

New Technologies for Water and Wastewater Treatment: A Survey of Recent Patents

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Abstract: The concern over increasing needs for drinking water and awareness for development of systems to improve water quality both for drinking purposes and for effluents from wastewater treatment and industrial facilities have provided incentives to develop new technologies and improve performance of existing technologies. In this paper, the patents on treatment of water and wastewater approved during the period from 1999 to 2007 were reviewed. The patents surveyed were classified into two groups as technologies for water purification systems for drinking water, and technologies for treatment of wastewater. An assessment of the current and future outlook for development of new technologies, methods of treatment, equipment and instruments which can be used for water and wastewater treatment applications are presented.

Keywords: Water treatment, water filtration, ultrapure water, wastewater treatment, ion exchange, disinfection, sorption, membrane filtration, nanofiltration, wastewater.

1. INTRODUCTION

Water is an essential substance for living systems as it allows the transport of nutrients and waste products in living systems. Research shows a clear correlation between diseases and the amount and types of fluids consumed, health-promoting properties of nutrients which can be added to water, optimal intake levels, and consumption patterns. Although three quarters of the Earth's surface is covered with water, most of that water is not suitable for human consumption. Today, hundreds of millions of people in vast regions of the world do not have access to water to meet their basic needs. Natural disasters also create conditions which limit the availability of water that is suitable for human consumption. Industrial processes use significant amounts of water which require treatment before discharging to surface water systems. Municipal wastewater treatment systems discharge their effluents which often impact the aquatic organisms. This paper provides a survey of new developments and innovations relative to water treatment for drinking purposes and wastewater treatment during the period from 1999 to 2007. For drinking water treatment, the recent technological advancements relate to primarily filtration (media filtration and membrane systems), disinfection processes, ion exchange, and carbon adsorption processes. For wastewater treatment, a significant majority of recent developments relate to biological processes and advanced treatment technologies such as adsorption. A review of the recent patents show innovative designs for treatment units, efficient approaches for water quality, as well as nanotechnology applications for removing impurities and disinfection purposes.

2. WATER TREATMENT SYSTEMS FOR DRINKING WATER

The general treatment of drinking water takes place in several steps to remove dissolved and suspended solids. The treatment processes may include processes such as flocculation, sedimentation, and media filtration to remove colloidal and suspended solids; ion exchange, carbon adsorption, and membrane processes to remove dissolved solids; and a disinfection step often achieved by chlorination, ozonation, and ultraviolet radiation (UV). Drinking water is obtained either from surface water or ground water aquifers. Figure 1 presents the general schematics of conventional treatment processes for drinking water treatment depending on the source water characteristics. The main concerns with surface water aquifers are the suspended solids and organic matter which may be present due to storm water runoff. Therefore, presedimentation, coagulation or coarse filtration processes are generally used for water treatment followed by disinfection. The main concern with the ground water aquifers which are used as drinking water sources are the presence of dissolved contaminants such as salts, organics, or gasses. As a result, in general aeration is used to remove dissolved gasses followed by softening to remove dissolved salts prior to disinfection. Regardless of the water source, when there is a need to further remove dissolved organics; air stripping, ion exchange, carbon adsorption, or membrane filtration processes may be used. A review of the recent patents show innovative design schematics for unit processes, efficient systems for water quality and quantity management, and nanotechnology applications. A significant amount of patents relate to filtration (media filtration and membrane systems), disinfection processes, ion exchange, and carbon adsorption technologies.

2.1. Filtration Systems

Filtration systems can be divided into several categories depending on the type of the media used for filtration and the

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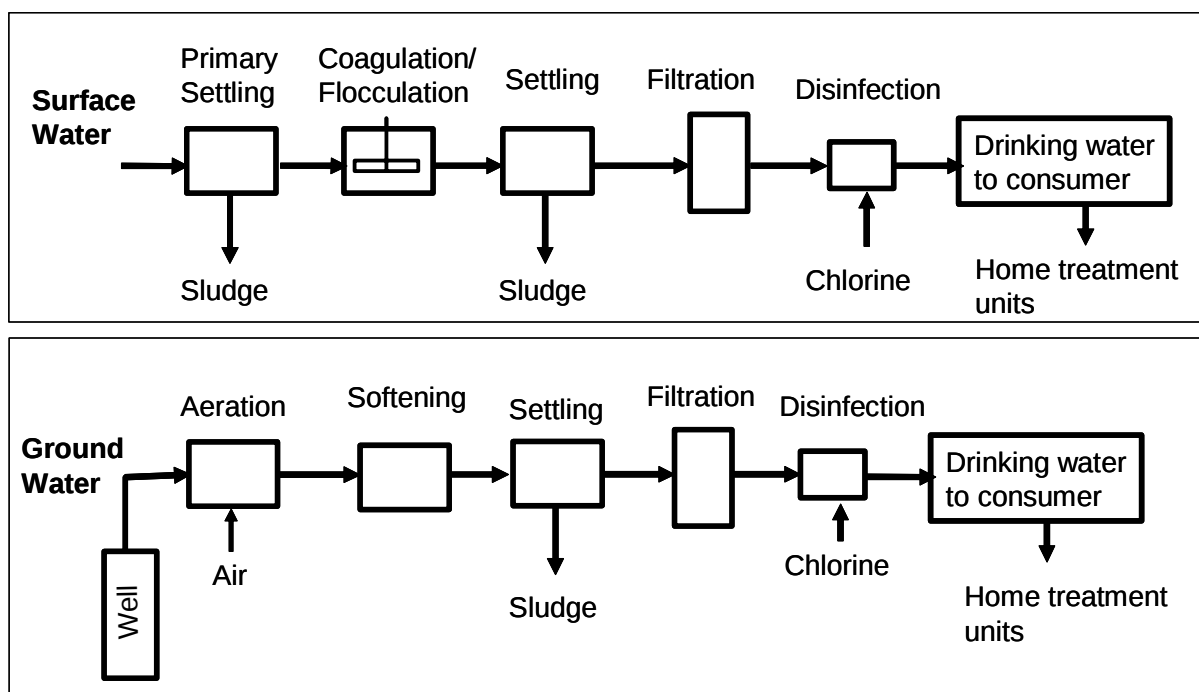


Fig. (1). Typical processes diagrams for water treatment.

size of the contaminants to be removed from water. The following sections present a review of the recent advancements that relate to different types of filtration systems used for drinking water treatment.

2.1.1. Media Filtration

Media filters remove suspended solids from water. Media filters are often constructed using one or more layers of sand, gravel, anthracite, and other inert media. As the water moves through filter media, suspended particles are trapped within the filter. The top layer removes organic compounds, which contribute to taste and odor. Most particles pass through surface layers but are trapped in the pore spaces and/or adhere to particle surfaces within the media.

Figure 2 present the compact treatment system developed by Wang [1]. The mineral filtering apparatus removes solids, chemicals, and pesticide residues, and adds nourishing elements to the water. The process includes multiple filtering steps, such as a gravity filter, ion exchange, sterilization unit, deodorizing segment, and a section for releasing minerals to water. As the raw water flows from top to bottom, it is treated by each step by filtration, deodorization, ions exchange, sterilizing, and magnetizing processes which improve the water quality suitable for drinking. The treated water contains minerals as nutrients for human consumption.

2.1.2. Membrane Filtration

Membrane filtration is a general term used for a number of different separation processes. The membrane acts as a filter that allows water flow through, while removing suspended solids and other substances. Membrane process can be pressure driven or dependent on electrical potential gradients, concentration gradients, or other driving forces. Pressure-driven membrane processes include microfiltration

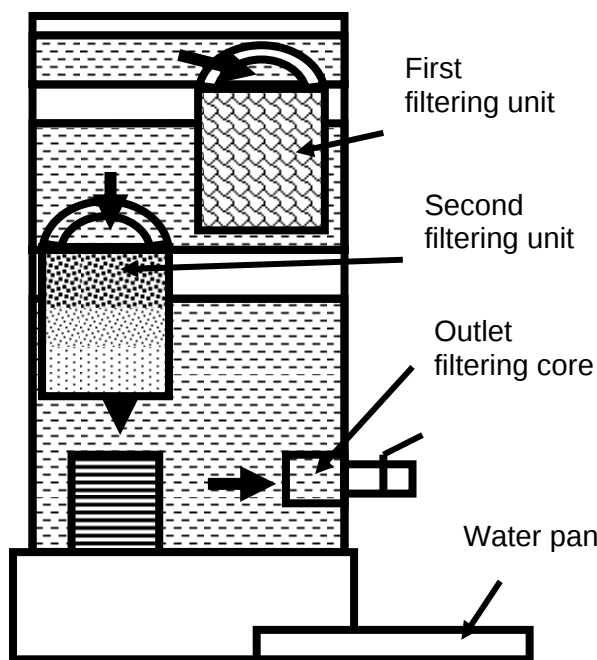


Fig. (2). Mineral filtering apparatus, adapted from US 6013180 [1].

(MF) and ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). MF and UF are characterized by their ability to remove suspended or colloidal particles via a sieving mechanisms based on the size of the membrane pores relative to that of the particulate matter. NF and RO constitute the class of membrane processes that is most often used in applications that require the removal of dissolved contaminants, as in the case of softening or desalination. Membranes, particularly those with molecular weight cutoffs in the range of 100 to 500 Daltons, are very effective for removing salts and organic compounds. Conventional water purification filters comprise polyolefin or polyester fabric or

felt, or dry or wet non-woven fabric or felt, span-bonded non-woven fabric or felt, equivalents thereof and active carbon materials or zeolite supported between the fabric or non-woven fabric or felt. For conventional water purification filters, it is necessary to form non-woven fabric or felt into a specific shape and also to provide support for zeolite or active carbon within the treatment cartridges.

Baird [2] disclosed a water purification system consisting of a two-stage reverse-osmosis filtration process utilizing a carbon block pre-filter and an RO filter using an annular design. The RO filter, which is positioned downstream from the carbon filter, may be formed around a perforated section of the central tube. An inlet enables unpurified feed water to flow into the carbon filter. The first channel, consisting of an annular surface in the carbon filter and an outer surface of the central tube, enables water to flow into the RO filter. Yoon *et al.* [3] developed nanofiltration membrane based water purifier without the need for a storage tank. The water purifier uses a nanofiltration membrane filter as the main filtering section and does not require a storage tank for containment of the purified water. In reverse osmosis systems, membrane fouling due to deposition of materials such as calcium and magnesium ions and salts on the membrane surface is an operational concern. Fouling of the membrane reduces the membrane flux, therefore, reduces the efficiency of the water purification system. Tonelli *et al.* [4] disclosed a method for producing high purity water using dealkalization and a double pass reverse osmosis membrane system with enhanced membrane life. The treatment method involves coagulant addition; membrane filtration; ion exchange for dealkalization; decarbonation; and pH adjustment. A second membrane module produces high purity water with a resistivity greater than 0.8 microhm-cm.

Pipes [5] devised a parallel desalting (PDS) unit comprising of a hybrid membrane softening (MS) system for demineralizing water for residential and commercial application. Parallel desalting is capable of producing soft water without the use of salt, or any other liquid chemical reagent normally used for pH adjustment in industrial membrane and precipitation processes. The PDS process balances the operation of a RO (potable water) membrane unit with a tubular microfiltration (MF) (wastewater) membrane unit. The optimum operational applications for the PDS system is about 90 percent of a potable, slightly brackish water supply; and a 100 percent reusable effluent for downstream recycling.

2.1.3. Filtration Cartridges

Some water filters use a replaceable filter element which removes solid matter. The filter element has a limited service life, requiring frequent replacement. A combination water filter tank was designed by Chang and Chuang [6] to remove settleable solids from water. The system could be used prior to filtration units to extend the service life of filter cartridges. The combination water filter tank allows the solid matter to settle to the bottom while the water passes through different segments of the tank which are separated by three transverse partition boards. Filter cartridges are also used in medical devices such as dialysis systems. Dialysis systems used for patients requiring hemodialysis or peritoneal dialysis involves pumping a large volume of dialysate through a dialyzing

device. In these filters, the used dialysate is generally discarded after a single pass through the filter. More recent dialysis devices allow pumping a fixed volume of dialysate through a dialyzing device, whereupon the used dialysate flows through a filter cartridge and is then returned to a dialysate reservoir for reuse. Fluid flow through a powdered filter medium in a filter cartridge is not laminar and results in a condition known as wicking or short circuiting. Wicking occurs when the fluid flows in the direction of least resistance which tends to be areas between the inner wall of the tubular housing and the powdered filter medium. Wicking results in the fluid bypassing the majority of the surface area of the granular filter medium. Thompson [7] developed filter cartridge assemblies with a tubular housing which minimized the short circuiting. The cartridge assemblies include sections with different filter media within the housing (i.e., an activated carbon section, an immobilized enzyme section, a powdered alumina section, a zirconium phosphate section, and a sodium zirconium carbonate or a mixture of hydrous zirconium oxide of the acetate form and sodium zirconium carbonate section).

2.1.4. Hybrid Filtration Systems

Technologies which combine coarse filtration with membrane filtration processes offer ease of operation and optimize the benefits of both types of filtration systems. Rhee [8] invented a water purifier which enables a used filter to be replaced with ease. It also allows replacing the used filter without having to shut off the water inlet port. Aalto *et al.* [9] disclosed improvements for the filtration unit of an earlier water treatment system. The system includes two compartments (i.e., a primary and a secondary unit) in a built-in manner in the same frame. The water moves by gravity from the primary chamber to the secondary unit where a thin film (filter) made of plastic is located. The main characteristic of this system is that underneath the primary space there is an accessory space that has an essentially smaller cross-section to keep the filter surrounded by unclean water.

Archer [10] developed a drinking water filter which can remove major contaminants from tap water and other drinking water sources, and adjust pH. The water filter contains a cylindrical cartridge with sponge filters used as dividers between different layers of filtration material and along a length of the cartridge. The sponge filters remove large and small sediments from 1 to 100 microns in size and greater. The filtration material includes a layer of granulated zinc and copper alloy, a fine mesh carbon block, a layer of granulated ion exchange resin, a layer of granulated activated carbon and layer of granulated activated calcite. The carbon block and the granulated carbon are used for removing chlorine, odor, color, cysts, protozoa and organic contaminants such as pesticides, herbicides, arsenic, mercury, and trihalomethanes. The zinc and copper alloy removes chlorine and heavy metals in the water and reduces bacteria in the water. The calcite is used to adjust the pH in the filtered water when the pH is below neutral.

2.2. Disinfection Systems

Typically, the last treatment process for drinking water treatment is the disinfection. Disinfection is used to

deactivate any pathogens which pass through the filters. The pathogens found in water include viruses, bacteria such as *Escherichia coli*, *Campylobacter* and *Shigella*, and protozoans such as *G. lamblia* and other *Cryptosporidia*. Disinfection can be accomplished in a contact tank by using a chemical disinfecting agent. The most common disinfectants include chlorine or its compounds such as chloramine or chlorine dioxide. Disinfection processes may also use other oxidants such as ozone, and UV radiation.

2.2.1. Combined Filtration and Disinfection Systems

Microorganisms can gradually adjust different environmental conditions and become resistant to disinfectants. World Health Organization recommends 0.5 ppm chlorine levels in drinking water. *Cryptosporium* can be resistant to 3% chlorine for 18 hours, and it is also resistant to UV radiation and ozone. In addition, microorganisms such as *Giardia* and *Cryptosporium* have a spore stage and the spores are smaller in size than the organisms. Lindqvist and Sparrman [11] invented a filtration/disinfection system for water purification consisting of two units. The first unit comprises of a filter which contains a filter bed of zeolite. This unit is connected to the second unit which is equipped with a UV lamp. Filtration step removes *Cryptosporidium* by passing water through the bed of zeolite consisting of at least 50% natural zeolite and radiating the water with UV-light. The system also includes a bag filter between the filter unit and the UV unit to capture particles after back flushing of the filter.

Hackett and Kingrey [12] invented a treatment system for treating fresh water in a cost effective manner to mix the disinfectant with water. The invention includes a water storage tank connected to a water source, a chlorination device connected to the water storage tank, a media filter partially contained within the water storage tank and a pump connecting the media filter vessel with the water storage tank. Flow through the chlorination device is regulated to provide adequate amounts of disinfectant to be released in tablet form. Adams [13] also developed a portable water filtration and disinfection device which uses UV as the disinfectant. The device includes a filtration system with at least two filters selected from the group including UV filters, activated carbon filters and reverse osmosis filters, depending upon the filtration needs of the user. The portable water filtration device also includes a battery unit connectable to an AC power source or to a solar panel for charging the battery to power the UV filter and the external pump for moving water into and through the portable water filtration device. Typically, the disinfection using UV radiation involves sheet flow for a thin layer of water flowing slowly under UV light. The microbial growth near the UV lamps reduces the effectiveness of UV disinfection process. Evans [14] disclosed a system for eliminating or inhibiting the growth of microorganisms using ultraviolet radiation and vortex type turbulence for water flow as shown in Fig. (3). This device allows easy maintenance of the UV light sources.

2.2.2. Disinfection Systems

Water distribution pipes between the treatment facilities and point of use may be several hundreds of meters long.

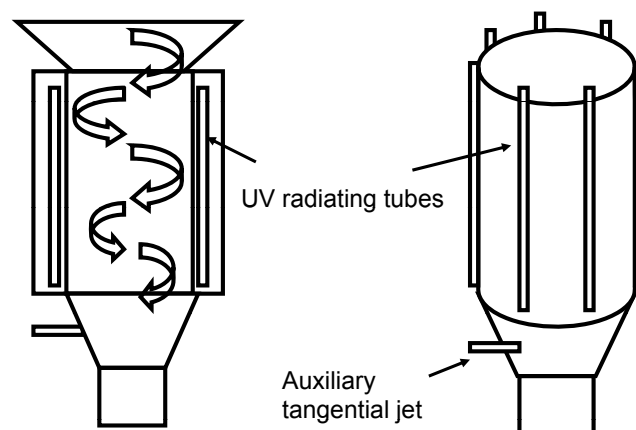


Fig. (3). Ultraviolet radiation treatment system, US 7217358 [14].

Impurities, metals dissolving from pipe materials, biofilm growth on pipe surfaces may contaminate the treated water. Biofilm forming in water distribution and storage systems is difficult to eliminate and provides a constant source of bacteria. Knapp and Morris [15] devised a cartridge that can fit into a conventional water filter housing and releases a dose of disinfectant (i.e., chlorine dioxide), into a water treatment system. The cartridge is filled with a water filtration/oxidation media comprised of a mixture of an inert filler material and a chemical composition that releases chlorine dioxide on contact with water. The concentration of the chlorine dioxide released into the water, as well as the duration of the release, may be varied by the selection of the media and amount of the filtration/oxidation media. Dendrimers are highly branched organic molecules with three dimensional structures. They are considered an important area of nanotechnology due to their specific physical and chemical characteristics. King and Hill [16] synthesized a dendrimer complex comprising a dendrimer and an antimicrobial agent which can be placed directly into a fluid to inhibit growth of microbes. The bacteria are removed from water by a bactericide placed in the dendrimer and allowing the water to contact with the dendrimer. After the antimicrobial agent is dispensed, the dendrimer complex can be removed and recycled to add functional groups to the dendrimer.

2.2.3. Dechlorination System

Residual oxidants remaining in the water may interfere with the final use of the water. Atnoor *et al.* [17] disclosed a process for removing strong oxidizing agents from liquids and, more particularly, to an apparatus and process for substantially reducing chlorine concentration in water. The process comprises of an input stream with chlorine concentration of between about 0.95 ppm and about 1.50 ppm; UV irradiation of the input stream to reduce the first chlorine concentration by about 76% to about 82%, and passing the first product stream through a softener unit for substantially reducing the chlorine concentration.

2.3. Ion Exchange, Water Softening and Sorption Systems

Dissolved solids in water can be removed by chemical processes such as ion exchange, precipitation, and carbon

adsorption as well as the physical separation by membrane filtration systems (i.e., RO).

2.3.1. Ion Exchange Systems

Ion exchange resins used for water softening can be divided into two categories as cationic and anionic resins. Cationic resins contain negative ionized groups capable of exchanging cations, and anionic resins contain positive ionic groups capable of exchanging anions. There are also amphoteric resins, which contain both anionic and cationic groups bound to the same lattice and resins (i.e., chelating or sequestering groups), capable of fixing particular ions. An ion exchange process takes place according to an equilibrium reaction between two solutions with different ionic concentrations. The ion exchange technologies currently available for the softening or demineralization of water for industrial use involve a cyclic process consisting of a production phase, during which treated water (demineralized or softened), and a regeneration phase, during which the exchanging resins are regenerated. The cyclic functioning of ion exchange plants is a drawback for these systems. Becucci [18] developed a system for use in ion exchange resin plants that allows the plant to operate continuously. The plant tank is divided into two separate compartments that work simultaneously. One compartment is used for water demineralization while the other compartment regenerates the ion exchange resins. Ion exchange filters are also used in fuel cells. In a fuel cell system, a liquid medium such as purified water is used for cooling or humidification of the fuel cell. When the liquid medium is circulated over the long term, due to ion separation from the casing of the fuel cell or eluting materials from various hoses or pipes, concentration of impurities in the liquid medium is gradually increased, which results into clogging or corrosion of the pipes. Takemoto and Suzuki [19] developed an ion exchange filter system to reduce ions contained in a liquid medium used in a fuel cell system. The invention employs an ion exchange filter apparatus, which can easily set a split flow ratio of the liquid medium flowing in the ion exchange filter and a bypass circuit. The devised system also allows replacement of the ion exchange filter efficiently.

2.3.2. Activated Carbon Systems

Removal of dissolved organics from water is often accomplished by activated carbon. Activated carbon is produced from a variety of carbon-containing raw materials, such as coal, wood and coconut shells. The unique properties of activated carbon relate to the carbon-based structure, which is highly porous over a broad range of pore sizes from visible cracks and crevices to cracks and crevices of molecular dimensions. Intermolecular attractions in these smallest pores result in adsorption forces, which cause condensation of adsorbate gases or precipitation of adsorbates from solution into these molecular scale pores. McLaughlin [20] developed a method for oxidizing carbon adsorbable organic compounds in a controlled manner within a bed of activated carbon. The bed of activated carbon is exposed to a source of molecular oxygen, such as air, and is controlled within a temperature range whereby the molecular oxygen is slowly oxidizes the activated carbon. Under the controlled set of conditions, the activated carbon oxidizes organic compounds present within the activated carbon bed. This technique has

widespread application for the controlled destruction of organic vapors and liquids by activated carbon and applications for the regeneration of spent activated carbons containing previously adsorbed organic compounds. Hokkiri-gawa *et al.* [21] have disclosed a water purification filter which can be formed by applying RB ceramics and/or CRB ceramics as a moldable carbon material. The RB ceramics and/or CRB ceramics of 10 to 2,000 angstroms in pore diameter and 0.1 to 1.1 cubic centimeters per gram in pore volume are used as an absorption and filtration material. Mitchell *et al.* [22] also disclosed a new filter system and materials which is comprised of a carbonized and activated lignosulfonate coated particles which can remove microorganisms from water. Cooper *et al.* [23] developed nanostructured material comprising defective carbon nanotubes chosen from impregnated, functionalized, doped, charged, coated, and irradiated nanotubes. The nanostructured material can be used for the purification of fluids, such as liquids and gases including applications for water purification. The defective carbon nanotubes contain a lattice distortion defect in at least one carbon ring.

2.3.3. Innovative Mixtures for Removing Dissolved Metals

Arsenic and metal ions may be present in groundwater naturally. Santina [24] developed a technology to remove arsenic and total organic carbon (TOC) from drinking water or wastewaters by using finely divided metallic iron in the presence of powdered elemental sulfur or other sulfur compounds such as manganese sulfide, followed by an oxidation step. A premix may be prepared by adding the iron, sulfur and oxidizing agent to water in a predetermined pH range. Use of various gradations and mixtures of the sulfur-modified iron (SMI) premix have been successfully demonstrated to remove arsenic (arsenite and arsenate); disinfection byproducts and precursors; copper; chrome VI; sulfate; and chlorinated solvents including trichloroethene. SMI premix has been manufactured using a wetted but non-fluid mix at room temperature and at elevated temperature. Spent SMI can be recycled as a non-hazardous material as feed material to a steel production facility.

2.4. Portable Water Treatment Systems

Some of the recent inventions for water treatment relate to compact systems which are portable. Carlotto [25] invented a compact water treatment system with various components (i.e., prefilters, osmotic membrane filters, pump) all of which are contained in an enclosure. The enclosure includes compartments to accommodate the components which are connected so that there is no need for piping. The system also includes a carbonation device that is connected to a bottle of carbon dioxide to carbonate the water.

Tanner *et al.* [26] also developed a portable water purification kit. The kit comprises of two containers, the first container for receiving untreated water, and a second container for receiving purified water and a dispensing spigot. A flocculant is mixed with water in the first container, produces partially purified water with solid matter (which is formed due to flocculation step). The second filter comprising of carbon removes the solid matter in the water coming from the first container.

2.5. Bottled Water

The consumption of bottled water has been increasing in the recent years. Oxygen enhanced bottled water, also referred to as super oxygenated water, has been claimed to have increased health benefits for athletes. DeWald [27] invented a method and apparatus for producing super-oxygenated water for human consumption. The method involves forcing atmospheric air through a filter to remove impurities, exposing the filtered air to ultra violet light to cleanse the air, and to form ozone and oxygen in the air, forcing the filtered air, ozone, and oxygen into a stream of flowing water to dissolve said air, ozone, and oxygen in said water, and spraying the stream of water having air, ozone, and oxygen dissolved therein into a vessel under high pressure.

2.6. Treatment Systems for Producing Ultrapure Water

The pharmaceutical industry requires various degrees of purified water for use in drug manufacture, injection of drugs, irrigation, and inhalation. The United States Pharmacopoeia (USP) has developed standards for specific quality of water used in the pharmaceutical industry, including purified water, sterile purified water, water for injection, sterile water for injection, sterile bacteriostatic water for injection, sterile water for irrigation, and sterile water for inhalation. Typically, sterile water for injection is used to dilute drugs which will be introduced into the bloodstream. Furukawa and Okumura [28] developed a system to produce ultrapure water. The system includes a heat exchanger, a UV oxidation chamber, an ion exchange unit, and a membrane filtering device. Water can be sterilized by either feeding bactericide at the membrane filtration step or alternatively by feeding the water through the heat exchanger and the UV oxidation apparatus. Arba *et al.* [29] developed a water treatment system and process for removing weakly ionized and/or organic materials from the water by pH adjustment. The innovative aspects of the invention include its ability to substantially reduce or eliminate the presence of weakly ionized and/or organic materials and chloramines. As shown in Fig. (4), the water treatment system includes processes selected from a group of treatment options consisting of a media filter unit, a water softener unit, a dechlorination unit, and combinations thereof. A second water treatment unit includes single or multi staged RO units. An electrodeionization unit may be used in the water treatment system, in place of or in series with the RO unit(s). The system can further include a media filter unit, a water softener unit, and/or a dechlorination unit positioned upstream of the first chemical treating unit. A mixed bed polisher unit can be placed downstream of the purified water outlet.

Rela [30] developed a water purifier using membranes, ion exchange resins and electricity to remove ionic, organic and suspended impurities from water to produce high quality pure water. Supply water is pre-treated by a sediment pre-filter module, a softener module and a sediment removal and dechlorination module. The pre-treated water is sent to the reverse osmosis module followed by the electrodeionization module, and the ultraviolet sterilization module. An important feature of the invention is the presence of a central microprocessor which utilizes a proprietary program to

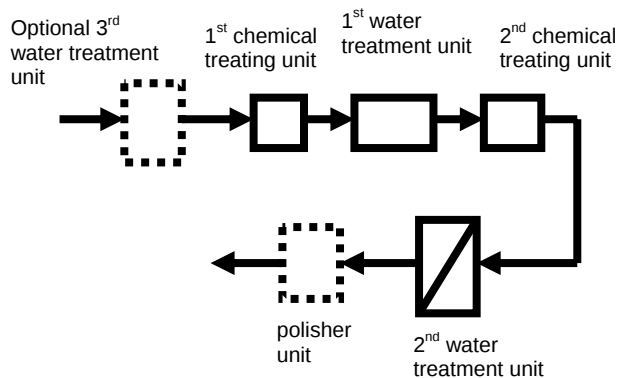


Fig. (4). Water treatment system, US 6398965 [29].

control the modules, valves and pumps to ensure satisfactory water quality and operation of the machine. The micro-processor is coupled to various monitors and sensors associated with the modules and determine the necessary or allowable operation of the valves and pumps. Gsell [31] developed an improved water purification system for production of USP purified water. The system includes a backwashable, chlorine tolerant microfilter or ultrafilter for initial filtration of the feed water followed by a dechlorinator prior to an optional, RO membrane unit. The backwashable, chlorine tolerant micro or ultrafiltration membranes eliminate the need for multi-media filters or cartridge filtration, and allow the downstream components to operate more efficiently and in a more sterile environment due to the higher level of initial filtration. Nachtman *et al.* [32] disclosed an ultrapure water production system comprising of a unique combination of purification media contained in a series of dual housings and preferably coupled with ultraviolet and ultrafiltration treatment and a novel arrangement of dispensing, solenoid valves, check valves and sensor devices. The purification media consists of redox media, acid-washed bituminous activated carbon, high energy bituminous grade or acid-washed coconut shell activated carbon, semiconductor grade mixed bed ion exchange resin, and catalytic activated carbon. The preferred redox media comprises a commercially available granulated Zn/Cu alloy. The redox reaction reduces free chlorine in the feed water to chloride ions that can be removed downstream by the ion exchange resin.

3. WASTEWATER TREATMENT SYSTEMS

Municipal wastewater treatment processes involve primary treatment processes which include physical-chemical processes such as sedimentation, secondary treatment processes which include biological units such as activated sludge or trickling filters. Fig. (5) presents the treatment scheme for wastewater treatment. The treated water is disinfected before it is discharge to a receiving body. The sludge produced is typically dewatered for land application. The wastewater treatment for industrial applications may involve treatment processes specifically designed to remove contaminants that are present in the industrial effluents. Examples of typical industrial wastewater treatment processes include sorption, membrane filtration, precipitation and pH adjustment.

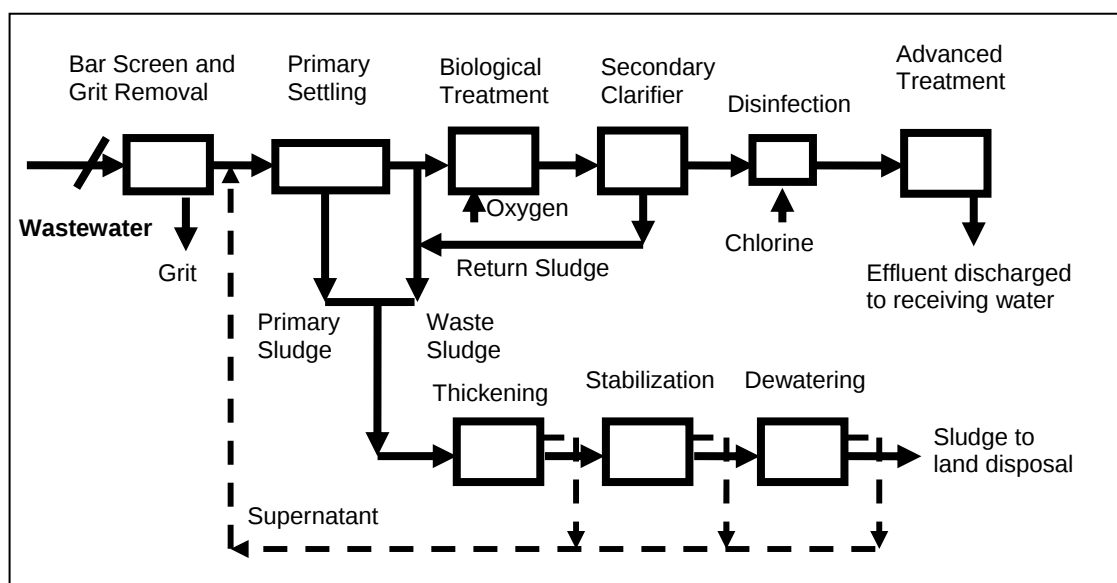


Fig. (5). Typical process diagram for wastewater treatment.

3.1. Physical-Chemical Processes

Physical-chemical processes for wastewater treatment typically include sedimentation, dissolved air flotation, and centrifugation to remove suspended solids and chemical coagulation, chemical precipitation, pH adjustment to remove dissolved or colloidal matter, and air stripping to remove dissolved gases. The conventional wastewater treatment systems with primary sedimentation tank and activated sludge treatment may not be able to meet the treatment needs to meet effluent discharge standards. To improve the solids removal efficiency, Funakoshi *et al.* [33] developed a sewage treatment system with a floating filter medium to separate solid components in the sewage as shown in Fig. (6). The sewage flows upwardly in the treatment tank and is filtered through the floating filter media layer made of cylindrical mesh floating filter media which have a smaller specific gravity than the sewage. To wash the floating filter medium, air is jetted from the air jetting pipes to generate a circular flow to scrape off solid components adhering to the filter medium. Kaltchev [34] developed a clarifier for liquids containing suspended matter. As shown in Fig. (7), the clarifier employs two liquid/solid separation techniques: dissolved air flotation and filtration on a filter medium (sand, anthracite or some other backwashable filter medium). The clarifier separates the suspended in two stages: by flotation--natural flotation (if the density of suspended solids density is lower than that of the liquid), or in combination with the dissolved air flotation technique; and then by filtration on a backwashable filter medium.

Jangbarwala [35] disclosed a system for purifying wastewater effluent to remove suspended and dissolved solids, such as metal salts using electric field. Industrial processes, such as semi-conductor fabrication, generate wastewater with high concentrations of suspended and dissolved solids. The process involves filtering the water with a cross-flow membrane filtration system in the presence of an electric field to drive suspended particles away from the membrane

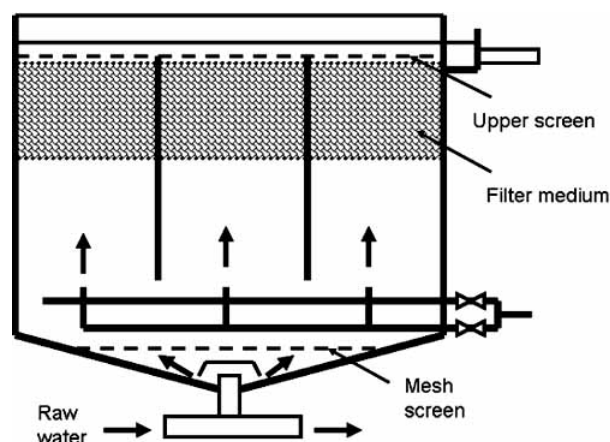


Fig. (6). Sewage treatment system with floating filter, US 5578200 [33].

surface. The membrane filter retains a significant fraction of the suspended solids. The permeate passes through a mixture of at least one cation-exchange resin and at least one anion-exchange resin placed between a cation-selective membrane and an anion-selective membrane in the presence of an electric field. The electric field is used to drive the cations in the permeate through the ion-selective membranes, thereby producing deionized water.

At construction sites and cement mills, a large amount of construction site sewage with a large concentration of silt and spall, as well as industrial dirt, is produced. When the sewage is discharged directly to water channels, it causes severe silting-up. For building and capital construction project, there is a need for a system apparatus to separate silt. The sewage disposal system used are of a hopper-type, which rotates to cause the silt solids to spiral down and discharged from the bottom of the hopper casing, while the

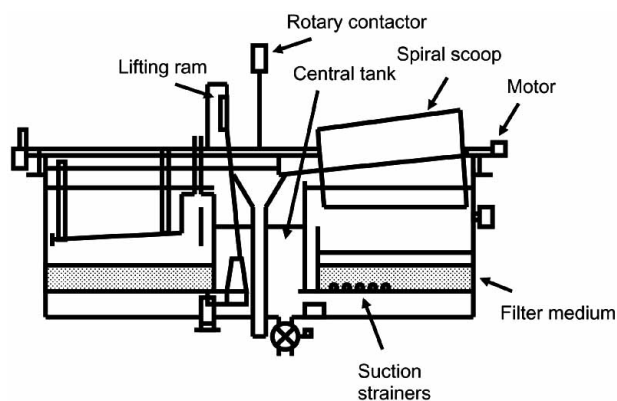


Fig. (7). Combined flotation and clarification system, US 6312592 [34].

oily water or clean water is thrown out in the same plane. However, this type of disposal apparatuses can not obtain ideal effect, thus can not meet the increasingly upgraded environment protection needs. Leung [36] developed a vortex sewage disposal apparatus, for the disposal of construction sewage, with no motor and simple to operate. It is capable of separating oil, water and slit, with both the separation effect and the oxygen content in water surpassing the minimum requirement required by environment protection.

Froth flotation is for wastewater treatment by using a gas (typically air) to separate solid particles or liquid droplets such as oil. During the process gas bubbles are dispersed in the aqueous phase to be treated. Chiang *et al.* [37] developed multi-stage flotation column for environmental applications such as waste water treatment, de-inking of recycled paper, chemical/biochemical waste clean-up, and mineral beneficiation, using a multi-stage flotation column. A series of draft tubes that are arranged axially and separated by baffles provide individual mixing stages in the flotation column and a special gas distributor generates fine gas bubbles. The draft tubes create repetitive loop flow of the feed fluid in each flotation stage. This provides uniform distribution of the gas bubbles throughout the column and significantly enhances mixing and contacts of the gas bubbles with the impurities to be removed.

The septic systems and sewage treatment plants in rural communities and small towns are aging fast and generally need to be replaced. Because the high cost of replacement, there is a need for an affordable, quality sewage treatment system for these communities. Thompson [38] developed a sewage filtration system for efficiently filtering wastewater from small residential areas without the use of additional sewage treatment plants. The system includes a conventional septic tank connected to each building structure's sewage system, a pair of two compartment tanks connected to the conventional septic tanks, and filtration unit. A chlorination line may be connected to system to chlorinate the filtered liquid prior to leaving the outlet line.

Wastewater from acidic hot springs in volcanic regions, acidic mine effluent and acidic underground water in regions of volcanic soil contain sulfuric acid formed by the oxidation

of sulfur-containing substances and iron sulfide ores. Oishi [39] developed a method for treating acidic waste water, particularly mine effluent using a solid material that is obtained by solidifying a mixture of rock wool and an inorganic binder mainly containing at least one kind selected from silicates, hydroxides and oxides of alkaline earth metals and alkali metals and has a porosity of 50% or more. When brought into contact with acidic waste water containing iron ions and sulfate ions, this waste treating material neutralizes the wastewater and removes heavy metals such as iron and arsenic.

Wet oxidation is a process for treating wastewater in the presence of oxygen at a high temperature under high pressure to oxidize and/or decompose oxidizable substances in the waste water. The wet oxidation treatment method for cleaning wastewater in liquid phase is a slow process when a catalyst is not used. Shiota *et al.* [40] developed a catalyst for the treatment of wastewater by wet oxidation. The catalyst comprises activated carbon, (a) component and (b) component (also referred to as "second component"). The oxidation of organic and/or inorganic oxidizable substances in waste water is accomplished with an oxygen containing gas in the presence of the catalyst under pressure while waste water retains the liquid phase thereof at temperature of 50 to less than 170°C. Hashimoto *et al.* [41] also disclosed a method and catalyst for treating wastewater by wet oxidation. The invention is applicable for wastewater treatment to remove organic or inorganic substances regardless of their concentration by wet oxidation process. Therefore, the reaction should be conducted at high temperatures under high pressure and the reaction times are relatively long. This limitation often necessitating use of a large system and increases the operation cost. The catalyst developed by Hashimoto *et al.* [41] is capable of increasing the reaction rate and moderating the reaction conditions.

3.2. Biological Methods

Biological methods are used for treating domestic and industrial waters by conversion of dissolved and suspended substrates into biomass which is separated and removed from the water. The disposal/reuse methods of the residues (biomass) require pre-treatment which generally consists of digestion, thickening and dehydration with conditioning, to increase the solid concentration to 20% to 40% is attained. The economic benefits could be significant when the water content of the residuals is reduced. Kotsaridou *et al.* [42] developed a method to reduce the residues generated in biological water treatment systems. The process use macromolecular carbohydrates and vitamins at a quantity of 0.0014 to 14 mg/kg of dry activated sludge per day. The conventional trickling filter utilizes a film of biomass fixed on a filter media to remove and aerobically convert organic matter to carbon dioxide, water and additional biomass and to oxidize ammonia to nitrates. The filter media typically comprises rock, wood, or corrugated plastic that maximizes the surface area of biomass for wastewater treatment. New construction of trickling filters uses predominantly plastic modules at depths of at least five feet to higher than forty feet. In principle, the trickling filter process has the biomass attached to a fixed medium. Recycling of the settled biomass is not required. A number of trickling filters collapsed due to

weak media. Good records and data associated with the trickling filter are essential in locating, identifying, and applying the proper corrective measure to solve problems. Ruppel [43] developed a system to enable a plant operator to assess biomass development, determine the optimum flushing rates and distributor speed options friendly to the biomass itself and to promote optimal sloughing and address concerns regarding media performance. The invention provides a filter media tower assembly comprising a first portion and a second portion, wherein the first portion is suspended within the second portion. The first portion is a removable media tower or cage for holding filter media, and the second portion is a media tower guide support structure. The media used may be corrugated structural plastic media, random dump media, stone, or any media commonly used in the art of trickling filters or water cooling systems. The design allows the weight of accumulated biomass on filter media to be more accurately and easily determined in real time, without substantial disruption of the filtration process. Furthermore, the removable media tower allows for inspection of actual biomass composition, as well as easy maintenance, repair or replacement of filter media.

Okamoto *et al.* [44] developed a wastewater treatment system using oyster shells as the biological growth media in the aeration chamber. Wastewater is fed to and purified in the shell contact aeration chamber. Shells with the mother-of-pearl layer on the inner surface is removed are used as microbial carrier. The rough surface of the shells has a high affinity to microorganisms. The treated wastewater purified in the aeration chamber described above is transferred to the activated carbon adsorption chamber where the wastewater is effectively decolorized. A denitrification chamber is provided upstream of the shell contact aeration chamber.

Matheson [45] disclosed a process which involves adding sulfur-containing oxygen scavenger to the source water stream and use of a biostimulant for the microorganisms. The process uses a biological denitrification process. Figure 8 presents a schematic of the innovative denitrification process. The bioreactor comprises of an open topped vessel with packing-type media. Bacteria effective for biological denitrification are attached to and supported on media. The oxygen scavenger works with the bacteria contained in lower bed portion to remove the dissolved oxygen contained in the source water stream. The biological breakdown of nitrate and nitrite compounds in bioreactor produces a nitrogen gas product. Park *et al.* [46] developed a method for treating high-concentrated organic wastewater, such as night soil or livestock wastewater, which has high levels of nitrogen and phosphorous. The treatment process comprises of an equalizing tank, stripping of ammonia selectively from the wastewater, fermenting non-degradable organic material, carrying out Anammox reaction of ammonia in the wastewater with nitrogen dioxide, denitrifying the wastewater, solid-liquid separation steps.

4. ANALYTICAL METHODS FOR WATER AND WASTEWATER QUALITY ANALYSIS

Analyzing contaminants in a water supply can often take significant time to complete, and furthermore is often difficult to carry out. Present techniques and apparatus generally require much time to obtain measurements or readings of water supply contaminants. Water utilities are confronted with the task of maintaining contaminants at reduced levels, while, at the same time, controlling the levels of treatment compounds to maintain a safe concentration for consumption by users or ultimate discharge of the water into the ecosystem. Often strict government regulations must be met

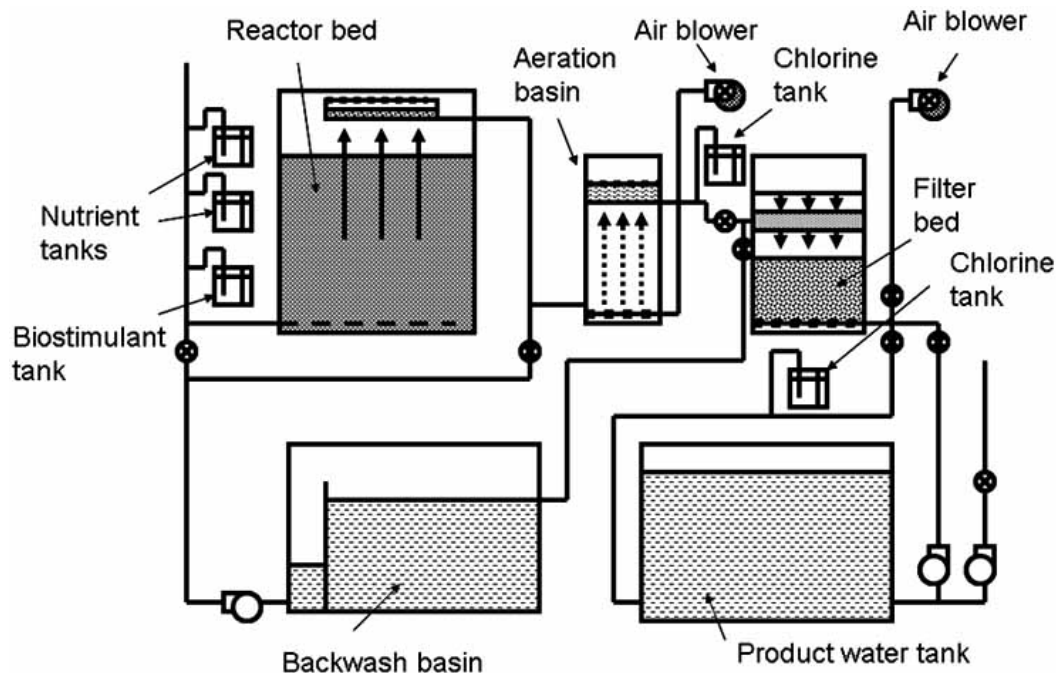


Fig. (8). Process and apparatus for biologically treating water, adapted from US 6146531 [45].

so as to have a minimum acceptable level of contaminants and maximum acceptable levels of treatment chemicals.

Dissolved organic matter is an important component in a water system that must be carefully monitored and controlled due to its relationship with the contaminants.

Kaplan [47] disclosed a method for measuring concentrations of contaminants aqueous water system using a bioreactor. The bioreactor containing the biofilm provides a measure of the amount of the dissolved organic carbon which is biodegradable. A bed facilitates the regulation of water flow through the bioreactor, and an autosampler allows for the measurement of total organic carbon, inorganic carbon and oxygen, between sample inflow and sample outflow at specified time intervals.

Titmas [48] developed a new method for separating dissolved materials (i.e., organic and inorganic solids and volatile constituents) from aqueous solutions. The method first extracts water from the flow stream (i.e., sample) being treated using a crystallization system which freezes the water onto a continuous loop wire rope and withdraws the wire rope from the chamber containing the feed stream. The concentrated solution is then heated to remove water at reduced pressures to separate the materials from the liquid medium.

5. CURRENT & FUTURE DEVELOPMENTS

The recent patents applicable for water and wastewater treatment address improvements for ease of operation, reliability, cost, size, maintainability, improved water quality, and analytical methods. There are also patents that show applications of nano technology especially in the areas of disinfection, ion exchange, and detection methods. With the increasing demand for drinking water and requirements for improved quality, more strict regulations for effluent discharge limits, and environmental awareness for water quality impacts, the research and development in water and wastewater technologies will increase in the coming years. The majority of the recent patents address the improvements for current technologies such as filtration and disinfection. The recent trends indicate that there will be new requirements to monitor and perhaps regulate the emerging groups of contaminants which are not currently regulated (i.e., microconstituents which originate from over the counter drugs entering wastewater systems). In the near future, the technological advancements are likely to be aligned with the anticipated requirements to improve water quality. With the advancements in materials science, nano technology, and information technology; it is likely that there will be new developments in the area of membranes filtration, disinfection/oxidation methods, ion exchange resins, sorption technologies, as well as water management methods utilizing information and telecommunication technologies with remote monitoring and control capabilities.

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