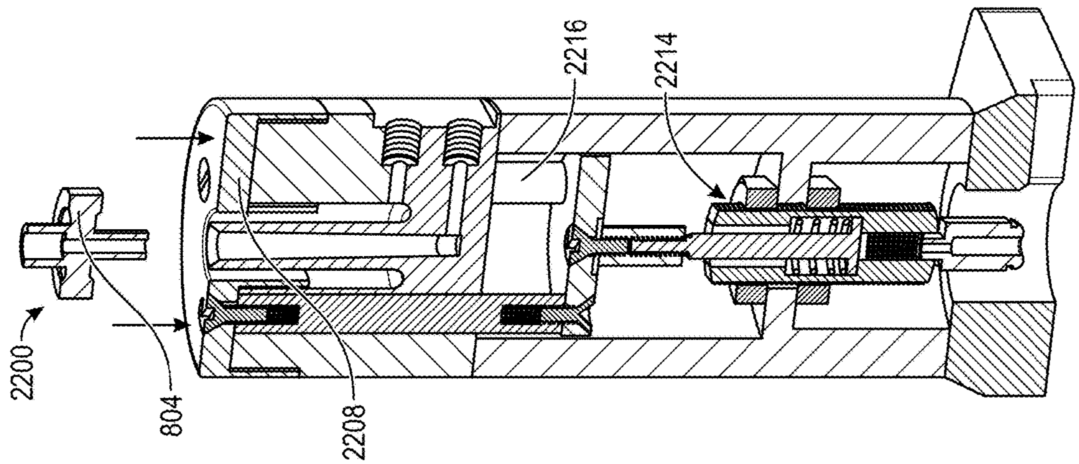


FIG. 22C

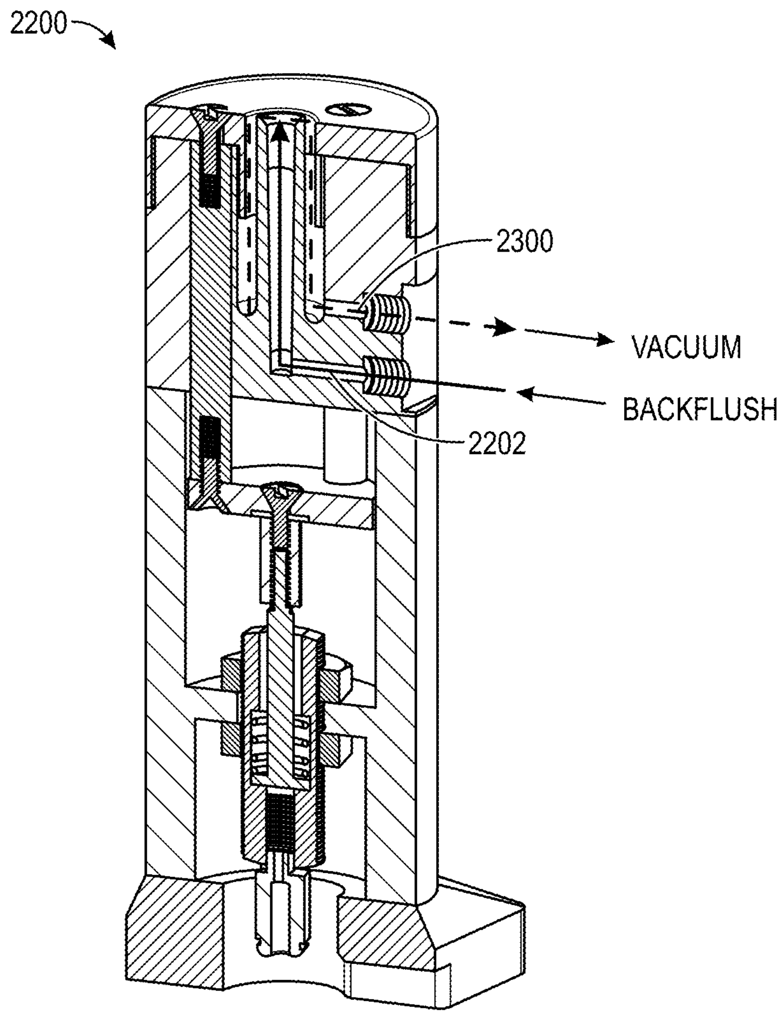


FIG. 23

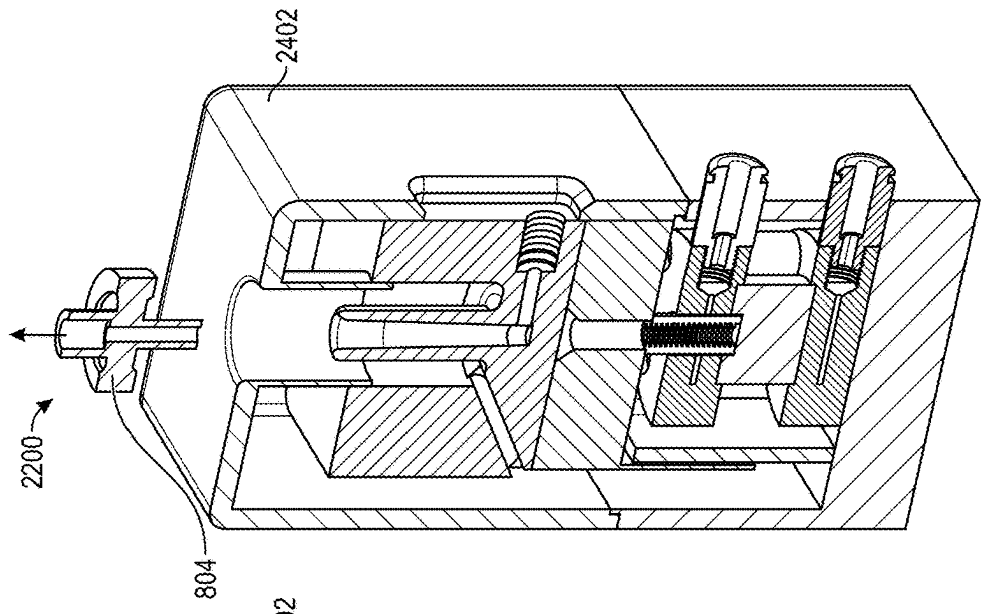


FIG. 24C

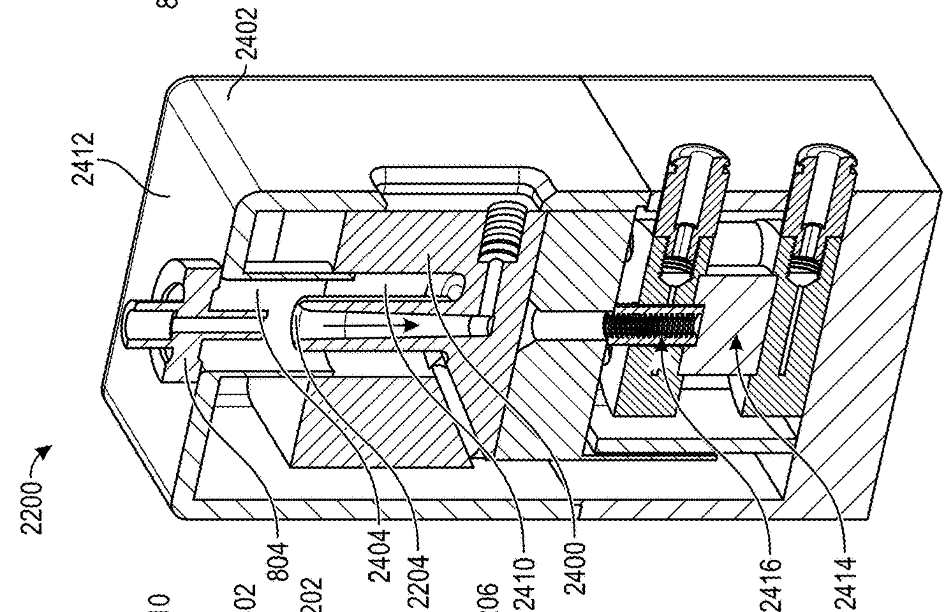


FIG. 24B

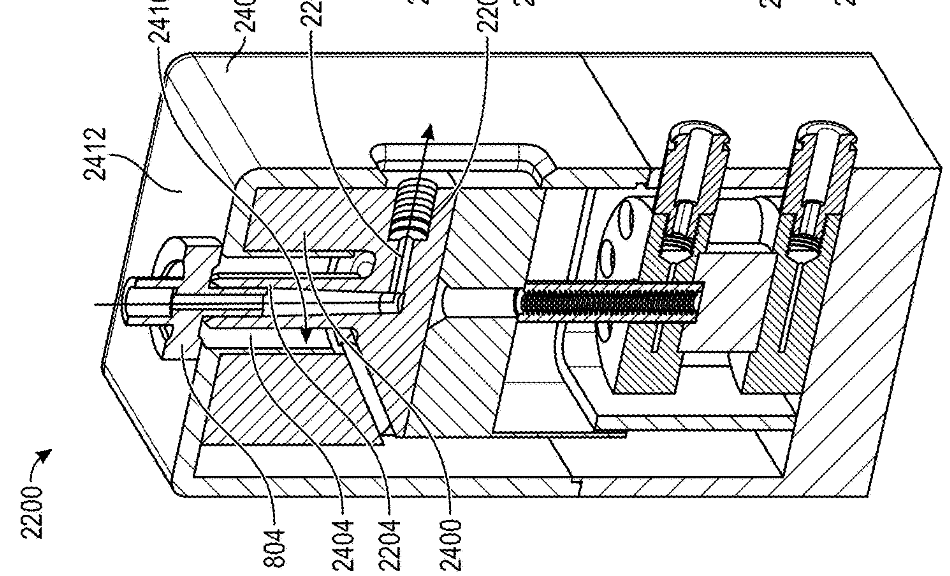


FIG. 24A

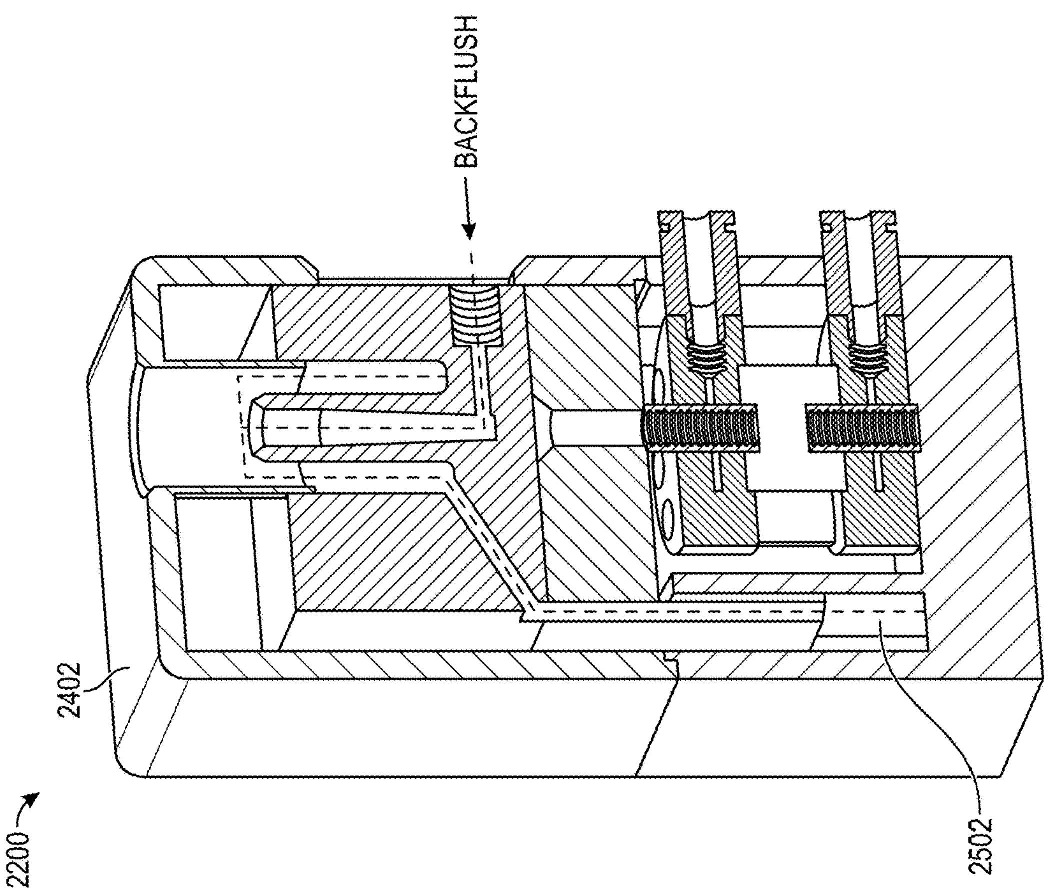


FIG. 25A

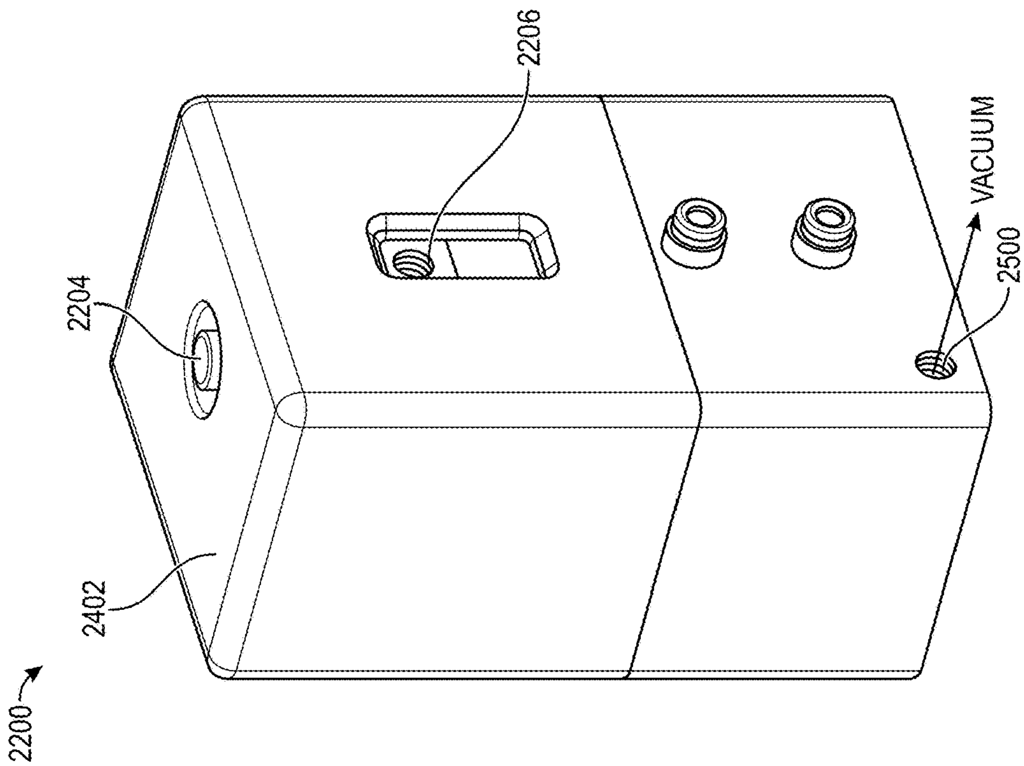


FIG. 25B

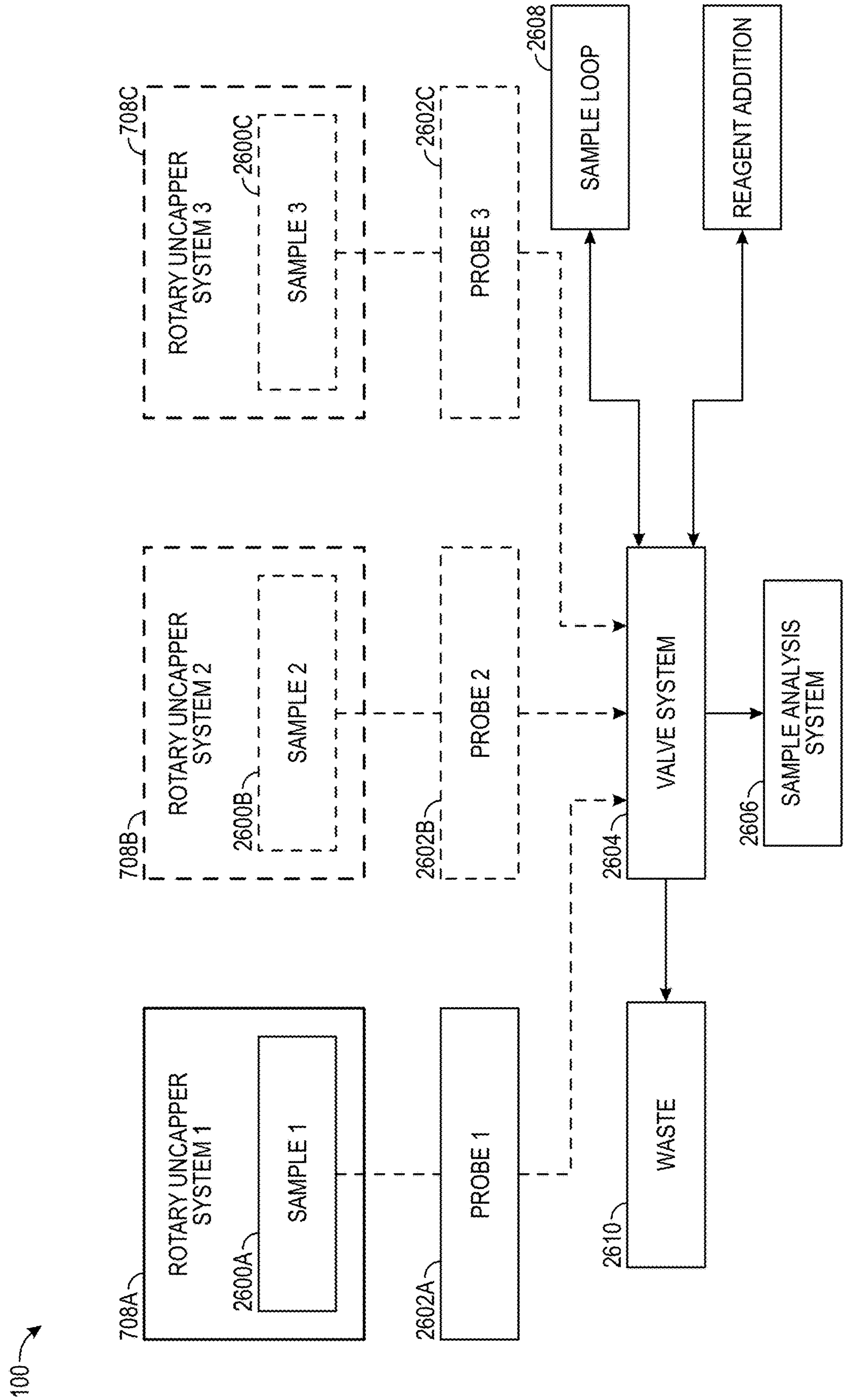

100
708A
ROTARY UNCAPPER SYSTEM 1
2600A
SAMPLE 1
2602A
PROBE 1
708B
ROTARY UNCAPPER SYSTEM 2
2600B
SAMPLE 2
2602B
PROBE 2
708C
ROTARY UNCAPPER SYSTEM 3
2600C
SAMPLE 3
2602C
PROBE 3
2604
VALVE SYSTEM
2606
SAMPLE ANALYSIS SYSTEM
2608
SAMPLE LOOP
REAGENT ADDITION
2610
WASTE

FIG.26

AUTOMATED FILTRATION SYSTEM WITH AUTOMATED ROTARY VIAL UNCAPPING SYSTEM AND FILTER REMOVAL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of 35 U.S.C. § 119(e) of U.S. Provisional Application Ser. No. 63/554,345, filed Feb. 16, 2024, and titled "AUTOMATED FILTRATION SYSTEM WITH FILTERS HAVING AN INTEGRATED PROBE," of U.S. Provisional Application Ser. No. 63/687,547, filed Aug. 27, 2024, and titled "AUTOMATED ROTARY VIAL UNCAPPING SYSTEM," and of U.S. Provisional Application Ser. No. 63/730,782, filed Dec. 11, 2024, and titled "AUTOMATED FILTRATION SYSTEM WITH AUTOMATED ROTARY VIAL UNCAPPING SYSTEM AND FILTER REMOVAL." U.S. Provisional Applications Ser. Nos. 63/554,345, 63/687,547, and 63/730,782 are herein incorporated by reference in their entireties.

BACKGROUND

[0002] In many laboratory settings, it is often necessary to analyze a large number of chemical or biochemical samples located in individual sample containers. In order to streamline such processes, the manipulation of samples has been mechanized. Such mechanized sampling is commonly referred to as autosampling and is performed using an automated sampling device or autosampler.

SUMMARY

[0003] Automated systems are described that remove a cap from a capped sample container, introduce a probe to the uncapped sample container, direct the sample through a filter to provide a filtrate, and transfer the filtrate to another uncapped sample container, a sample fluid line in fluid communication with a sample analysis system, or combinations thereof. In an aspect, a system embodiment includes, but is not limited to, an autosampler arm configured to couple with a sample probe having a filter coupled to the sample probe, the autosampler arm configured to position the sample probe within a first sample container holding a fluid sample for filtering and subsequent analysis; a pump/vacuum source configured to remove at least a portion of the fluid sample from the sample container and to transfer fluid sample through each of the filter and the sample probe to generate a filtrate; and a control system communicatively coupled with each of the autosampler arm and the pump/vacuum source to cause the autosampler arm to position the autosampler arm adjacent at least one of a second sample container or a sample port in fluid communication with an analysis system and to cause the pump/vacuum source to dispense the filtrate into at least one of the second sample container or the sample port.

[0004] In an aspect, a system embodiment includes, but is not limited to, an autosampler arm configured to couple with a sample probe having a filter coupled to the sample probe, the autosampler arm configured to position the sample probe within a first sample container holding a fluid sample for filtering and subsequent analysis; a rotary uncapper including a stage configured to support the first sample container and an uncapper head configured to remove a cap from the first sample container prior to introduction of the sample probe to the first sample container; a pump/vacuum source configured to remove at least a portion of the fluid sample from the sample container and to transfer fluid sample through each of the filter and the sample probe to generate a filtrate; and a control system communicatively coupled with each of the autosampler arm and the pump/vacuum source to cause the autosampler arm to position the autosampler arm adjacent at least one of a second sample container or a sample port in fluid communication with an analysis system and to cause the pump/vacuum source to dispense the filtrate into at least one of the second sample container or the sample port.

[0005] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

DRAWINGS

[0006] The Detailed Description is described with reference to the accompanying figures. The use of the same reference numbers in different instances in the description and the figures may indicate similar or identical items.

[0007] FIG. **1** is a schematic diagram of an automated filtration system in accordance with an example embodiment of the present disclosure.

[0008] FIG. **2** is an isometric view of an automated filtration system, such as an embodiment of the automated filtration system of FIG. **1**, shown with sample containers held in sample racks and filters having integrated sample probes in accordance with an example embodiment of the present disclosure.

[0009] FIG. **3**A is a side view of an autosampler arm of the automated filtration system of FIG. **2** shown with an attached filter with integrated sample probe in accordance with an example embodiment of the present disclosure.

[0010] FIG. **3**B is a side view of the autosampler arm of FIG. **3**A shown with a sample fluid line coupled with the autosampler arm and fluidically coupled with the filter with integrated sample probe in accordance with an example embodiment of the present disclosure.

[0011] FIG. **4** is an isometric view of a filter probe storage, such as an embodiment of the filter probe storage of the automated filtration system of FIG. **1**, shown with a plurality of filters having integrated sample probes supported by a rack in accordance with an example embodiment of the present disclosure.

[0012] FIG. **5** is an isometric view of a filter retainer, such as an embodiment of the filter retainer of the automated filtration system of FIG. **1**, shown in accordance with an example embodiment of the present disclosure.

[0013] FIG. **6** is a schematic diagram of a control system for the automated filtration system of FIG. **1**, shown in accordance with an example embodiment of the present disclosure.

[0014] FIG. **7** is a schematic diagram of an automated filtration system in accordance with an example embodiment of the present disclosure.

[0015] FIG. **8**A is a side view of a sample probe of the automated filtration system of FIG. **7**, in accordance with an example embodiment of the present disclosure.

[0016] FIG. **8**B is a partial cross-sectional isometric view of the sample probe of FIG. **8**A shown with a particulate filter into which an end of the sample probe fits, in accordance with an example embodiment of the present disclosure.

[0017] FIG. **8**C is a partial side view of the sample probe of FIG. **8**A shown drawing sample fluid from a sample container in accordance with an example embodiment of the present disclosure.

[0018] FIG. **8**D is a partial side view of the sample probe of FIG. **8**C shown with a filter affixed to an end of the sample probe and dispensing filtrate into a different sample container in accordance with an example embodiment of the present disclosure.

[0019] FIG. **8**E is a partial side view of the sample probe of FIG. **8**D shown with the filter removed and dispensing another fluid to mix with the filtrate in the different sample container in accordance with an example embodiment of the present disclosure.

[0020] FIG. **9** is a schematic diagram of an automated cap removal system for making a sample container available to a sample probe of an autosampler in accordance with an example embodiment of the present disclosure.

[0021] FIG. **10** is an isometric view of an automated cap removal system of having an open sample container supported by a rotary stage with a sample probe inserted therein in accordance with an example embodiment of the present disclosure.

[0022] FIG. **11**A is an isometric view of an automated cap removal system including a rotary stage configured to hold and rotate about at least two axes a fluid container having a removable cap in accordance with an example embodiment of the present disclosure.

[0023] FIG. **11**B is an isometric view of the automated cap removal system of FIG. **11**A, shown with the rotary stage having rotated the fluid container beneath an uncapper head in accordance with an example embodiment of the present disclosure.

[0024] FIG. **12**A is a side view of the automated cap removal system of FIG. **11**A, shown with an uncapper assembly configured to move the uncapper head towards the removable cap disposed on the fluid container in accordance with an example embodiment of the present disclosure.

[0025] FIG. **12**B is a partial side view of the automated cap removal system of FIG. **11**A, shown with the uncapper head interacting with the removable cap disposed on the fluid container in accordance with an example embodiment of the present disclosure.

[0026] FIG. **13**A is a partial perspective view of the automated cap removal system of FIG. **11**A, shown with a scanner interacting with a label on the fluid container in accordance with an example embodiment of the present disclosure.

[0027] FIG. **13**B is a partial side view of the automated cap removal system of FIG. **13**A.

[0028] FIG. **14** is a side view of a grip mechanism of the rotary stage of the automated cap removal system of FIG. **11**A, shown with the grippers moveably engaging and disengaging with the fluid container in accordance with an example embodiment of the present disclosure.

[0029] FIG. **15**A is a partial side view of the automated cap removal system of FIG. **11**A, shown with the fluid container secured by a grip mechanism and with the uncapper head rotatably removing the cap disposed on the fluid container with an upward motion of the uncapper assembly in accordance with an example embodiment of the present disclosure.

[0030] FIG. **15**B is a partial side view of the automated cap removal system of FIG. **15**A, shown with the removeable cap held by the uncapper head of the uncapper assembly in accordance with an example embodiment of the present disclosure.

[0031] FIG. **16** is a partial perspective view of an underside of the uncapper head of the automated cap removal system of FIG. **11**A in accordance with an example embodiment of the present disclosure.

[0032] FIG. **17** is an isometric view of the automated cap removal system of FIG. **11**A, shown with the rotary stage having further rotated the position of the uncapped fluid container, such as to be accessible by a fluid probe of an autosampler, in accordance with an example embodiment of the present disclosure.

[0033] FIG. **18**A is a partial side view of the automated cap removal system of FIG. **17**, shown with the removeable cap held by the uncapper head of the uncapper assembly in preparation to replace the cap back onto the fluid container in accordance with an example embodiment of the present disclosure.

[0034] FIG. **18**B is a partial side view of the automated cap removal system of FIG. **17**, shown with the removeable cap lowered and rotated by the uncapper head of the uncapper assembly to replace the cap onto the fluid container in accordance with an example embodiment of the present disclosure.

[0035] FIG. **19**A is a partial isometric view of a sample container placement system with a container gripper positioned above a sample container in accordance with an example embodiment of the present disclosure.

[0036] FIG. **19**B is a partial isometric view of the sample container placement system of FIG. **19**A shown with the container gripper engaging the sample container in accordance with an example embodiment of the present disclosure.

[0037] FIG. **20** is a side view of the sample container placement system of FIG. **19**A shown with the container gripper engaging and lifting the sample container for transport to the automated cap removal system in accordance with an example embodiment of the present disclosure.

[0038] FIG. **21**A is a partial top view of the sample container placement system of FIG. **19**A shown with the container gripper engaging and positioning the sample container above the automated cap removal system in accordance with an example embodiment of the present disclosure.

[0039] FIG. **21**B is a partial isometric view of the sample container placement system of FIG. **19**A shown with the container gripper following placement of the sample container in the automated cap removal system in accordance with an example embodiment of the present disclosure.

[0040] FIG. **22**A is a cross-sectional view of a filter disengagement system for a filter retainer, shown with the filter engaged with a sample port, in accordance with an example embodiment of the present disclosure.

[0041] FIG. **22**B is a cross-sectional view of the filter disengagement system of FIG. **22**A, shown decoupling the filter from the sample port via an extension configuration, in accordance with an example embodiment of the present disclosure.

[0042] FIG. 22C is a cross-sectional view of the filter disengagement system of FIG. 22A, shown in a reset configuration to facilitate removal of the filter, in accordance with an example embodiment of the present disclosure.

[0043] FIG. 23 is a cross-sectional view of the filter disengagement system of FIG. 22A, shown in a backflush and rinse configuration, in accordance with an example embodiment of the present disclosure.

[0044] FIG. 24A is a cross-sectional view of a filter disengagement system for a filter retainer, shown with the filter engaged with a sample port, in accordance with an example embodiment of the present disclosure.

[0045] FIG. 24B is a cross-sectional view of the filter disengagement system of FIG. 24A, shown decoupling the filter from the sample port via a retraction configuration, in accordance with an example embodiment of the present disclosure.

[0046] FIG. 24C is a cross-sectional view of the filter disengagement system of FIG. 24A, shown with filter removal, in accordance with an example embodiment of the present disclosure.

[0047] FIG. 25A is a cross-sectional view of the filter disengagement system of FIG. 24A, shown in a backflush and rinse configuration, in accordance with an example embodiment of the present disclosure.

[0048] FIG. 25B is an isometric view of the filter disengagement system of FIG. 24A, shown in a backflush and rinse configuration, in accordance with an example embodiment of the present disclosure.

[0049] FIG. 26 is a schematic diagram of an automated filtration system configured to direct filtrate to a sample line in fluid communication with a sample analysis system for analyte detection, in accordance with an example embodiment of the present disclosure.

DETAILED DESCRIPTION

Overview

[0050] Many analytical methods include a filtration step for a fluid sample prior to analyzing an analyte concentration of the sample, such as through mass spectroscopy, liquid chromatography, or other analytical techniques. The filtration step can be a manual process handled by a laboratory technician wherein the technician loads a sample from a first sample container into a syringe, attaches a filter to the syringe, and pushes the plunger on the syringe to expel sample liquid through the filter to introduce filtrate into a second sample container. The filter can be removed and disposed of after each sample filtration to prevent cross contamination between samples.

[0051] However, such manual filtering processes provide multiple health and safety concerns. For instance, many laboratories handle large numbers of sample containers, which leads to individual lab technicians repeating the same motion throughout the day. Such repeated motion can be a risk for repetitive motion injury, repetitive stress injury, and the like. These risks can increase as the force utilized by the lab technician to dispense fluid through the filter becomes larger due to small pore sizes on the associated filters, such as with micron-scale filters used in many laboratory settings. Additionally or alternatively, the risks can include risk of cross contamination or environmental exposure of sample contents if the filter is not firmly attached to or secured against the syringe during dispensing operations. For instance, if the filter is not firmly attached during a dispensing operation, the force of fluid flowing through the filter can push the filter, or a portion thereof, off the end of the syringe, which can cause sample to spray erratically from the syringe. For samples containing acids or other potentially hazardous fluids (e.g., acid-digested samples), exposure of the sample to the environment outside of the syringe or proper sample containers can injure individuals, cross contaminate other samples awaiting analysis, and so forth.

[0052] An automated sampling device, or autosampler, can automate certain sample handling procedures to save laboratory labor costs and improve reproducibility. Autosamplers can include a sample probe mounted relative to a vertically-oriented rod which moves the sample probe along or across one or more directions of movement. For instance, the sample probe can be coupled to a vertically-moveable portion of the rod by a probe support arm or other device to move the probe in a vertical direction, such as to position the probe into and out of sample container (e.g., tubes or other vessels), rinse containers, standard chemical containers, diluent containers, and the like, on a deck of the autosampler. In other situations, the rod can be rotated to facilitate movement of the probe about a horizontal plane, such as to position the probe above other sample vessels and other vessels positioned on the deck.

[0053] A probe of an autosampler can be inserted into a sample container to draw a sample through the probe and into a fluid line, however if the sample is to be filtered prior to analysis, particulates present in the sample can attach to or deposit on interior walls of the probe and/or the fluid line. Such presence of particulates can be a source of cross contamination of future samples, can lead to clogging autosampler components (e.g., requiring downtime for equipment maintenance), and the like, even if a filter is attached prior to dispensing the sample. Moreover, attempting to pass a fluid sample through a filter that has been utilized to filter particulates during a drawing procedure of the autosampler presents a risk of reintroducing the particulates back into the sample as the particulates are dislodged during the dispensing procedure. Additionally, in order to replace or change a filter, such as to avoid subsequent sample contamination, to avoid pressure buildup with the system due to filter clogging, or the like, the filter should be removed from contact with the probe. However, such a removal or replacement can require a laboratory technician to manually accommodate the process, which takes additional time and cost to facilitate, can pose additional exposure risks of the technician to particulates or latent sample in the filter, or can utilize automated processes that can jam, clog, or otherwise lead to downtime due to system failures with attempting to dislodge a filter from the probe or that loosely hold the filter onto the probe, which can result in sample flow pushing the filter off the probe during a dispensing procedure.

[0054] Further, various samples are held in capped sample vessels, such as to isolate the samples from environmental contamination or prevent evaporation or sample degradation. However, the process of uncapping and filtering a sample poses many problems with coordinating the uncapping and filtering, particularly when a new filter is utilized for each sample. Traditional vial uncapping methods are labor-intensive and prone to human error. Manual uncapping often requires repetitive motions that can lead to physical strain or injury for operators and exposes samples to potential contamination from environmental factors or human contact. In scenarios where vials contain hazardous or dangerous substances, manual handling poses a risk to the safety of users.

[0055] Accordingly, systems and methods are disclosed for automated filtering of samples using a replaceable filter configured to couple with a sample probe with subsequent removal of the filter following transfer of filtrate from the filter (e.g., into a sample container, into a sample line coupled with an analysis system, etc.). In aspects, the system utilizes a filter with an integrated probe to draw a filtered sample into a sample fluid line, remove the filter with integrated probe, and dispense filtered sample into a filtered sample container. The sample fluid line contains filtered sample, such that particulates that could otherwise attach to or deposit on interior walls of the fluid line are removed from the sample when the sample is drawn from the sample container via the integrated probe and through the filter into the sample fluid line. In aspects, the system utilizes a rigid sample probe having an end configured for insertion into a filter, where an output end of the filter can be positioned over a sample container or coupled with an input port for a sample analysis system. In an aspect, a system includes a filter retainer to permit an autosampler arm to position the filter with integrated probe into the filter retainer after a filtered sample has been drawn into the sample fluid line. The filter retainer provides a surface against which the filter with integrated probe is positioned to permit the autosampler arm to rise while the filter with integrated probe is pulled from a connector of the autosampler arm (e.g., ferrule) or while the filter is removed from the end of the sample probe.

[0056] The system can include a filter probe storage that holds a plurality of filters with integrated probes or individual filters available for the autosampler arm to attach a fresh filter prior to inserting the probe into a sample container to draw and filter a sample (e.g., for filters with integrated probes) or subsequent to drawing sample into the probe (e.g., for attaching a filter to an end of the sample probe). In an aspect, the system includes a control system to control the flow rate of sample removed from sample containers for filtration. For instance, the system can include a bubble sensor to identify whether bubbles are introduced to the sample fluid line (e.g., via high flow rate of sample through the filter), where a system controller can reduce the draw speed (e.g., through control signal(s) to a pump or vacuum source in fluid communication with the filter with integrated probe) to avoid introducing bubbles in the sample fluid line.

[0057] In aspects, the system can facilitate processing of capped sample containers with an automated cap removal system that automates the cap removal and replacement process, significantly reducing the need for manual intervention and minimizing the risk of injury associated with repetitive uncapping tasks. The automated cap removal system can facilitate movement of a sample container according to two axes of rotation, with a first axis used to rotate the sample container for cap removal and replacement via an uncapper head and a second axis used to position a rotary stage to receive the capped sample container and to make the uncapped sample container available for a sample probe to remove sample therefrom. In aspects, the automated cap removal system features an integrated barcode scanner that enhances accuracy in sample tracking and reduces human error. By automating the identification and logging of vials through barcode scanning, the automated cap removal system ensures precise tracking and data management, further improving the overall efficiency and reliability of the vial handling process. In an aspect, the automated cap removal system limits the amount of time vials are open to reduce risk of contamination and eliminates user interaction with the contents of the vials, thus protecting the user from exposure to harmful substances. In implementations, the materials used in the construction of the automated cap removal system are selected for corrosion resistance, which can ensure component longevity and reliability, even when handling vials containing corrosive substances, thereby maintaining operational efficiency and minimizing maintenance requirements.

[0058] In aspects, the filter retainer system includes a filter disengagement system to facilitate disengagement between an output end of the filter and a sample inlet port used to transfer filtrate to a sample preparation system (e.g., to introduce reagents, diluents, standard solutions, etc. to the filtrate), to a sample analysis system, or combinations thereof. The filter disengagement system can transition between differing structural configurations to remove the filter from the sample inlet port, such as to push or pull the end of the filter from the sample inlet port.

Example Implementations

[0059] Referring to FIGS. **1** through **26**, an automated filtration system ("system **100**") is shown, with FIGS. **1** through **6** illustrating aspects of the system **100** for drawing filtered sample into a sample line, removing the filter after filtering the sample, and dispensing the filtered sample is shown in accordance with an example embodiment of the present disclosure, and with FIGS. **7** through **26** illustrating aspects of the system **100** for automatically uncapping sample containers for access to a sample probe with subsequent attachment of a filter or with the filter having an integrated sample probe. The system **100** generally includes an autosampler having an autosampler arm ("autosampler arm **102**") configured to attach with a filter having an integrated probe ("filter probe **104**") or a probe configured to attach a filter to a bottom end of the probe (e.g., shown with respect to FIGS. **8**A and **8**B). For instance, the probe can be a generally tubular structure having sufficient length to be inserted into an interior volume of a sample container and receive fluid through the tubular structure. The filter of the filter probe **104** can include, but is not limited to, micron-scale pores to filter samples for analytical determination of chemical composition of the fluid without substantial solid particulates present in the fluid. The filter probe **104** is fluidically coupled with a sample fluid line **106** (e.g., shown in FIG. **3**B) to receive fluid from the filter probe **104** through action of a pump, vacuum source, or other negative pressure system ("pump/vacuum source **108**") fluidically coupled with the sample fluid line **106**.

[0060] The autosampler arm **102** is configured to interact with containers **110** of the system **100**, either directly or via the filter probe **104**, to withdraw samples from the containers **100**, to introduce filtered samples into the containers, to introduce other fluids into the containers, or the like. In implementations, the containers **110** are positioned on a deck of the autosampler, such through support by a sample rack or other support structure. The containers **110** can include, for example, one or more sample vials, sample tubes, wells of a microtiter plate, or other fluid containers or combinations thereof. In implementations, the containers **110** include sample containers **112** containing unfiltered liquid samples for analysis, filtered sample containers **114** configured to receive filtered sample (e.g., filtrate) that was drawn through the filter probe **104** and into the sample fluid line **106**, and prepared filtered sample containers **116** configured to receive portions of filtered sample for further sample preparation, such as by adding diluent, internal standard, reactive chemicals, or the like, or combinations thereof.

[0061] The system **100** is also shown including a filter probe storage **118** and a filter retainer **120**. The filter probe storage **118** includes a plurality of filter probes **104** for interaction with the autosampler arm to connect a filter probe **104** to an end **200** of the autosampler arm **102** (e.g., shown in FIG. **2**). An example filter probe storage **118** is shown in FIGS. **2** and **4**. In implementations, the filter probe storage **118** includes a rack **202** having a plurality of apertures **204** through a top surface **206** of the rack **202**. Probes of the filter probes **104** can be inserted into the aperture **204** to rest the filter of the filter probe **104** against the top surface **206**. During operation, in preparation to draw an unfiltered sample, the autosampler arm **102** can position the end **200** over a filter probe **104** and lower the autosampler arm **102** until the end **200** is secured within an end **208** of the filter probe **104**. A secured configuration between the end **200** of the autosampler arm **102** and the end **208** of the filter probe **104** is shown in FIG. 3B.

[0062] Referring to FIG. **5**, the filter retainer **120** facilitates removal of the filter probe **104** from the end **200** of the autosampler arm **102**, such as to remove the filter probe **104** following passage of the sample fluid through the filter. Alternatively or additionally, the filter retainer **120** facilitates removal of a filter from an end of a sample probe following dispensing of the filtrate from the sample probe (e.g., the sample probe described herein with respect to FIG. **8**A). The filter retainer **120** is shown including a shield **500** defining a front aperture **502** and a top portion **504** coupled with the shield **500**, where the top portion **504** defines a top aperture **506**. The front aperture **502** is configured to permit the filter probe **104** to pass through the shield **500** and into an interior region **508** of the filter retainer **120** defined by the shield **500**. For example, the front aperture **502** can include a first portion **502**A configured to conform to the generally tubular shape of the probe of the filter probe **104** and can include a second portion **502**B configured to conform to a generally disk-shaped filter of the filter probe **104** to permit the filter probe **104** to pass through the shield **500**. In implementations, the top aperture **506** extends to a front end **510** of the top portion **504** to intersect with the front aperture **502** to permit the end **200** of the autosampler arm to pass through the top aperture **506** when maneuvering to position the filter probe **104** through the front aperture **502** of the shield **500** and into the interior region **508**. Such a configuration of apertures can also facilitate removal of a filter from a bottom end of a sample probe, such as the sample probe described herein with respect to FIG. **8**A. When the system **100** is ready to remove the filter probe **104**, the autosampler arm **102** can lift vertically relative to the filter retainer **120** where the top portion **504** pushes against the filter of the filter probe **104** until the filter probe **104** is pulled from the end **200** of the autosampler arm **102**. In implementations, the filter retainer **120** includes a chute to pass the removed filter probe **104** into a waste container to maintain the filter retainer **120** in a ready state to receive another filter probe **104**.

[0063] In implementations, the system **100** can include a sensor to control operation of one or more functions. For example, referring to FIGS. **1**, **6**, and **7**, the system **100** is shown including a bubble sensor **122** positioned relative to the sample fluid line **106** and/or the filter probe **104** to detect that liquid is flowing through the filter probe **104**. The bubble sensor **122** can include, for example, one or more optical sensors, pressure sensors, ultrasonic transducers, conductivity sensors, or other sensors, and combinations thereof. If one or more bubbles are sensed by the bubble sensor **122**, the system **100** can reduce the rate of filtering (e.g., by controlling operation of the pump/vacuum source **108**) to control the rate of filtrate production, such as to minimize the amount of bubbles in the filtrate within the sample fluid line **106**. For example, the bubble sensor **122** can output a sense signal to a control system **600** communicatively coupled with the bubble sensor **122** and the pump/vacuum source **108**. Upon receipt of a sense signal indicative of the presence of bubbles that exceed a threshold bubble amount, the control system **600** can transmit one or more control signals to the pump/vacuum source **108** to reduce the rate at which sample is drawn through the filter probe **104**. In implementations, the control system **600** utilizes a feedback loop to maintain a desired flow rate of sample through the filter probe **104** while maintaining bubbles within the filtrate below a threshold value. The control system **600** can also be communicatively coupled with the autosampler arm **102** to control positioning of the autosampler arm **102** via motor control, such as to move the autosampler arm **102** between the filter probe storage **118**, the containers **110**, and the filter retainer **120**, or relative to other components of the system **100** described herein.

[0064] Referring generally to FIGS. **1-6**, an example filtration process includes positioning the end **200** of the autosampler arm **102** (e.g., via motor control by the control system **600**) above a filter probe **104** held by the filter probe storage **118**. In implementations, the control system **600** can execute software protocols to track availability of the particular positions of the filter probe storage **118** and the containers **110** to facilitate proper sample container locations for sample withdrawal and filtered sample deposit. The autosampler arm **102** then lowers onto the filter probe **104** to connect the end **200** of the autosampler arm **102** with the end **208** of the filter probe **104**. The autosampler arm **102** then raises the filter probe **104** from the filter probe storage **118** and positions the probe of the filter probe **104** above the next sample for filtration present in the sample containers **112**.

[0065] The autosampler arm **102** then lowers the probe into the appropriate sample container **112**, where the pump/vacuum source **108** operates to draw a sample into the probe and through the filter of the filter probe **104**, introducing filtered sample into the sample fluid line **106**. In implementations, the only sample fluids that enter the sample fluid line **106** are filtered samples that passed through the filter of the filter probe **104**. When the appropriate amount of sample is received through the filter probe **104** (e.g., determined via mass flow controller, timer, pump speed, etc., or combinations thereof), the system **100** positions the autosampler arm **102** to introduce the filter probe **104** to the filter retainer **120**. For instance, the filter probe **104** is introduced through the front aperture **502** and the autosampler arm **102** is raised to retain the filter probe **104** within the interior region **508**. By removing the filter probe **104**, the autosampler arm can dispense filtered sample through the end **200** (e.g., via operation of the pump **108**) without having the filtered sample pass through the filter of the filter probe **104**, thereby avoiding reintroduction of filtered particulates maintained in the filter probe **104** back into the filtrate during the dispensing procedure.

[0066] The autosampler arm **102** can be fitted with a separate dispensing probe or can directly dispense the filtered sample into the appropriate filtered sample container **114**. For samples that are to be further prepared prior to analytical determination, the samples can be transferred from the filtered sample container **114** to the appropriate prepared filtered sample container **116** for introduction of one or more additional fluids (e.g., diluent, internal standard, reaction chemical, or the like, or combinations thereof), however it is contemplated that such sample preparation could also be facilitated directly in the filtered sample container **114** without transfer to a separate container. Alternatively or additionally, the system **100** can operate to draw an unfiltered sample into the sample fluid line **106**, then connect the filter probe **104** onto the autosampler arm **102** for dispensing of a filtered sample into the filtered sample container **114**.

[0067] The system **100** can operate to prepare a single sample for analysis by filtering the sample, dispensing the filtered sample into the filtered sample container **114**, and then optionally further preparing the sample for analysis through addition of one or more additional fluids with the sample (e.g., in filtered sample container **114** or prepared filtered sample container **116**). The system **100** can also operate to filter a plurality of samples by filtering the samples and depositing the samples into individual filtered sample containers **114** prior to facilitating any further addition of fluids to the filtered samples. Alternatively or additionally, groups of samples can be handled individually to individually filter samples and add fluid(s) to the filtered sample individually before proceeding to the next sample, whereas other groups of samples can be handled to filter the group before adding further fluids to the filtered samples from the group. In implementations, the control system **600** facilitates sample preparation, such as by facilitating the order of samples processed, the desired end volume of samples, the standard type added to the sample, the number of samples processed from a filtered sample, or the like, or combinations thereof.

[0068] Referring to FIG. **7**, the system **100** is shown having a probe **700** coupled with the autosampler arm **102** and configured to receive a filter from a filter storage **702** onto a bottom end of the probe **700** following introduction of a sample into the probe **700** and/or the sample fluid line **106** attached to the probe. An example of the probe **700** is shown in FIGS. **8**A and **8**B having a top end **800** configured to secure to the autosampler arm **102** (e.g., via screw fit arrangement) and a bottom end **802** configured to secure to a filter **804**. The bottom end **802** can have a tapered outer surface **806** that tapers inward towards an inner fluid channel **808** as the probe **700** extends from the top end **800** to the bottom end **802** to facilitate placement of the bottom end **802** of the probe **700** into a top port **810** of the filter **804**. In implementations, the tapered outer surface **806** includes a chamfer **812** at the distal portion of the bottom end **802** to provide a range of alignment paths (e.g., an alignment path **814** is shown in FIG. **8**B) to insert the bottom end **802** into the top port **810** of the filter **804**. For example, during operation of the system **100**, the probe **700** is inserted into the sample container **112**, sample is drawn into the probe **700** through action of the pump/vacuum source **108**, and the autosampler arm **102** then positions the probe above the filter storage **702** to introduce the filter **804** onto the bottom end **802** of the probe **700**. Following attachment of the filter **804** to the probe **700**, the autosampler arm **102** can reposition the probe **700** to move the filter **804** to a predetermined location for dispensing of the filtrate, including but not limited to, the sample container **112**, a separate fluid container (e.g., the filtered sample container **114**, the prepared filtered sample container **116**), a sample port in fluid communication with the sample analysis system **704**, or the like, or combinations thereof. For example, the autosampler arm **102** can position the probe **700** to place a bottom port **816** of the filter **806** into contact with a sample port fluidically coupled with a sample preparation system and/or a sample analysis system (e.g., sample analysis system **704** shown in FIG. **7**), examples of which are described herein with respect to FIGS. **22**A through **25**B.

[0069] In implementations, the filter **804** includes a bottom port **816** through which the filtrate is dispensed, where the bottom port **816** can be positioned above a fluid container to dispense the filtrate into the fluid container, positioned to interface with a sample port fluidically coupled with a sample preparation system and/or a sample analysis system (e.g., sample analysis system **704** shown in FIG. **7**), or combinations thereof. For example, the autosampler arm **102** can position the probe **700** to place the bottom port **816** of the filter **804** over a fluid container to dispense filtrate into the fluid container and to introduce one or more additional fluids or chemicals to the filtrate, such as to add diluent, internal standard, reactant chemicals, or the like, or combinations thereof, to prepare the filtrate for sample analysis. An example is shown with respect to FIGS. **8**C through **8**E, where the autosampler arm **102** is shown in FIG. **8**C positioning the probe **700** within the sample container **112** to draw sample fluid **818** from the sample container **112** into the probe (e.g., through action of the pump/vacuum source **108**). In implementations, the autosampler arm **102** introduces the bottom end **802** of the probe **700** to a bottom end **820** of the sample container **112**, such as to ensure that no bubbles are drawn into the probe **700** during the sample drawing process. For instance, the bottom end **802** of the probe **700** can be positioned within the bottom 5% to 20% of the height of the sample container **112** measured from the bottom of the sample container **112**. In implementations, the probe **700** has a length of about 8 inches, however other lengths can be utilized without departing from the scope of the present disclosure, such as lengths less than 8 inches or length more than 8 inches, to facilitate fluid transfer with differing heights of sample containers.

[0070] Referring to FIG. **8**D, the probe **700** is shown holding the sample fluid **818** and having the filter **804** secured to the bottom end **802**. For instance, the autosampler arm **102** can move the probe **700** to the filter storage **702** to insert the bottom end **802** into the top port **810** of the filter **804**. The autosampler arm **102** is shown having positioned the probe **700** with the filter **804** to a second container (e.g., the prepared filtered sample container **116**) to inject filtrate **822** into the second container through the bottom port **816** of the filter **804**. Alternatively or additionally the second container can be brought underneath the probe **700**, such as through action of the container placement system **706**, the rotary uncapper **708**, or other container movement device. Referring to FIG. **8**E, the probe **700** is shown with the filter **700** having been removed (e.g., through interaction of the autosampler arm **102** and filter **804** with the filter retainer **120**). The probe **700** is positioned such that the bottom end **802** can introduce another fluid **824** (e.g., an internal standard, a diluent, a reactant, etc.) into the second container to mix with the filtrate **822** to provide a prepared filtrate **826** for analysis.

[0071] Referring again to FIG. **7**, the system **100** is shown including a container placement system **706** and a rotary uncapper **708** that coordinate operations to provide the sample container **112** in an uncapped state to receive the probe **700** (and/or the filter probe **104**) to draw sample from the sample container **112** into the probe **700** for filtering. The container placement system **706** is generally configured to move a sample container **112** from a first location, such as a sample rack on a laboratory bench, to the rotary uncapper **708** for removal of any caps, lids, septums, or the like, on the sample container **112** to make the interior of the sample container **112** available for access by the probe **700**. An example container placement system **706** is described further herein with reference to FIGS. **19**A through **21**B.

[0072] An example rotary uncapper **708** is shown in FIGS. **9** through **18**B. For instance, referring to FIG. **9**, the rotary uncapper **708** is shown diagrammatically including an uncapper head **900**, a rotary stage **902**, a container scanner **904**, and a motor system **906** operably coupled to the uncapper head **900** and the rotary stage **902** to drive rotational and/or vertical motion of the uncapper head **900** and the rotary stage **902** to facilitate uncapping and repositioning of the sample container **112** for access by the fluid probe **700**. The rotary uncapper **708** is shown in FIG. **10** with an open/uncapped sample container **112** with the probe **700** inserted therein and with the probe **700** being supported by the autosampler arm **102** coupled with a support **1000** configured to translate through a slot **1002** in an autosampler deck (e.g., via action of a motor (not shown)).

[0073] Referring to FIGS. **11**A and **11**B, the rotary stage **902** can begin with a fluid container **112** held in a container aperture **908** rotated in any position (e.g., **360** degrees of rotation about a vertical axis, such a first axis **1200** shown in FIG. **12**A) and then subsequently moves the fluid container **112** (e.g., via action by the motor system **906**) beneath the uncapper head **900** in preparation for removal of a cap **1100** positioned on a sample container base **1102**. In implementations, the fluid container **112** can be placed in the container aperture **908** automatically through action of the container placement system **706**, described further herein.

[0074] Referring to FIG. **12**A, the rotary uncapper **708** is shown moving the uncapper head **900** axially along a second axis **1202** to interact with the removable cap **1100** of the fluid container **112**. For example, the rotary uncapper **708** can transition the uncapper head **900** between a raised configuration (e.g., shown in FIG. **12**A) and a lowered configuration (e.g., shown in FIG. **12**B) axially along the second axis **1202** to bring the uncapper head **900** into contact with the cap **1100** in the lowered configuration For instance, referring to FIG. **12**B, the uncapper head **900** is shown surrounding the cap **1100**, with an interior surface **1204** of the uncapper head **900** interfacing with the cap **1100** to provide structural interaction such that rotation of the uncapper head about the second axis **1202** drives rotation of the cap **1100** about the second axis **1202**. In implementations, the rotary uncapper **708** detects the location of the fluid container **112** as the proper location for uncapping based on motor/encoder feedback. For instance, when the rotary uncapper **708** detects that the fluid container **112** is rotated about the first axis **1200** through action of the motor system **906** on the rotary stage **902** and is determined to be underneath the uncapper head **900** based on motor/encoder feedback, the motor system **906** can cause the uncapper head **900** to be lowered axially along the second axis **1202** into position surrounding the cap **1100** for removal. In implementations, the motor system **906** includes a lifting rod **1206** coupled with an uncapper head housing **1208** that supports the uncapper head **900** above the rotary stage **902**. Upon activation or deactivation of the lifting rod **1206**, the motor system **906** can move the uncapper head **900** axially along the second axis **1202**.

[0075] The rotary uncapper **708** is configured to reposition the fluid container **112** as needed to bring a label **1300** into a scanning area **1302** of the container scanner **904** to provide the system **100** with information about the fluid container **112**, the sample held therein, analyses to be performed on the sample, and the like, and combinations thereof. The label **1300** can include, but is not limited to, an image, a barcode (e.g., 2D barcode, matrix barcode, etc.), characters for character recognition, or the like, or combinations thereof. For example, referring to FIGS. **13**A and **13**B, the uncapper head **900** is configured to rotate the fluid container **112** in a close/tightening direction (e.g., clockwise about the second axis **1202**) to permit the container scanner **904** to bring the label **1300** into the scanning area **1302** of the container scanner **904** to permit the container scanner **904** to scan the label **1300** and generate a sense signal. The identifying information on the label **1300** can correspond to a table that stores the label identifying information with the corresponding information about the fluid container **112**, the sample held therein, analyses to be performed on the sample, and the like, and combinations thereof.

[0076] The rotary uncapper **708** can facilitate manipulating the fluid container **112** within the container aperture **908** to assist with removal and replacement of the cap **1100** on the sample container base **1102**, such as to hold the sample container base **1102** stationary or to counter-rotate the sample container base **1102** during cap removal and replacement. For example, referring to FIG. **14**, the rotary stage **902** is shown including grippers **1400** positioned adjacent the container aperture **908**. The grippers **1400** moveably engage and disengage with the sample container base **1102** (e.g., under control by the motor system **906**) to permit or prevent rotation or vertical movement of the fluid container **112** during operation of the system **100**. An example cap removal operation is shown with respect to FIGS. **15**A and **15**B, where the fluid container **112** is shown secured by the grippers **1400** to prevent rotation of the sample container base **1102** and with the uncapper head **900** rotatably removing the cap **1100** with each of an upward motion (e.g., axially along the second axis **1202**, through motion of the uncapper head housing **1208**) and a rotational motion (e.g., rotating around the second axis **1202**), holding the cap **1100** within the uncapper head **900**. In implementations, the rate of rotation and lifting of the uncapper **900** head matches the pitch of the threading on the sample container base **1102** and cap **1100**.

[0077] Referring to FIG. **16**, an example of the uncapper head **900** of the rotary uncapper **708** is shown including a suction cup **1600** within an area bounded by the interior surface **1204** of the uncapper head **900** to hold the cap **1100** in place within the uncapper head **900** while raised above the sample container base **1102**. For example, the suction cup **1600** can include a vacuum port **1602** fluidically coupled with a vacuum source (e.g., the pump/vacuum source **108**) to assist with holding the cap **1100** in place within the uncapper head **900**. The operation of the vacuum can be coordinated with rotation of the uncapper head **900** such that the vacuum is engaged during rotation to secure the cap **1100** during vertical cap removal and disengaged following rotation of the cap during replacement of the cap **1100** onto the sample container base **1102**. In implementations, the uncapper head includes a rigid end effector that is machined or otherwise constructed to match the profile of the cap. For example, the interior surface **1204** can include protrusions **1604** that complement protrusions (e.g., can be positioned between grooves formed by the protrusions) on an exterior surface of the cap **1100** to provide interlocking structures between the uncapper head **900** and the cap **1100** to assist with rotating the cap **1100** during rotational operation of the uncapper head **900**.

[0078] Following uncapping of the fluid container **112**, the rotary uncapper **708** can reposition the uncapped sample container base **1102** to provide access to the sample contained therein to the fluid probe of the autosampler (e.g., probe **700**, filter probe **104**, etc.). For example, referring to FIG. **8**, the rotary stage **902** is shown having repositioned the sample container base **1102** from underneath the uncapper head **900** to a position approximately **180** degrees rotated about the first axis **1200**, such as to be accessible by a fluid probe of the autosampler. In implementations, the rotary stage **902** can rotate **360** degrees about the first axis **1200** to reposition the fluid container **112** amongst a variety of positions.

[0079] The rotary uncapper **708** can also replace the cap **1100** onto the sample container base **1102**, such as following removal of sample by the fluid probe. Replacement of the cap **1100** can preserve remaining sample within the fluid container **112**, such as if replicate sample analysis is desired. For example, referring to FIGS. **18**A and **18**B, the cap **1100** is shown held by the uncapper head **900** (e.g., under vacuum by the suction cup **1600**) in preparation to replace the cap **1100** back onto the sample container base **1102** and subsequently lowered (e.g., along the second axis **1202**) and rotated (e.g., about the second axis **1202**) by the uncapper head **900** to replace the cap **1100** onto the sample container base **1102** while the grippers **1400** hold the sample container base **1102** stationary. In implementations, the rate of rotation and descent of the uncapper head **900** matches the pitch of the threading on the sample container base **1102** and cap **1100**. In implementations, rotation of the cap **1100** is torque-controlled by the motor system **908** to prevent over-or under-rotation.

[0080] The system **100** can facilitate automatic placement of the fluid container **112** into the container aperture **908** of the rotary uncapper **708** according to any suitable mechanism. For example, the system **100** is shown in FIGS. **19**A through **21**B including the container placement system **706** having a container gripper **1900** configured to move above a specific fluid container **112** (e.g., from a sample rack **1902**, shown in FIG. **19**A), position the container gripper **1900** around the fluid container **112** (e.g., shown in FIG. **19**B), lift the fluid container **112** (e.g., shown in FIG. **20**), reposition the fluid container **112** above container aperture **908** of the rotary uncapper **708** (e.g., shown in FIG. **21**A), and set the fluid container **112** within the container aperture **908** (e.g., shown in FIG. **21**B). In implementations, the container gripper **1900** includes pneumatically-powered tongs that close and open responsive to application or removal of a pneumatic fluid (e.g., air, inert gas, etc.) introduced to an inlet port **1904** of the container gripper **1900**. In implementations, the container gripper **1900** is supported by a support rod **1906** coupled with a motor system to move the container gripper **1900** through translational movement of the support rod **1906** (e.g., along a slot **2100** in an autosampler deck **2102** supporting the sample rack **1902**), vertical movement of the container gripper **1900** along the support rod **1906**, and rotational movement of the container gripper **1900** about an axis defined by the support rod **1906** to permit the container gripper **1900** to access any fluid container **112** in the sample rack **1902** and move the respective containers to the rotary uncapper **708**.

[0081] Once the system **100** has drawn a fluid sample into the probe of the autosampler, the filtrate can be directed to one or more locations for sample preparation, sample analysis, or combinations thereof. For example, the filtrate prepared by the filter probe **104** or from transfer out of the filter **804** via the probe **800** can be introduced to a collection tube (e.g., another sample container base **1102**) for introduction of one or more additional fluids. For instance, the system can introduce, through the probe **800** or another probe, one or more diluents, internal standard solutions, reagents, or combinations thereof, to the filtrate held in the collection tube. In implementations, the system **100** facilitates mixing of the filtrate with one or more mixing techniques including, but not limited to, magnetic stir plates and bars, introduction of bubbles via the probe **800** or another probe (e.g., as described in U.S. patent application Ser. Nos. 12,881,906 and 17/091,581, which are incorporated by reference herein), or combinations thereof.

[0082] Referring to FIGS. **22**A through **26**, the system **100** can direct the filtrate to a sample line for analysis by an analysis system, with or without additional sample preparation for the filtrate. For example, the system **100** is shown introducing the bottom port **816** of the filter **804** to a filter disengagement system **2200**, which can be coupled with the filter retainer **120** or separate therefrom, to introduce filtrate received from the filter **804** (e.g., via sample supplied through the probe **700** to the top port **810** of the filter **804**, not shown) to a sample fluid line **2202** for subsequent transfer from the filter disengagement system **2200** (e.g., for further sample preparation or for sample analysis, as described herein). For instance, the filter disengagement system **2200** is shown with the bottom port **816** of the filter **804** introduced to, and coupled with, a sample port **2204** configured to receive the filtrate from the filter **804** (e.g., through pushing of the sample through the probe **700** and into the filter **804**, via action of the pump/vacuum source **108**). The sample port **2204** is fluidically coupled with the sample fluid line **2202** to direct the filtrate received from the filter **804** into the sample fluid line **2202** to carry the filtrate from the filter disengagement system **2200** (e.g., via a sample outlet port **2206**).

[0083] Since the filter **804** is inserted into the sample port **2204** with sufficient force to prevent splashing of sample or dislodging the filter **804**, the filter disengagement system **2200** can include one or more systems to disengage the filter **804** from the sample port **2204**, such as to prevent the bottom port **816** of the filter **804** from sticking within the sample port **2204** following filtrate transfer. For instance, the bottom port **816** of the filter **804** can be introduced to the sample port **2204** with sufficient force to prevent spraying of the filtrate out from an area between the bottom port **816** and the sample port **2204**, however friction fit between the bottom port **816** and the sample port **2204** can cause the filter **804** to become stuck, where attempting to move the probe **700** away from the sample port following filtrate transfer could otherwise pull the probe **700** from the filter **804**, leaving the filter **804** attached to the sample port **2204**. For example, the filter disengagement system **2200** is shown in FIGS. **22**A through **23** having a disengagement structure to push the filter **804** away from the sample port **2204** following filtrate transfer, and is shown in FIGS. **24**A through **25**B having a disengagement structure to pull the sample port **2204** away from the filter **804** following filtrate transfer.

[0084] Referring to FIG. **22**A, the filter disengagement system **2200** is shown with the bottom port **816** of the filter **804** inserted within the sample port **2204**. The filter disengagement system **2200** includes a disengagement structure **2208** defining an aperture **2210** in which the sample port **2204** resides when the disengagement structure **2208** is in an engaged configuration. For instance, when the disengagement structure **2208** is in the engaged configuration, a bottom surface of the filter **804** can rest against a top surface **2212** of the disengagement structure **2208** while the bottom port **816** is positioned within the sample port **2204**. In implementations, the sample port **2204** is substantially level with the top surface **2212** of the disengagement structure **2208** when the disengagement structure **2208** is in the engaged configuration.

[0085] Referring to FIG. **22**B, the filter disengagement system **2200** is shown disengaging the filter **804** from the sample port **2204** by pushing the disengagement structure **2208** outwards away from the sample port **2204** which in turn pushes the bottom surface of the filter **804** away from the sample port **2204**. In implementations, the filter disengagement system **2200** includes a motor system **2214** coupled with the disengagement structure **2208** via a rod **2216** whereby extension of the rod **2216** upwards causes a proportional movement upwards of the disengagement structure **2208**. Referring to FIG. **22**C, the filter disengagement system **2200** is shown with the disengagement structure **2208** reset into the engaged configuration, but with the filter **804** pulled away from the filter disengagement system **2200**, such as through action by the autosampler arm **102** pulling the probe **700** away from the filter disengagement system **2200**. In implementations, the filter **804** can then be separated from the probe **700** via the filter retainer **120**, such as in preparation to affix a new filter **804** onto the probe **700** for subsequent sample handling.

[0086] The filter disengagement system **2200** can facilitate rinsing of the internal fluid passages, such as to rinse any residual fluids within or around the sample port **2204**, the sample fluid line **2202**, or the like, prior to introduction of a filtrate from a subsequent sample. For example, FIG. **23** shows introduction of a rinse fluid into the sample outlet port **2206** for passage into the sample fluid line **2202** to backflush the rinse fluid into the aperture **2210** around the sample port **2204**. The rinse fluid is then removed from the sample port **2204**, the sample fluid line **2202**, and the aperture **2210** through application of a vacuum to a fluid flush line **2300** in fluid communication with the aperture **2210**.

[0087] Referring to FIG. **24**A, the filter disengagement system **2200** is shown with the bottom port **816** of the filter **804** inserted within the sample port **2204** and with a disengagement structure **2400** to pull the sample port **2204** away from the filter **804** following filtrate transfer. The disengagement structure **2400** is shown defining an annular aperture **2410** formed around the sample port **2204**. The filter disengagement system **2200** is also shown having a housing **2402** defining a collar **2404** configured to fit within the annular aperture **2410** around the sample port **2204** when the disengagement structure **2400** is in an engaged configuration. For instance, when the disengagement structure **2400** is in the engaged configuration, a bottom surface of the filter **804** can rest against a top surface **2412** of the housing **2402** while the bottom port **816** is positioned within the sample port **2204**. In implementations, the sample port **2204** is substantially level with the top surface **2412** of the housing **2402** when the disengagement structure **2208** is in the engaged configuration.

[0088] Referring to FIG. **24**B, the filter disengagement system **2200** is shown disengaging the filter **804** from the sample port **2204** by pulling the disengagement structure **2400** downwards away from the top surface **2412** of the housing **2402** within the collar **2404**, which in turn maintains the the bottom surface of the filter **804** on the housing **2402** while the sample port **2204** is pulled away from the bottom port **806** of the filter **804**. In implementations, the filter disengagement system **2200** includes a motor system **2414** coupled with the disengagement structure **2400** via a rod **2416** whereby retraction of the rod **2416** downwards causes a proportional movement downwards of the disengagement structure **2400** while the housing **2402** remains stationary. Referring to FIG. **24**C, the filter disengagement system **2200** is shown with the filter **804** pulled away from the filter disengagement system **2200**, such as through action by the autosampler arm **102** pulling the probe **700** away from the filter disengagement system **2200** while the disengagement structure **2400** is in a disengaged configuration. In implementations, the filter **804** can then be separated from the probe **700** via the filter retainer **120**, such as in preparation to affix a new filter **804** onto the probe **700** for subsequent sample handling.

[0089] The filter disengagement system **2200** having the internal disengagement structure **2400** can also facilitate rinsing of the internal fluid passages, such as to rinse any residual fluids within or around the sample port **2204**, the sample fluid line **2202**, the collar **2404**, or the like, prior to introduction of a filtrate from a subsequent sample. For example, FIG. **25**A shows introduction of a rinse fluid into the sample outlet port **2206** for passage into the sample fluid line **2202** to backflush the rinse fluid into the aperture **2410** around the sample port **2204**. The rinse fluid is then removed from the sample port **2204**, the sample fluid line **2202**, and the aperture **2410** through application of a vacuum to a fluid flush line **2500** (e.g., shown in FIG. **25**B) in fluid communication with a rinse channel **2502** that fluidically couples with the aperture **2410** while the disengagement structure **2400** is in the disengaged configuration.

[0090] The system **100** can direct the filtrate to a sample analysis system for analytic determination of one or more components of the filtrate. For example, referring to FIG. **26**, the system **100** is shown with a first rotary uncapper system **708**A configured to handle a first sample **2600**A for transfer by a first probe **2602**A to a valve system **2604** in fluid communication with a sample analysis system **2606** (e.g., which can include the sample analysis system **704**). The sample analysis system **2606** can include, but is not limited to, an inductively-coupled plasma (ICP) analytical instrument, such as an ICP mass spectrometer. In implementations, the valve system **2604** is in fluid communication with the filter disengagement system **2200** to receive the filtrate passed therethrough (e.g., via the sample outlet port **2206**). The valve system **2604** can include one or more multiport valves configured to direct the filtrate to one or more additional locations, such as to a sample loop **2608** (e.g., to hold a desired amount of filtrate before transferring to the analysis system **2606**), to a waste location **2610**, or the like, or to introduce one or more fluids to the filtrate in an inline configuration of the valve system **2604** or another location, such as to introduce one or more reagents, internal standard solutions, diluents, or the like, or combinations thereof to provide a prepared filtrate sample. For example, the system **100** can introduce one or more reagents (e.g., acid(s)) to the filtrate prior to sending the sample to the analysis system **2606**. Alternatively or additionally, the system **100** can introduce one or more reagents to a fluid sample without filtering through the filter **804**, such as to measure an unfiltered acidified sample, which can be compared against analytic results of acidifying the filtrate from a fluid sample from the same fluid container **112**.

[0091] In implementations, the valve system **2604** can receive filtrate from sample containers **112** originating from more than one rotary uncapper **708**, such as where the analysis system **2606** can process a sample more rapidly than a sample can be handled by a given rotary uncapper **708** with subsequent filtration through the filter **804**. For instance, when filtering samples having a high amount of particulates, the system **100** may transfer the sample through the filter **804** at a slower rate than for samples having less particulate loads to avoid clogging of system components or developing high internal pressures, where the slower flow rates produce a filtrate at a rate less than the rate of sample analysis by the analysis system **2606**. For example, FIG. **26** shows the system **100** introducing filtrate from three separate probes (e.g., **2602**A, **2602**B, **2602**C) that take sample from three separate samples (e.g., **2600**A, **2600**B, **2600**C) handled by three separate rotary uncapper systems (e.g., **708**A, **708**B, **708**C) to the valve system **2604** to maintain a high uptime for the analysis system **2606**. While the system **100** is shown handling filtrate from three different sources, the system **100** is not limited to such configuration and can handle fluids from any number of sources, including less than three and more than three, without departing from the scope of the present disclosure.

[0092] Electromechanical devices (e.g., electrical motors, servos, actuators, or the like) may be coupled with or embedded within the components of the system **100** to facilitate automated operation via control logic embedded within or externally driving the system **100**. The electromechanical devices can be configured to cause movement of devices and fluids according to various procedures, such as the procedures described herein. The system **100** may include or be controlled by a computing system having a processor or other controller configured to execute computer readable program instructions (i.e., the control logic) from a non-transitory carrier medium (e.g., storage medium such as a flash drive, hard disk drive, solid-state disk drive, SD card, optical disk, or the like). The computing system can be connected to various components of the system **100**, either by direct connection, or through one or more network connections (e.g., local area networking (LAN), wireless area networking (WAN or WLAN), one or more hub connections (e.g., USB hubs), and so forth). For example, the computing system can be communicatively coupled to the autosampler arm **102**, the rotary uncapper **708**, the container placement system **706**, the filter disengagement system **2200**, the valve system **2604**, alternative or additional fluid handling systems (e.g., valves, pumps, etc.), other components described herein, components directing control thereof, or combinations thereof. The program instructions, when executed by the processor or other controller, can cause the computing system to control the system **100** (e.g., control positioning of the uncapper head, the rotary stage, or the sample probe, control movement of fluids via the sample probe, etc.), control operation of the container scanner, or the like, according to one or more modes of operation, as described herein.

[0093] It should be recognized that the various functions, control operations, processing blocks, or steps described throughout the present disclosure may be carried out by any combination of hardware, software, or firmware. In some embodiments, various steps or functions are carried out by one or more of the following: electronic circuitry, logic gates, multiplexers, a programmable logic device, an application-specific integrated circuit (ASIC), a controller/microcontroller, or a computing system. A computing system may include, but is not limited to, a personal computing system, a mobile computing device, mainframe computing system, workstation, image computer, parallel processor, or any other device known in the art. In general, the term "computing system" is broadly defined to encompass any device having one or more processors or other controllers, which execute instructions from a carrier medium.

[0094] Program instructions implementing functions, control operations, processing blocks, or steps, such as those manifested by embodiments described herein, may be transmitted over or stored on carrier medium. The carrier medium may be a transmission medium, such as, but not limited to, a wire, cable, or wireless transmission link. The carrier medium may also include a non-transitory signal bearing medium or storage medium such as, but not limited to, a read-only memory, a random access memory, a magnetic or optical disk, a solid-state or flash memory device, or a magnetic tape.

Conclusion

[0095] It will be appreciated that features described herein with respect to embodiments or implementations can be combined with any other feature or features described with respect to the same or alternative embodiments, unless context otherwise dictates, without departing from the scope of the present disclosure.

[0096] Although the subject matter has been described in language specific to structural features and/or process operations, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims.

What is claimed is:

1. An automated filtration system for sample preparation for chemical analyses comprising:
an autosampler arm configured to couple with a sample probe having a filter coupled to the sample probe, the autosampler arm configured to position the sample probe within a first sample container holding a fluid sample for filtering and subsequent analysis;
a pump/vacuum source configured to remove at least a portion of the fluid sample from the sample container and to transfer fluid sample through each of the filter and the sample probe to generate a filtrate; and
a control system communicatively coupled with each of the autosampler arm and the pump/vacuum source to cause the autosampler arm to position the autosampler arm adjacent at least one of a second sample container or a sample port in fluid communication with an analysis system and to cause the pump/vacuum source to dispense the filtrate into at least one of the second sample container or the sample port.

2. The automated filtration system of claim **1**, wherein the sample probe is directly coupled with the autosampler arm, and wherein the sample probe includes a bottom end positioned distal from the autosampler arm, the bottom end configured to secure to a fluid port of the filter.

3. The automated filtration system of claim **2**, wherein the bottom end includes a tapered outer surface that tapers inward towards an inner fluid channel through which the fluid sample is permitted to flow.

4. The automated filtration system of claim **3**, wherein the tapered outer surface further defines a chamfer at a distal portion of the bottom end for insertion into the fluid port of the filter.

5. The automated filtration system of claim **2**, wherein the filter includes a second port downstream from the first port relative to the sample probe, wherein the control system is configured to cause the autosampler arm to position the sample probe adjacent the sample port in fluid communication with the analysis system and to fluidically couple the second port with the sample port to dispense the filtrate from the second port into the sample port for analysis by the analysis system.

6. The automated filtration system of claim **5**, wherein the sample port is coupled with a filter disengagement system defining a housing configured to separate a bottom surface of the filter from the sample port while permitting coupling between the second port of the filter and the sample port.

7. The automated filtration system of claim **6**, wherein the filter disengagement system includes a disengagement structure coupled with the housing, the disengagement structure configured to extend away from the sample port to push the bottom surface of the filter from the sample port to permit decoupling of the second port of the filter and the sample port.

8. The automated filtration system of claim **6**, wherein the filter disengagement system includes a disengagement structure coupled with the sample port, the disengagement structure configured to retract away from the housing to pull the sample port from the second port of the filter while retaining the bottom surface of the filter on the housing to permit decoupling of the second port of the filter and the sample port.

9. The automated filtration system of claim **1**, wherein the sample probe is integrated with a bottom port of the filter, and wherein the filter includes a top port configured to detachably engage with an end of the autosampler arm.

10. The automated filtration system of claim **9**, wherein the pump/vacuum source is configured to draw the fluid sample through the sample probe and into the filter and to direct the filtrate into a fluid line fluidically coupled with the filter and the sample probe.

11. The automated filtration system of claim **10**, further comprising a filter retainer configured to remove the filter and integrated sample probe from the autosampler arm, the filter retainer defining a front aperture into which the filter and integrated sample probe is permitted to pass and defining a top aperture into which the end of the autosampler arm is permitted to pass, wherein upon lifting of the autosampler arm, the filter is held against an inner surface of the filter retainer and removed from the end of the autosampler arm.

12. The automated filtration system of claim **10**, wherein the control system is configured to cause the autosampler arm to position the end of the autosampler arm adjacent the second sample container subsequent to filter removal.

13. An automated filtration system for sample preparation for chemical analyses comprising:
an autosampler arm configured to couple with a sample probe having a filter coupled to the sample probe, the autosampler arm configured to position the sample probe within a first sample container holding a fluid sample for filtering and subsequent analysis;
a rotary uncapper including a stage configured to support the first sample container and an uncapper head configured to remove a cap from the first sample container prior to introduction of the sample probe to the first sample container;
a pump/vacuum source configured to remove at least a portion of the fluid sample from the sample container and to transfer fluid sample through each of the filter and the sample probe to generate a filtrate; and
a control system communicatively coupled with each of the autosampler arm and the pump/vacuum source to cause the autosampler arm to position the autosampler arm adjacent at least one of a second sample container or a sample port in fluid communication with an analysis system and to cause the pump/vacuum source to dispense the filtrate into at least one of the second sample container or the sample port.

14. The automated filtration system of claim **13**, wherein the sample probe is directly coupled with the autosampler arm, and wherein the sample probe includes a bottom end positioned distal from the autosampler arm, the bottom end configured to secure to a fluid port of the filter.

15. The automated filtration system of claim **14**, wherein the bottom end includes a tapered outer surface that tapers inward towards an inner fluid channel through which the fluid sample is permitted to flow.

16. The automated filtration system of claim **15**, wherein the tapered outer surface further defines a chamfer at a distal portion of the bottom end for insertion into the fluid port of the filter.

17. The automated filtration system of claim **14**, wherein the filter includes a second port downstream from the first port relative to the sample probe, wherein the control system is configured to cause the autosampler arm to position the sample probe adjacent the sample port in fluid communication with the analysis system and to fluidically couple the

second port with the sample port to dispense the filtrate from the second port into the sample port for analysis by the analysis system.

18. The automated filtration system of claim **17**, wherein the sample port is coupled with a filter disengagement system defining a housing configured to separate a bottom surface of the filter from the sample port while permitting coupling between the second port of the filter and the sample port.

19. The automated filtration system of claim **13**, wherein the sample probe is integrated with a bottom port of the filter, and wherein the filter includes a top port configured to detachably engage with an end of the autosampler arm.

20. The automated filtration system of claim **19**, wherein the pump/vacuum source is configured to draw the fluid sample through the sample probe and into the filter and to direct the filtrate into a fluid line fluidically coupled with the filter and the sample probe.

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