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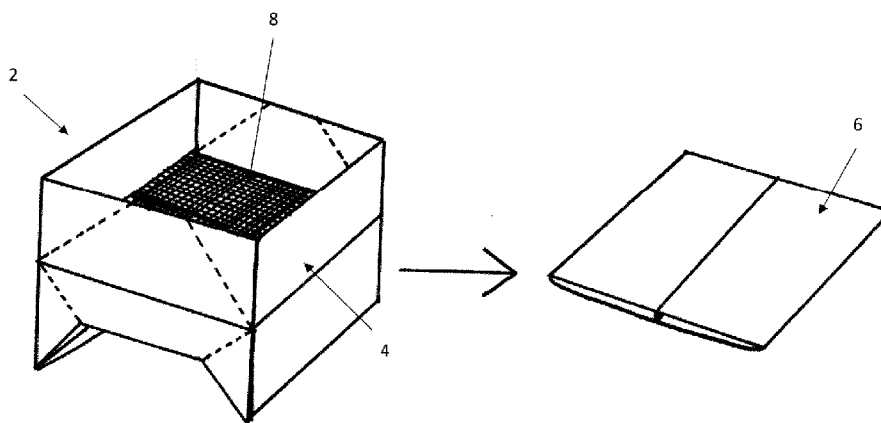


FIG. 1

(57) Abstract: A device for collecting contaminants from water samples is provided. The device includes a solid sorbent that collects and stores the contaminants from water samples. The solid sorbent is configured to allow for the preservation of the stored contaminants. The concentrations of the contaminants in the water samples are determined via analysis of the solid sorbent or via elution of the stored contaminants from the sorbent and analysis of the eluate solution.



**SYSTEM AND METHOD FOR PRESERVATION, TRANSPORT, AND
ANALYSIS OF WATER SAMPLES**

PRIORITY INFORMATION

This application claims priority from provisional application Ser. No. 62/327,503 filed April 26, 2016, which is incorporated herein by reference in its entirety.

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BACKGROUND OF THE INVENTION

The invention is related to the field of water quality monitoring, and in particular the invention describes technology to enable water samples to be preserved in a compact form that is suitable for storage and/or transport to centralized laboratories for chemical, microbial, or other analysis.

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The safety of drinking water is judged by its physical, chemical, and microbial characteristics. Drinking water must be free of pathogens, contain low levels of toxic chemicals, and be tasteless, odorless, and colorless. Water quality is assessed in terms key parameters for biological contamination, where coliform bacteria is used as a proxy for fecal contamination; physical contamination, by use of parameters such as turbidity and pH; and chemical contamination, where acceptable limits are specified for contaminants such as arsenic, fluoride, nitrate, pesticides, and heavy metals such as lead, nickel, and copper. Many of these contaminants, such as arsenic and heavy metal contamination, occur naturally, whereas other contaminants such as nitrate and pesticides results from human activities.

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Water quality monitoring is typically performed using field test kits, mobile/local laboratories, or more centralized government or commercial laboratories.

Field tests provide rapid results with minimal training, but the accuracy, throughput, and sample processing ability in the field is limited. On the other hand, centralized laboratories are relatively expensive and often involve transportation of significant volumes (e.g. 250 to 1000 milliliters (mL)) of water over long distances to urban areas
5 where these laboratories are located. This poses major difficulties on the ability to acquire water quality data. For example, field testing to quantify low levels (<100 micrograms per milliliter ($\mu\text{g}/\text{mL}$)) of arsenic contamination is cumbersome, and contaminants like mercury, lead, cyanide need to be analyzed in the laboratory. Testing for all the major types of pathogens is impossible in the field and even in the
10 laboratory; instead, total coliform bacteria are measured as a proxy indicator of fecal contamination. Field tests provide positive/negative or semi-quantitative results, and testing in centralized laboratories is required for accurate analysis. These challenges place major limitations on the ability to acquire water quality data and involve considerable fieldwork.

15 Although similar problems of water quality exist in many other parts of the world, these challenges are exemplified in the case of India. India's drinking water problems are grave in terms of both availability as well as quality. While increasing the volume of water available for drinking and other domestic consumption is not the focus of this technology, it should be noted that according to India's National Rural
20 Drinking Water Program (NRDWP), 30% of India's habitation get less than 40 liters (L) per capita per day (lpcd), the amount required to maintain acceptable level of individual health and sanitation. Added to this are the problems of water quality, which is our focus here. Out of India's 11,274,819 documented sources of drinking water, by the year 2013-14, water quality testing data was available for only
25 1,734,882 (15.38%) (see <http://indiawater.gov.in/IMISReports>). Of the tested sites,

8% were found contaminated with chemical, bacteriological, or other contaminants beyond acceptable levels set by the NRDWP. Much of this contamination is attributable to sources of water, as 77% of India's population obtains its drinking water supply from sources other than piped water such as hand pumps, tube and dug wells, tanks, ponds, springs, canals, and rivers. The most vulnerable 10-14% population is reported to drink from uncovered and untreated water sources.

India recognizes water as a public good and access to safe water for drinking, cooking and other domestic as well as livestock use as a fundamental right. It employs an elaborate regulatory machinery for the provision, security, and safety of water that includes roles and responsibilities at national, state, district, sub district, and village levels. The regulatory framework also defines a role for healthcare workers, NGOs, and public-private partnerships. That being said, however, the demand for water quality management far exceeds the shear capacity for testing samples, and the resources and knowhow of the local communities to deal with the results of such testing. The NRDWP reports confess that for the skeleton infrastructure of Water Testing Laboratories available at the district level, it is simply impossible to meet the overall need to test the total 0.5 million water samples each year, if India were to meet the set target of once a year chemical and twice a year bacteriological test.

One of the key challenges in meeting this target is that accurate quantification of many contaminants requires analytical equipment which is not cost-effective to deploy at the sub-district level where routine testing occurs. In particular, trace contaminants such as arsenic, heavy metals, and pesticides require quantification via methods such as atomic adsorption spectroscopy (AAS), inductively coupled plasma-optical emission spectroscopy (ICP-OES), inductively coupled plasma-mass spectrometry (ICP-MS), or gas chromatography-mass spectrometry (GC-MS) in order

to accurately detect contamination at their acceptable limits. These analytical instruments are present in state laboratory facilities, but require more capital investment and technical expertise than is available for district and sub-district laboratories. As a result, routine testing frequently quantifies only those contaminants
5 which can be detected using the methods available at the district and sub-district level, with limited ability to identify harmful levels of those contaminants which require analytical equipment that is only available at the state level.

When one considers these constraints for India and other locations, one use case which would benefit for improved sampling technology is the collection of
10 samples at local laboratories in a manner which makes them easy to transport to centralized laboratories with more advanced analytical equipment. While this is difficult to do with full-sized liquid samples due to their weight and the need for additional sample precautions such as acidification and/or temperature control, the ability to store contaminants in a solid matrix would facilitate easier transport between
15 laboratories via methods such as the postal service. In addition to transfer between labs, the ability to store contaminants in a compact solid matrix would facilitate storage within laboratory facilities so that samples taken over time can be analyzed at a later date if the need emerges. This utility has already been demonstrated for medical diagnostics through the use of dried blood spot (DBS) testing, where blood
20 samples are dried on a paper matrix, sent to centralized testing and storage facilities, and can be analyzed for small molecules and pathogens for as long as ten years. This ability to analyze samples of drinking water or other fluids at a different time or place would provide benefit to analytical applications in drinking water, environmental monitoring, and other applications.

SUMMARY OF THE INVENTION

According to one aspect of the invention, there is provided a device for collecting and releasing contaminants from water samples. The device includes at least one solid sorbent that is capable of adsorbing target contaminants, preserving the target contaminants for extended periods of time, and releasing the target
5 contaminants for subsequent analysis. Means for supporting or containing the at least one solid sorbent and facilitating rapid adsorption of the contaminants is provided. A package stores the at least one solid sorbent with adsorbed contaminants.

According to another aspect of the invention, there is provided a device for
10 collecting and releasing contaminants from fluid. The device includes at least one solid sorbent that adsorbs and releases target contaminants. Means for supporting or containing the at least one solid sorbent and facilitating rapid adsorption of the contaminants is provided. A package stores the at least one solid sorbent with adsorbed contaminants.

According to another aspect of the invention, there is provided a method of
15 collecting and releasing contaminants from water samples. The method includes providing a water sampling device having at least one solid sorbent, and exposing the device to a sample of water. Also, the method includes allowing the at least one solid sorbent to adsorb one or more contaminants from the water, and removing the device
20 from contact with the water. Furthermore, the method includes releasing the one or more contaminants from the at least one solid sorbent at a later time, and performing analysis on the released contaminants.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is schematic diagram illustrating a foldable container structure used in accordance with the invention to collect contaminants;

FIG. 2 is schematic diagram illustrating a tea bag arrangement used in accordance with the invention to collect contaminants;

FIG. 3 is schematic diagram illustrating an impregnated rigid or flexible materials accordance with the invention to collect contaminants;

FIG. 4 is schematic diagram illustrating a packed bed geometry arrangement used in accordance with the invention to collect contaminants;

FIG. 5 is a graph illustrating the adsorption isotherms of copper on cellulose, from experiments in which copper at various concentrations from 0.025mg/L to 5mg/L was adsorbed from 30mL of pH buffered deionized water using 0.15g GE Whatman Grade 1 Qualitative filter paper;

FIGs. 6A-6B are scanning electron microscopy (SEM) images illustrating the granular morphology and surface morphology of iron oxide xerogels, where the xerogels are synthesized via epoxide-assisted gelation using a metal chloride precursor (either iron(III) chloride hexahydrate or aluminum(III) chloride hexahydrate) dissolved in ethanol before the addition of an epoxide (propylene oxide), followed by gelation and drying at room temperature for 18 days before sputtering with gold and imaging via SEM;

FIG. 7 is a graph illustrating the Barrett-Joyner-Halenda (BJH) pore size analysis of iron oxide and alumina xerogels, where the xerogels are synthesized via epoxide-assisted gelation using a metal chloride precursor (either iron(III) chloride hexahydrate or aluminum(III) chloride hexahydrate) dissolved in ethanol before the addition of an epoxide (propylene oxide), followed by gelation, five solvent

exchanges in ethanol, drying for at least seven days at room temperature, and drying for three days at 130 degrees Celsius ($^{\circ}\text{C}$) to remove any residual moisture before BJH analysis via nitrogen adsorption and desorption;

FIG. 8 is a graph illustrating the adsorption isotherms of arsenic(III) on iron oxide xerogel at neutral and basic pH values, from experiments in which arsenic(III) (in the form of sodium arsenite) at various arsenic concentrations from 0.05 mg/L to 500 mg/L was adsorbed from 30 mL samples (with pH values modified via the addition of sodium hydroxide) onto iron oxide xerogels with sorbent masses from 23 to 102 mg (average mass 51 mg) over an adsorption period of at least 24 hours;

FIG. 9 is a graph illustrating the recovery of copper, nickel and lead from DOWEX G-26 ion exchange resin (commercially available from Dow Chemical Company) after dry storage for up to 4 months. Various amounts of resin, from 0.5g to 3g of resin were contacted with 250mL of water with 400 mg/L or 3200mg/L total dissolved solids and 0.250mg/L each of copper, nickel and lead. After adsorption, resin was blotted dry and allowed to dry at room temperature. After a certain time of dry storage, cations were eluted from the dry resin samples using 5 or 10% hydrochloric acid and the concentration of recovered cations was measured using ICP-OES

FIG. 10 is a graph illustrating the recovered arsenic concentration as a function of the initial arsenic sample concentration for iron oxide xerogels adsorbing arsenic(III) at neutral pH and desorbing the sampled arsenic at high pH, where arsenic(III) (in the form of sodium arsenite) was adsorbed from 30 mL samples onto iron oxide xerogels with sorbent masses from 38 to 61 mg (average mass 48 mg) over an adsorption period of at least 20 hours, dried and stored at room temperature for 12 to 34 days, and eluted from the dry xerogel samples via desorption into 30 mL of 0.1

molar (M) sodium hydroxide solution over a desorption period of 24 hours, with initial and recovered concentrations quantified via ICP-MS;

FIGs. 11A-11B is a table and graph illustrating the adsorption kinetics of copper onto DOWEX G-26 cation exchangeresin contained in different tea bag geometries made of propylene meshes and flexible epoxy adhesive. After fabrication, bags were held stationary in 250mL of stirring water with hardness 400mg/L and 0.250mg/L each copper, nickel and lead. Samples of solution were removed over the course of the experiment and the samples were analyzed using ICP-OES to generate concentration versus time curves for comparison of tea bag performance.

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DETAILED DESCRIPTION OF THE INVENTION

The invention describes a water quality monitoring paradigm using sampling technology, materials, and system-level protocols to enable dry sample preservation of water samples to facilitate easy ambient-temperature shipping, storage, and rapid processing at centralized laboratories to greatly improve the ability to monitor the water quality. The ability to easily store and ship water samples has the potential to open a new paradigm in water quality management. Dry water sample preservation techniques described here are expected to facilitate easy shipping, storage, and rapid chemical and microbial analysis of water quality in centralized laboratories.

Several approaches can be conceived for dry preservation of water samples. Commercially available dried blood spot (DBS) sorbents already used for chemical and microbial analysis in human blood samples could be applied to water sample analysis. Custom-designed sorbents could also be used for this purpose. For example, membranes or porous media can be functionalized with positive charge using

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polyethyleneimine to bind negatively-charged bacteria when water is flushed through. In addition, high-surface-area inorganic morphologies such as silica or metal-oxide xerogels frequently present charged sites that may change charge with pH and redox conditions. Also, polymers containing stationary charged groups, such as ion
5 exchange resins, can be used to adsorb positively or negatively charged species over a wide range of pH conditions. Water samples that are preserved in dry (or compact) state can then be analyzed using existing laboratory-based chemical and microbial analysis methods.

The key consideration in chemical preservation is to ensure a quantitative
10 relationship between the concentration of analytes in original water sample and the laboratory results from the preserved sample. On one hand, strongly adsorbing sorbents may be used to facilitate concentration of the chemical during filtration across the sorbent. On the other hand, sorbents can provide a surface for chemicals to precipitate or crystallize out when water evaporates.

15 The water sample to be analyzed is flowed through or contacted by a porous sorbent, where the porosity and dimensions of the sorbent are designed to ensure adsorption of the analytes of interest. It is well-known that the amount of analyte that can be adsorbed will depend on the nature of the sorbent, total surface area of the sorbent, volume of weight of the sorbent, volume of the water sample, concentration
20 of the analyte, pH, and any competing species in the water sample. A greater amount of sorbent or greater surface area of sorbent will result in greater amount of analyte adsorption. Furthermore, the diffusion and adsorption kinetics of the analyte will influence the amount adsorbed. Therefore, the porosity and dimensions (e.g. thickness or cross-section area) of the sorbent can be tuned to control the flow rate (for
25 example, driven by gravity) and the sorbent surface area to achieve rapid adsorption.

Examples of sorbents include cellulose (including filter paper) and surface modified cellulose (including cellulose nitrate and amidoximated cellulose), synthetic polymers such as polyamide, polyacrylamide and polyacrylonitrile, cation or anion ion exchange resins made of polystyrene-divinylbenzene or polyacrylic acid, chitin and chitosan, zeolites, mineral clays, lignin, xerogels with metal-oxide or silica backbone, activated carbon, carbon nanotubes, and composites of these materials.

As an explicit example of these sorbents, FIG. 6A-6B shows the granular morphology and surface morphology of iron oxide xerogels, as imaged by scanning electron microscopy (SEM). Xerogels are high surface area, nanoporous materials which can be easily and cheaply synthesized from precursor salts via epoxide-assisted gelation. Surface area and pore size distribution of fabricated iron oxide and alumina xerogels can be determined using Brunauer-Emmett-Teller (BET) and Barrett-Joyner-Halenda (BJH) analysis, as shown in FIG. 7. The surface area of the fabricated iron oxide xerogels is 330 square meters per gram of xerogel (m^2/g), while the alumina xerogels have a surface area of 460 m^2/g .

In many cases, complete adsorption of the analyte or analytes of interest can be desirable, but in some cases partial adsorption can be sufficient provided that it is consistent and a calibration can be established to relate the analyte concentration in the water sample to the amount adsorbed. Furthermore, given that certain conditions such as pH can affect analyte adsorption, chemicals (e.g. buffer) may be added to the water sample or incorporated into the device or sorbent to facilitate adsorption. Additionally, sensors that measure pH, turbidity, conductivity or other parameters may be incorporated in the device to provide additional information for device operation and monitoring purposes. Other mechanisms that are known to promote adsorption of different species on surfaces can also be used; for example, it is well-

known that charged species can be adsorbed on electrodes under the application of an electric potential, such as that used in capacitive deionization method for water desalination. In some cases, sorption in solids or liquids (which may be encapsulated in a matrix in the form of droplets) can be used instead of surface adsorption. For example, hydrophobic organic species in water can preferentially partition into oil or into some polymeric substances such as poly(dimethyl siloxane). Alternatively, adsorption (or sorption) may be achieved by immersing a sorbent material into a water sample, with or without stirring, for a sufficiently long period of time.

After adsorption is completed either by flowing the water sample through, by immersion, or any other means, the sorbent can be dried, or the residual water sample can be discarded, while retaining the desired analyte(s) on or in the sorbent. The sorbent may or may not be dried to remove water, stored, or transported to a different location. It is noted that the weight or volume of the sorbent (and any device the sorbent can be incorporated in) is less than that of the original water sample. By selecting materials with high adsorption capacities, the amount of sorbent needed for sampling is minimized. For example, commercial filter paper can adsorb 0.6 milligram (mg) copper per gram (g) of filter paper, as shown in FIG. 5, whereas cation exchange resins can exchange 2 moles of charge per liter of resin, which corresponds to different amounts of heavy metal cations depending on their charge. Due to their high surface area, iron-oxide xerogels reliably adsorb high amounts of arsenic at neutral pH (pH = 6 - 9), with arsenic capacities as high as 120 mg per g xerogel sorbent, as shown in in FIG. 8, As a result, heavy metal cations from a 1L water sample can be preserved on a sorbent such as a filter paper weighing 1g to 10g or ion exchange resins weighing 0.2g to 10 g. Arsenic can be preserved from a 1L water sample using xerogels weighing 0.1g to 5g. To retrieve the original

concentration of analyte(s), the sorbent can be directly analyzed using methods that accept the sorbent without further processing (e.g. X-ray Fluorescence (XRF), X-ray Photoelectron Spectroscopy (XPS), graphite-furnace atomic absorption spectroscopy (GFAAS), laser ablation mass spectrometry (LA-MS), laser-induced breakdown spectroscopy (LIBS), or elemental analysis following chemical and/or microwave digestion.

Alternatively, the analytes can be released into water or any liquid solution with controlled or known composition, so as to avoid interference with the analyte concentration measurement, such as deionized water, nitric, hydrochloric or sulfuric acid solution, or sodium hydroxide solution, with the desorbed analytes then quantified by use of methods such as ultraviolet/visible spectroscopy, flame atomic absorption spectroscopy (FAAS), ICP-OES, and ICP-MS. Examples of desorption methods include acidic pH dissolution of the sorbent (e.g. filter paper in nitric acid), acid pH elution (e.g. ion exchange resins in hydrochloric or nitric acid) or use of a pH where adsorption is no longer favorable (e.g. use of high-pH solutions such as sodium hydroxide to desorb anions from iron-oxide xerogels). For example, at least 80% of the amount of copper, lead or nickel adsorbed to ion exchange resins can be recovered from the sorbent after up to 4 months of dry storage at room temperature, as shown in FIG. 9. Similarly, the amount of arsenic recovered from iron-oxide xerogels after adsorption at neutral pH and desorption at high pH (by use of 0.1 M sodium hydroxide) follows a consistent power-law relationship over the entire concentration range of interest for drinking water samples (up to 5000 ppb) after dry storage periods of as long as 34 days at room temperature, as shown in FIG. 10. The amount or concentration of the analyte(s) measured by these methods can then directly correlate

with the analyte concentration in the original water sample, or it can be related to the concentration of the analyte in the original water sample using calibration.

Similarly, dry or compact preservation of microbial contaminants can enable (1) direct culture of microbes for analysis and (2) nucleic acid (DNA/RNA) analysis.

5 The process can involve concentration of the microbes by filtration or stirring and adsorption, or the use of cell lysis media to extract and adsorb nucleic acids or other biomolecules. For example, lysing the cells followed by filtering through a DNA-binding sorbent may be used to extract DNA and store it on the sorbent. The DNA can be released for analysis. Such sorbents and conditions to elute (remove) nucleic
10 acids and other molecules are known, for example, for sorption and elution of DNA on silica.

Alternatively, bacteria can be captured using positively charged sorbents or filtered through a porous sorbent and the captured cells can be lysed (burst) before DNA analysis; for example, microbes could be captured in hydrogel matrices which
15 facilitate their survival without allowing appreciable growth, such as methods that have been previously used for human cells. DBS cards and kits available for nucleic acid extraction and preservation may be adapted for analysis of water samples; for example, the FTA card marketed by GE Healthcare incorporates chemicals to lyse (burst) cells and bind their DNA, which can be preserved in dry state and is eluted
20 upon exposing the card to water. Similarly, filtering or sorption may be used for preserving viable *E. coli* that can be cultured after dry or wet storage in a volume or weight that is smaller than that of the original sample. Preservatives may be added to the water sample or on the sorbent. For example, trehalose is a suitable preservative that retains high viability of *E. coli* after air-drying.

Materials for preservation of water samples can be integrated into cost-effective, easy-to-use devices that can be implemented for water monitoring paradigm in large-scale deployments.

Sorbents are molded into a geometry or contained in a device, whose
5 geometry is optimized for fast contaminant absorption kinetics, for device operation time on the order of 10 minutes or less. Optimal geometries for rapid uptake may differ depending on the sorbent and so different geometries may be used for different sorbents. Additionally, any material used in the device must be compatible with the entire adsorb/store/release protocol. For example, kinetics of copper uptake on ion
10 exchange resins contained in polypropylene tea bags are negatively affected by the particle size of ion exchange resin; however, the opening size of the polypropylene mesh does not affect the kinetics significantly with all copper adsorbed within 10 minutes, as shown in FIGS. 11A-11B.

These devices should include the capability for collection of a prescribed
15 volume of water, and reuse for repeated collections without cross-contamination. This includes use of containers with set or marked volumes, and a disposable sorbent that may be removed from the container and shipped to a laboratory for analysis, with a new sorbent inserted for the next water sample. The sorbent can include filter paper, xerogels, polymers, or composites. Also, the sorbent can be of the form of a packed-
20 bed cartridge containing sorbent granules, a cartridge containing the sorbent coated onto a monolithic structure such as a honeycomb for well-defined flow, a rigid wafer consisting of a porous matrix impregnated with sorbent particles, a rigid wafer consisting of a porous matrix coated with a conformal layer of sorbent, a membrane consisting of a flexible matrix (such as paper or fabric) coated with a layer of
25 additional sorbent, or a membrane consisting of a flexible matrix (such as paper or

fabric) impregnated with sorbent (as particles or a coating), where the shape of the flexible matrices may be maintained during sample collection and shipping via a rigid support around the edges of the flexible matrix.

The inventive device includes the active sorbent material, which takes up the
5 contaminants from solution, and any supporting structure necessary for device
operation and maximum interaction between the sorbent surface and sample solution. The device can include multiple sorbents, each specific for the uptake of a specific
contaminant or class of contaminants (for example, cationic, anionic, and organic
contaminants). The sorbents may be mixed together, or they may be modularly
10 contained to allow for detachment of one type of sorbent and separate storage,
transport, release, and/or analysis of each contaminant. All materials contained in the
device are compatible with the entire sampling and preservation protocol.

The device is contained in clean packaging, such as an envelope or small thin
box. When ready for use, the user removes the device from the packaging and applies
15 the water sample to the device following an established protocol for the specified
time. The device may then be blotted of excess water using clean absorbents and/or
dried at room temperature, after which the device is deposited back in the original or
specifically provided packaging for clean long term storage and/or transportation.
Additionally, if the device does not need to be dried prior to storage and/or
20 transportation, the device may be directly deposited in the appropriate packaging
without drying or blotting.

FIG. 1 shows a foldable container 2 that can be compacted for transport,
shipped in an envelope, or fold into a shippable container itself used as a dry sampling
device. Here, the container 2 (or other structure, e.g. a sheet or spiral) can be placed
25 in a first configuration 4, such that a larger surface area is exposed to the water during

the collection step. In the first configuration 4, the exposed area to the water includes a solid sorbent 8 used to collect contaminants. Then, the container 2 would be transformed to a second configuration 6 after sample collection encapsulating the sorbent 8, such that its included volume is substantially smaller than the first

5 configuration 4 and therefore is more suitable for transport to a second location such as a centralized testing facility. Embodiments of such a container 2 include a paper ‘cell’ which can collapse to a near-flat packing; a creased sheet (e.g., a miura-ori pattern) that can be unfolded into a container containing water and then folded for transport. Therefore, the transformable element 6 can also form the sample collection

10 and capture container itself, or comprise a section of a container into which it is placed. Another embodiment would flow the water or other solution over and/or through the foldable element during the capture phase, and optionally later during the release phase.

FIG. 2 shows a tea bag arrangement 12 used in accordance with the invention.

15 A tea bag 12, encloses the sorbent material 14. The tea bag 12 is fabricated from layers of plastic mesh or fabric 16, which are glued, melted or sewed together into a bag structure of an optimized geometrical shape that retains flexibility. The tea bag 12 may be fabricated from chemically inert materials such as polytetrafluoroethylene (PTFE) or polypropylene (PP) so that contaminant adsorption and release occurs

20 consistently from the sorbent matrix 14 alone. The tea bag 12 can be either a free-standing structure, or have a handle or loop, which aids the user in using the tea bag to capture the contaminants. A single tea bag can contain multiple compartments for different sorbents.

In some embodiments, the sorbent support has a rigid or flexible handle, a

25 string, or other mechanism of holding that enables the sorbent to be immersed, stirred

in, or exposed to the water, such that the fingers of the operator do not touch the sorbent or the water sample and cause contamination.

FIG. 3 shows an impregnated rigid or flexible materials arrangement 20 used in accordance with the invention. Impregnated rigid or flexible materials, in which the sorbent 32 is contained in the structure of the porous supporting material. Deposition of the sorbent material is achieved through direct chemical reaction, inclusion of the sorbent material during supporting material synthesis or adhesion using an appropriate adhesive. Supporting materials include synthetic filtration membranes, and filter paper sheets. The supporting material can already be in the desired geometry (such as a filter paper disk) prior to deposition, or the entire impregnated material can be synthesized in bulk and cut or molded into the desired geometry post synthesis, such as a fibrous brush, woven mat or porous monolith.

FIG. 4 shows a packed bed geometry arrangement 36 used in accordance with the invention. The packed bed geometry arrangement includes a layer 38 of sorbent that is contained between two porous supports 40, 42 in a cylindrical or rectangular geometry. The packed bed 36 can include multiple layers of sorbents, which can be taken apart and dried, transported and processed separately.

The sorbent material can include coated structures, such as plastic meshes, porous strips, fabrics, cotton or synthetic fibers, porous monolithic structures or honeycombs. The materials to be coated may be in their desired form prior to being coated or be coated in bulk, allowing for manipulation of the coated material into the desired geometry after processing, such as a fibrous brush or woven mat.

Also, the sorbent materials can be formed into other high-surface-area structures. The sorbent material makes up the majority of the device, such that these devices may or may not have significant supporting material, unlike the other

embodiments aforementioned. Sorbents, such as polymers or xerogels, may be formed into structures during synthesis or molded/formed into a structure after synthesis.

Examples include sorbent polymer fibers or films that are woven into a mat or fabric, or cut into short sections and fused together at one end in a brush format; polymers or xerogels that are cast into a mesh mold during synthesis; and materials that are melted and extruded into different geometries through electrospinning or 3D printing. These high-surface-area structures can consist solely of the sorbent material, or of composite materials incorporating the sorbent and other materials (such as chitosan or other polymers) which confer flexibility, toughness, or other desired mechanical properties to the structure.

Application of the water sample to these devices may occur through processes such as 1) flow of solution through the device, 2) flow of solution over the device, 3) stirring the device within the water sample, or 4) static adsorption by placing the device within the solution or the solution within the device. Additional supporting equipment necessary to using the sorbent can be included with the original packaging. Examples include rigid outer supports for sorbent impregnated, coated or formed membranes, foldable flow-through application systems in a cup or box form for use of flow through or flow over geometries (such as membranes or meshes) and a handle or frame for materials to be rigidly supported while being stirred with water samples.

Moreover, the invention provides the capability for filtering and spatially defined deposition of chemical and bacterial contaminants from the prescribed volume of water may be achieved by use of different sorbents in the same device connected to a single or multiple water containers within the device. The amount of water sampled by each sorbent may be controlled by appropriate choice of resistance to fluid flow (pressure divided by fluid flow rate) for the fluid flow pathways

corresponding to each sorbent. A single-use sample collection “card” can be used by the invention, which receives the filtered/deposited constituents and can be mailed by post or the like. Also, there should be a requirement for only simple text or graphical instructions, and offering visual confirmation of successful use, and ease of

5 distribution and collection of the samples. The invention could be fabricated using environmentally sustainable materials, and using local manufacturing capacities.

In other embodiments of the invention, the inventive device can include at least one of a pH sensor, a salinity sensor, a turbidity meter, a chromogenic sensor, or other kinds of sensor. Moreover, the time frame when removing the inventive device

10 from the water to the analysis can range from 7-30 days. In addition, it can take between 3 and 15 minutes for the sorbent to absorb one or more contaminants from the water.

The invention reduces the cost and time limitations imposed by traditional water quality monitoring, by stably preserving contaminations in a compact and/or

15 dry form, which can be shipped to the advanced labs using the existing postal service structure and associated fees. Dry preservation enables the transport of samples from a range of distances to advanced laboratories, allowing more water sources can be accurately analyzed for complete contaminant arrays using standard analytical techniques, potentially increasing the monitoring capabilities and reach of centralized

20 bodies. Additionally, analysis protocols developed with the dry preservation technology complement the existing standard analytical procedures, so that the dry sampling technology aids the existing system.

Although the present invention has been shown and described with respect to several preferred embodiments thereof, various changes, omissions and additions to

the form and detail thereof, may be made therein, without departing from the spirit and scope of the invention.

What is claimed is:

What is claimed is:

CLAIMS

- 1 1. A device for collecting and releasing contaminants from water samples
2 comprising:
3 at least one solid sorbent that is capable of adsorbing target contaminants,
4 preserving the target contaminants for extended periods of time, and releasing the
5 target contaminants for subsequent analysis;
6 means for supporting or containing the at least one solid sorbent and
7 facilitating rapid adsorption of the contaminants; and
8 a package for storing the at least one solid sorbent with adsorbed
9 contaminants.

- 1 2. The device in claim 1, wherein the macroscopic surface to volume ratio of the at
2 least one solid sorbent is greater than 10 per mm, not including sorbent pore area.

- 1 3. The device in claim 1, wherein the at least one solid sorbent is separated after
2 contaminant adsorption.
1

- 1 4. The device in claim 1, wherein the at least one solid sorbent comprises particles
2 that are contained within a mesh or porous material.

1 5. The device in claim 1, wherein the at least one solid sorbent comprises particles
2 that are coated on a mesh, wire, brush, or fabric.

1 6. The device in claim 1, wherein the at least one solid sorbent is fabricated so that it
2 remains intact during analysis and assumes the desired geometry during adsorption,
3 storage, and release of contaminants without the need for additional device geometry
4 aside from the at least one sorbent and packaging.

1 7. The device in claim 1, wherein the containment means is a foldable vessel.

1 8. The device in claim 1, wherein the at least one solid sorbent comprises multiple
2 kinds of sorbents that adsorb different classes of contaminants.

1 9. The device in claim 1 further comprising at least one pH sensor, a salinity sensor, a
2 turbidity meter, or a chromogenic sensor.

1 10. The device in claim 1 further comprising one or more additional reagents for
2 controlled release into the fluid sample during contaminant adsorption, so as to
3 enhance contaminant adsorption.

1 11. The device in claim 1, wherein the at least one solid sorbent is in the form of a
2 porous composite with another material that provides mechanical support or other
3 desired mechanical properties.

1 12. A device for collecting and releasing contaminants from fluid samples
2 comprising:
3 at least one solid sorbent that adsorbs and releases target contaminants,
4 means for supporting or containing the at least one solid sorbent and
5 facilitating rapid adsorption of the contaminants; and
6 a package for storing the at least one solid sorbent with adsorbed
7 contaminants.

1 13. The device in claim 12, wherein the at least one solid sorbent comprises xerogel.

1 14. The device in claim 13, wherein the xerogel comprises an iron oxide matrix.

1 15. The device in claim 12, wherein the at one least solid sorbent material comprises
2 ion-exchange resin.

1 16. The device in claim 15, wherein the ion-exchange resin comprises a copolymer
2 incorporating polystyrene and divinylbenzene.

1 17. The device in claim 13, wherein at least one solid sorbent material is cellulose,
2 either untreated or with modification to enhance adsorption or desorption.

1 18. The device in claim 13, wherein the at least one solid sorbent is incorporated into
2 modules which can be removed from a sampling geometry after adsorption of the
3 contaminant.

1 19. A method of collecting and releasing contaminants from water samples
2 comprising:
3 providing a water sampling device having at least one solid sorbent;
4 exposing the device to a sample of water;
5 allowing the at least one solid sorbent to adsorb one or more contaminants
6 from the water;
7 removing the device from contact with the water;
8 releasing the one or more contaminants from the at least one solid sorbent at a
9 later time; and
10 performing analysis on the released contaminants.

1 20. The method in claim 19, wherein the device is packaged for storage or
2 transportation before the release step.

1 21. The method as in claim 19, wherein the device dries after the removal step and
2 before the release step.

1 22. The method as in claim 19, wherein the duration between the removal step and
2 the analysis step is at least 24 hours.

1 23. The method as in claim 19, wherein the duration between the removal step and
2 the analysis step is at least 7 days.

1 24. The method as in claim 19, wherein the duration between the removal step and
2 the analysis step is at least 30 days.

1 25. The method in claim 19, wherein the at least one solid sorbent comprises at least
2 one of an ion exchange resin, xerogel, or cellulose.

1 26. The method in claim 19, wherein the at least one solid sorbent absorbs
2 multivalent cations, organic molecules, arsenic, fluoride, chromium, multivalent
3 anions, viruses, bacteria, protozoa, parasitic organisms, nucleic acids, and proteins.

1 27. The method of claim 19, wherein the device is stored in a package to prevent
2 contamination.

1 28. The method in claim 19, wherein the one more contaminant is adsorbed by
2 manually stirring the device in the sample.

1 29. The method in claim 19, wherein the one or more contaminants are adsorbed by
2 flowing the sample through the device.

1 30. The method in claim 19, wherein the one or more contaminants are adsorbed by
2 immersing the device in the sample.

1 31. The method in claim 19, wherein the one or more contaminants are released by
2 flowing a release solution through the device.

1 32. The method in claim 19, wherein the one or more contaminants are released by
2 immersing the device in a release solution.

1 33. The method of claim 19, wherein the one or more contaminants adsorption step
2 requires less than 15 minutes.

1 34. The method of claim 19, wherein the one or more contaminants adsorption step
2 requires less than 3 minutes.

1 35. The method of claim 19, wherein at least 80% of the one or more contaminants in
2 the sample are adsorbed and released.

1 36. The method of claim 19, wherein the amount of target contaminants in the sample
2 and the amount that is released is consistent.

1 37. The method in claim 19, wherein the device is transported to another location
2 after adsorption for storage or analysis.

1 38. The method in claim 37, wherein the device is transported via the postal service
2 or a commercial shipping service.

1 39. The method in claim 19, wherein the device is stored at the same location after
2 adsorption for analysis at a later date.

1 40. The method in claim 19, wherein the device utilized is the device described in
2 claim 1.

1 41. The method in claim 19, wherein the device utilized is the device described in
2 claim 12.

1 42. A method of collecting and releasing contaminants from water samples
2 comprising:
3 providing a fluid sampling device containing at least one solid sorbent;
4 exposing the device to a sample of fluid;
5 allowing the at least one solid sorbent to adsorb one or more contaminants
6 from the fluid,
7 removing the device from the fluid;
8 releasing the one or more contaminants from the at least one solid sorbent; and
9 performing analysis on the one or more contaminants.

1 43. A method of collecting and releasing contaminants from water samples
2 comprising:
3 providing a fluid sampling device containing at least one solid sorbent;
4 exposing the device to a sample of fluid;
5 allowing the at least one solid sorbent to adsorb one or more contaminants
6 from the fluid;
7 removing the device from contact with the fluid; and

- 8 performing direct analysis on the at least one solid sorbent to determine the
- 9 one or more contaminants adsorbed on the at least one solid sorbent.

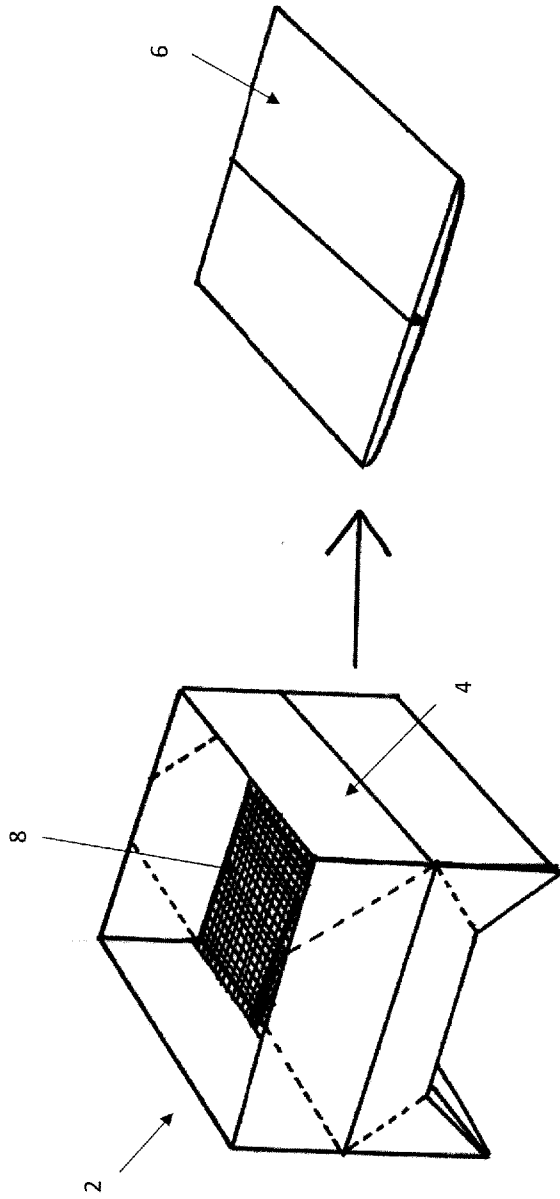


FIG. 1

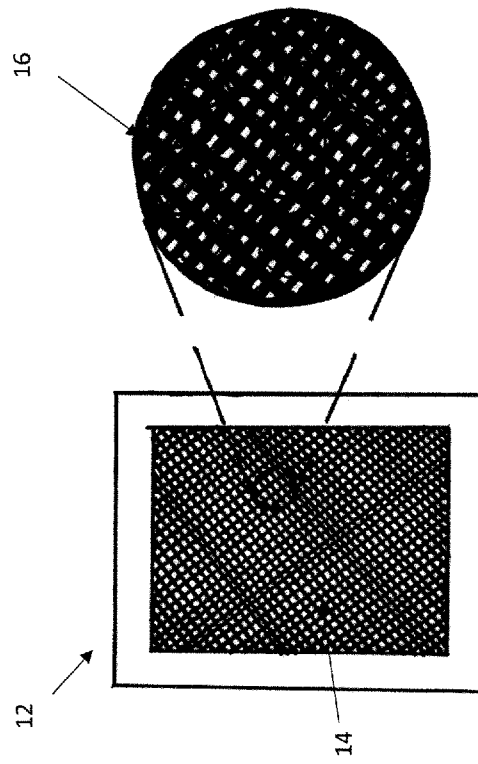


FIG. 2

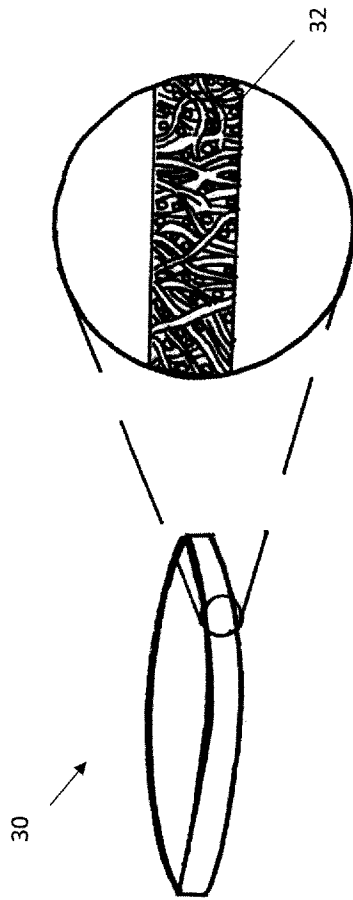


FIG. 3

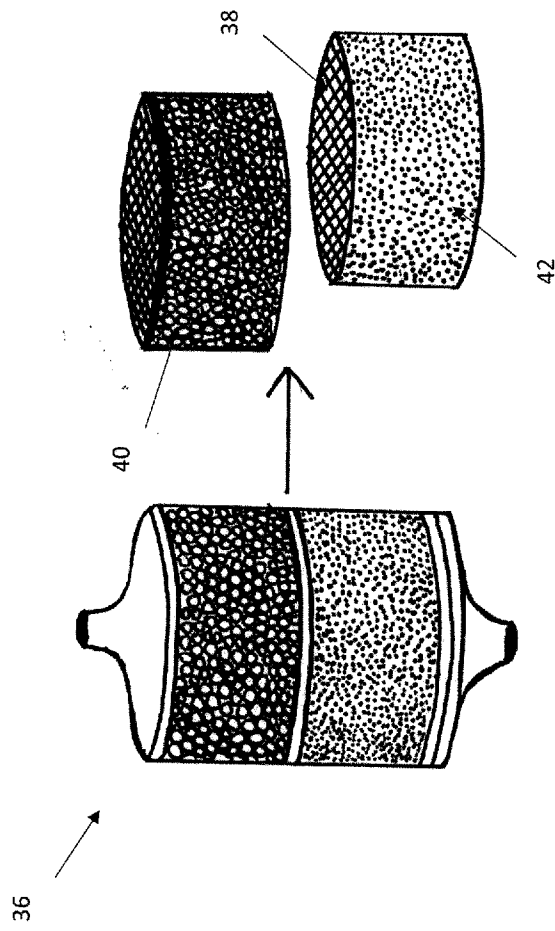


FIG. 4

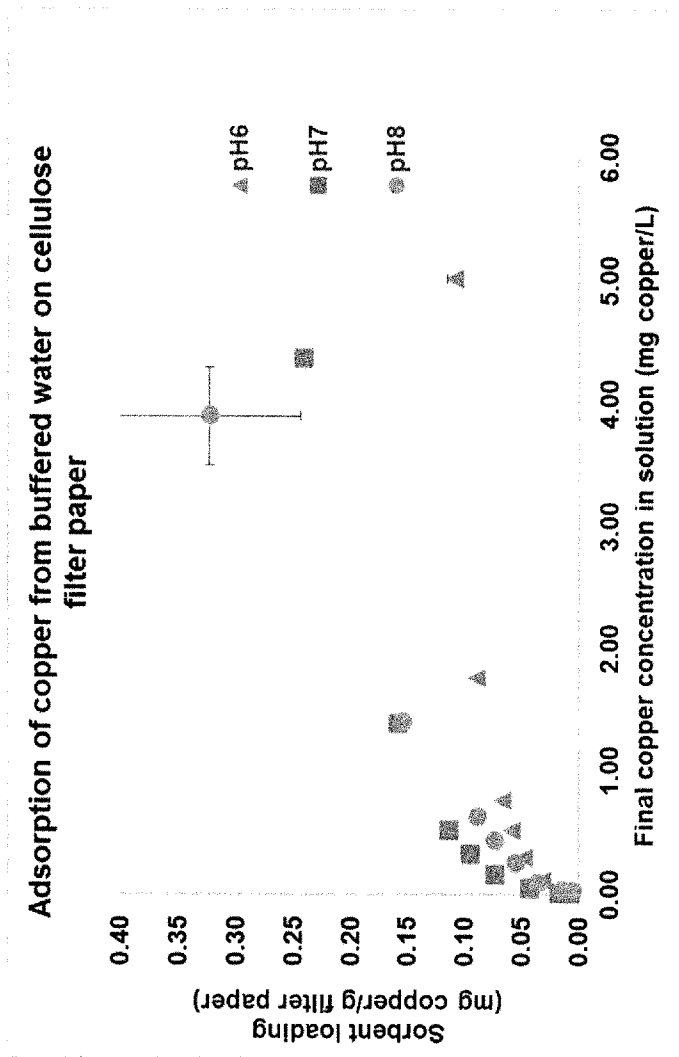


FIG. 5



FIG. 6B

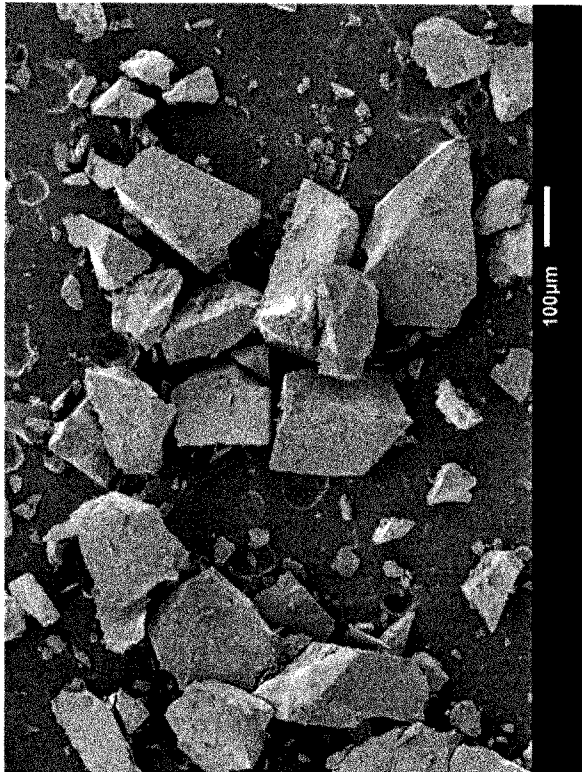


FIG. 6A

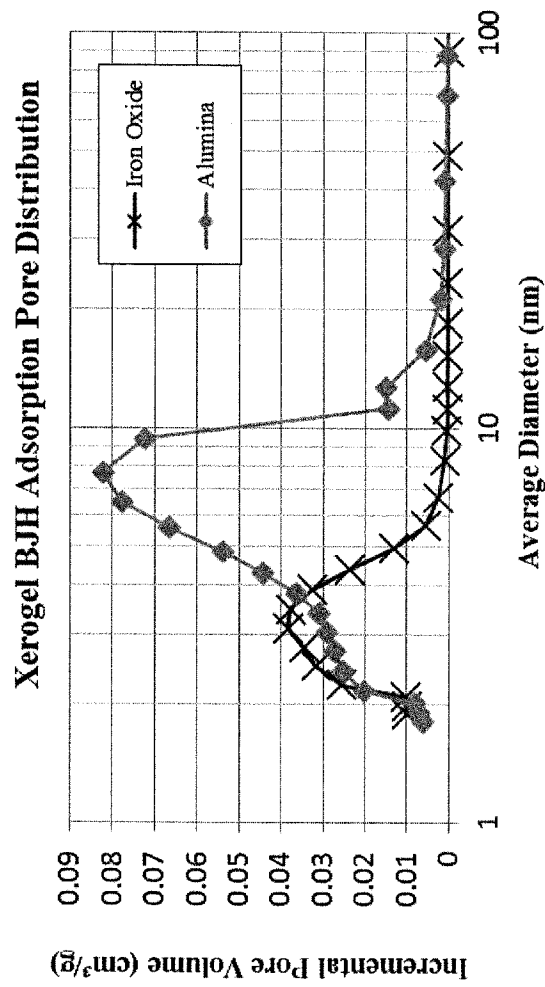


FIG. 7

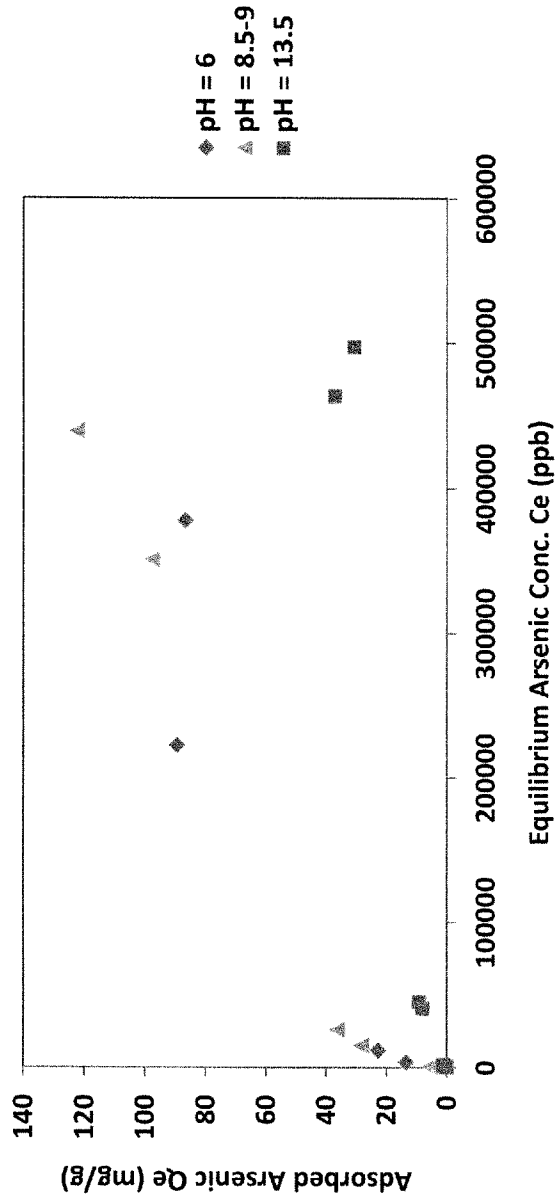


FIG. 8

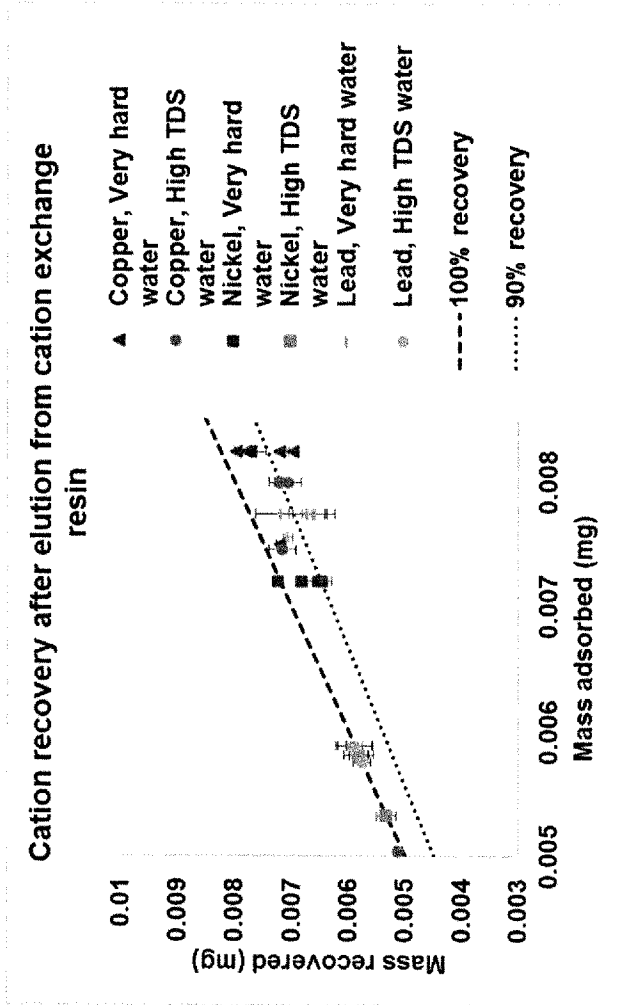


FIG. 9

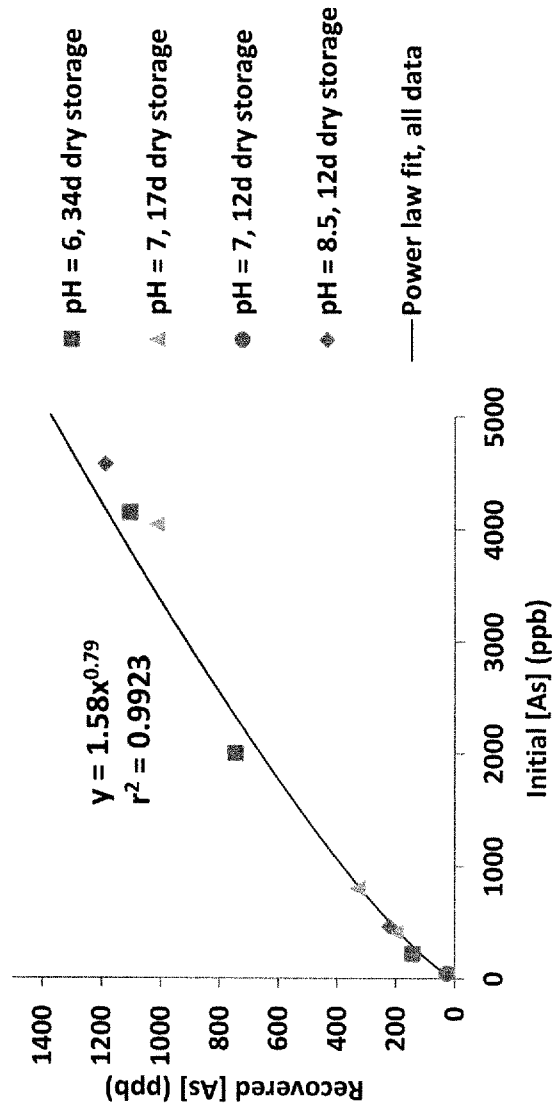


FIG. 10

Copper removal from very hard water using different tea bag geometries

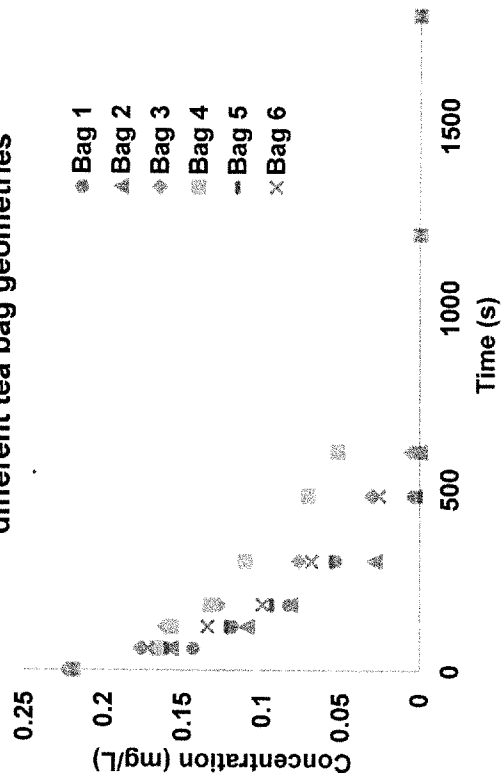


FIG.11B

Tea bag #	1	2	3	4	5	6
Resin size (µm)	650	650	650	300-400	650	650
Bag mesh size (µm)	400	300	150	150	400	400
Bag shape	Rectangle	Rectangle	Rectangle	Rectangle	Long rectangle	Circle

FIG. 11A