Chapter 1

Introduction

1.1 DRINKING WATER

Drinking water is vital to all the living organisms in this planet. Earth’s surface covers about 71.4% of water, which means two thirds of earth’s surface is covered by water and the remaining with land. Among that, 96.5% of the water is found in the form of oceans and seas, 1.7% of water in another form like ice (solid state), 1.7% of water is found in the form of ground water and the remaining in the form of water vapor in air. Based on these, only 2.5% of water is in the form of fresh water and remaining water is in the form of ice and ground water (in lakes and oceans). Within these, 2.5% of water is contaminated due to water pollution.

Water pollution is one of the challenging task in the today’s world. Mainly water is polluted by human activities of throwing the waste into the water bodies such as lakes, oceans, seas and ground water. Water pollution is affecting not only the human beings but also affects the environment in diverse ways. Due to water pollution more than 14,000 human beings surveillance have adversely got affected throughout the globe, where as in India approximately 580 lives are affected, due to these water related problems. When the pollutants such as particles, ions, chemicals or substances are discharged into the water bodies either directly or indirectly without any treatment, it leads to the water pollution which means the water is not enough safe for drinking purposes.

There are two categories for the source of water pollution based on their origin. One way of polluting water is through point source, which refers to contaminants entering into the water bodies in the form of single way, identifiable source, such as pipe or ditch. Second way of polluting water is through the non-point source, which is diffusion of the contaminant whose origin is not from a single source. The following figure shows the pictorial representation of source of water pollution.
1.2 TYPES OF WATER POLLUTION

Based on the water originating from many sources, different types of water pollution exists viz. oxygen depletion, surface water, nutrients, microbiological, ground water, chemical water, suspended matter and oil spillage pollution.

1.2.1 SURFACE WATER POLLUTION

Surface water is nothing but the natural water such as rain water, lakes, oceans and seas. When the surface water is in contact with hazardous materials such as chemicals or in any other form, it leads to surface water pollution.

1.2.2 NUTRIENTS POLLUTION

This is mainly based for the development and growth of plant nutrients. A high quantity of nutrients is available in wastewater, sewage, fertilizers, which can cause excess weed and algae growth if large concentrations end up in water. This will make the water undrinkable, and even clog filters. Too much algae will also use up all the oxygen in the water, and other water organisms in the water will die out because of oxygen starvation.
1.2.3 OXYGEN DEPLETING

Microorganisms are present in water bodies, which live in water feed on biodegradable substances. As the concentration of the biodegradable matter (things that easily decay) exceeds the limit, there is an excess growth of microorganisms which in turn use more amount of oxygen in water. This process is called as oxygen depletion. As a consequence of water depletion, harmless aerobic microorganisms die and anaerobic microorganisms begin to thrive and some of the anaerobic microorganisms are harmful to as it produces hazardous toxins like sulfides and ammonia.

1.2.4 Ground water pollution

Most of the Earth’s water is either underground in soil or under rock structures, which is called as aquifers. Humans utilize such aquifers to get drinking water, and build wells to access the same. Pollution of such water is called as groundwater pollution and is frequently produced by contamination from pesticides leading to drinking water pollution.

1.2.5 Microbiological pollution

Microbiological water pollution is generally caused by microorganisms that live in water and cause fish, animals and humans to become ill. Various microorganisms exist like, bacteria, viruses and protozoa, which cause serious diseases like cholera etc.. Such diseases generally are more prone to people of poorer countries, as they are deprived of the modern facilities to treat polluted water.

1.2.6 Chemical water pollution

Industrial and agricultural work makes use of diverse chemicals that gets into water thereby polluting it. Many pollutants from industries like metals, solvents pollute rivers and lakes, which are poisonous to many forms of aquatic life affecting their development, fertility and even fatal. Pesticides are used in farming to control weeds, insects and fungi and run-offs of such these leads to polluting water and affect aquatic life. As a consequence, many forms of life like birds, animals and human are indirectly affected when they consume such affected species. Another form of chemical polluting the water is petroleum that contaminates water through oil spills when a ship ruptures. Though such oil spills are localized over a defined space, it generally could be spread for miles. Such oil spills could be even fatal to most of the aquatic species and sea birds.
1.2.7 Suspended matter pollution

There exists few pollutants, which are not miscible in water as their molecules are too complex to get into water molecules. These kinds of materials are called particulate matter, which could be a source of water pollution. Such particles suspend and eventually settle at the bottom of water, which pose a threat to marine life that lives on the floor of rivers or lakes. Biodegradable substances suspended in water can also be hazardous by elevating the amount of anaerobic microorganisms.

1.2.8 Oil spillage pollution

Oil spills like from petroleum generally have only a localized effect on aquatic life but can spread for miles, leading to the death of many aquatic species and sea birds.

1.3 EFFECTS OF WATER POLLUTION

The effects of water pollution may occur in different forms.

- The wildlife in environment are getting damaged by groundwater pollution, which is in the form of pesticides, affecting reproductive systems.
- Agricultural wastewater, fertilizer and sewage water contains the most of the organic metals discharging into waters that leads to increase in the production of algae bacteria, causing the depletion of oxygen. Lower level of oxygen will not be enough for the survival of life most indigenous organisms and hence there is an upset in the natural ecological balance in rivers and lakes.
- Swimming in and thereby orally consuming contaminated water leads to skin rashes and health issues like cancer, reproductive problems, typhoid fever and stomach sickness in humans.
- Industrial pollutants and agricultural waste materials can accumulate in fish and later eaten by human beings. Fishes will get easy accumulation of poison metals and the same also later consumed by human beings.
- As water temperature rises, the ecosystems are immediately getting affected and coral reefs are affected due to the bleaching effect at higher warmer temperatures. In addition, the warm water forces indigenous water species to seek cooler water in other areas, which may lead to an ecological damaging.
Human-produced articles like plastic bags and 6-pack rings can harm aquatic species due to suffocation caused with such items.

Flooding is yet another issue caused by water pollution, which results because of the buildup of solid waste and soil erosion in rivers and water bodies.

Oil spills in water is fatal to marine life organisms as they ingest it and oil does not dissolve in water, leading to suffocation in fish and birds.

1.4 WASTE WATER TREATMENT

Wastewater treatment is a technique to transform wastewater to an effluent that can be either returned to the water cycle with minimal environmental issues or reused, where in the latter case is termed as water reclamation and implies avoidance of disposal by utilizing treated wastewater effluent for diverse purposes. Treatment involves removal of the impurities from water and there exists certain common methods to treat both water and wastewater. The physical infrastructure adopted for treating wastewater is called a "wastewater treatment plant" (WWTP).

Satisfactory wastewater disposal either by surface, subsurface routes or dilution method depends primarily on the treatment procedure before it is disposed. A relevant treatment is imperative to avoid contamination of receiving waters to a degree, which might interfere with their best or intended use, be it be for water supply, recreation, or any other purpose.

Wastewater treatment involves the application of a well-accepted technology to improve the water quality. In general, such treatment involves the collection of wastewater in a central, segregated location (the Wastewater Treatment Plant) followed by subjecting the same to diverse treatment methods. As such treatment involves the usage of large volumes of wastewater, it is generally carried out on continuously flowing wastewaters (continuous flow or "open" systems) rather than as "batch" or a series of periodic treatment processes, wherein the treatment is carried out in parcels or "batches" of wastewaters. Most of the wastewater treatments are continuous flow and few processes like vacuum filtration, sludge storage, the addition of chemicals, filtration and removal or disposal of the treated sludge, are generally carried out as periodic batch operations.
Wastewater treatment could also be categorized by the nature of the treatment process being utilized; viz. physical, chemical or biological with examples for such treatments are given below. A complete treatment system consists of the application of a wide variety of physical, chemical and biological processes to the wastewater system. Few physical, chemical and biological treatment methodologies for treating waste water are listed below (Ku et al., 2001).

**Physical Treatment**

- Sedimentation (Clarification)
- Screening
- Aeration
- Filtration
- Flotation and Skimming
- Degassification
- Equalization

**Chemical Treatment**

- Chlorination
- Ozonation
- Neutralization
- Coagulation
- Adsorption
- Ion Exchange

**Biological Treatment**

- *Aerobic Methods*
  - Activated Sludge Treatment Methods
  - Aerobic Digestion
  - Oxidation Ponds
  - Trickling Filtration
  - Lagoons

- *Anaerobic Methods*
  - Anaerobic Digestion
  - Septic Tanks
Lagoons

1.4.1 PHYSICAL METHODS

In the physical methods, no gross chemical or biological changes are involved and the process is purely a physical phenomenon for the treatment of wastewater like coarse screening to get rid of larger entrained sedimented objects and impurities. Sedimentation is a physical phenomenon happening due to the settling of solids by gravity. It usually consists of holding the wastewater in a tank for a short span of time period of time under quiescent conditions, allowing the heavier particles to settle, and removing the "clarified" effluent. It is a very common process for separation of solids and is commonly used in wastewater treatment operations. A yet another physical treatment processes used for water treatment consists of aeration that is, physically adding air to supply oxygen to the wastewater. The physical phenomena used in treatment consists of filtration, where in the wastewater is passed through a filter medium to separate solids. A typical example is sand filters for removing entrained solids from treated wastewater. There are few phenomena happening during the sedimentation process, which could be used advantageously to improve the water quality. Floating greases or oils on the surface and further skimming or physically removing them from the wastewaters is carried out generally as part of the overall treatment process.

1.4.2 CHEMICAL METHOD

Chemical treatment involves the utilization of chemical reactions to enhance the quality of water and the widely used chemical treatment is chlorination. In this treatment process, chlorine, which is a strong oxidizing reagent, is employed for killing bacteria and slow down the rate of decomposition of wastewater. A yet another strong oxidizing agent used for water treatment is ozone. One of the routinely adopted chemical processes in many industrial wastewater treatments is neutralization, which consists of acid or base addition for pH adjustment to reach neutrality. Lime is generally used as a neutralization agent as it is a base. Coagulation is a chemical process where in it forms an insoluble end product via chemical reaction, which will remove the impurities from waste water. Among the coagulating chemicals, polyvalent metals are routinely used in wastewater treatment and some of the coagulants used are lime (used for neutralization), iron based compounds (like ferric chloride or ferric sulfate) and alum (aluminum sulfate).
There are certain processes for water treatment that could be both physical and chemical in nature. The use of activated carbon for adsorption of organics involves both chemical and physical processes. Other processes like ion exchange, involves exchange of certain ions for other ions and this technique is not exploited to a great extent in wastewater treatment process.

1.4.3 BIOLOGICAL METHODS

Biological treatment methods involves the use of microorganisms especially bacteria for the biochemical decomposition of wastewaters to stable end products. In this case, sludge formation is reported and a portion of the waste is converted to carbon dioxide, water and other end products. In general, biological treatment process is categorized into aerobic and anaerobic methods, with reference to the availability of dissolved oxygen. Wastewater treatment generally involves the removal of solids from the water while the remaining is discharged to receiving water without interfering with its best or proper use. The discarded materials are in general organic and inorganic and the solids and liquids which are removed as sludge should also be treated before discharged. In addition to the aforesaid generic treatment process, water should also be treated to control odors, to retard biological activity, or destroy pathogenic organisms.

Though there are numerous methodologies for wastewater treatment, which involves a combination of physical, chemical and biological methods, the whole treatment they may all be generally grouped under six categories based on the treatment methodologies:

- Preliminary Treatment
- Primary Treatment
- Secondary Treatment
- Disinfection
- Sludge Treatment
- Tertiary Treatment

Degrees of treatment are indicated by use of the terms primary, secondary and tertiary treatment. Tertiary treatment, would be any treatment added onto or following the secondary treatment.
1.4.3.1 Preliminary Treatment

In most of the plants involved for water treatment, preliminary treatment is utilized to safeguard pumping equipment and enable subsequent treatment processes. Preliminary treatment based systems are so designed to enable the removal of larger suspended and floating solids, heavy inorganic solids, and oils or greases. Some of the devices commonly used for preliminary treatment are:

- Screens - rack, bar or fine
- Comminuting devices - grinders, cutters, shredders
- Grit chambers
- Pre-aeration tanks

Apart from the above said techniques, chlorination is also used in the preliminary treatment process and the same is regarded as a unique method by itself. Preliminary treatment devices require careful design and operation.

1.4.3.2 Primary Treatment

In the primary treatment process, most of the dissolved solids are separated or removed from wastewater by physical process of sedimentation. Some of the colloidal salts are also removed when certain chemicals are used with primary sedimentation tanks and in the primary treatment, biological activity in considered negligible. This treatment reduces the velocity of wastewater so that the solids settle and will make the material float to the surface. Hence primary devices consist of settling tanks, clarifiers or sedimentation tanks and based on the variations in diverse parameters like design, operation, and applications, settling tanks can be categorized into four general groups:

- Septic tanks
- Two stover tanks - Imhoff and several proprietary or patented units
- Plain sedimentation tank with mechanical sludge removal
- Upward flow clarifiers with mechanical sludge removal

With the use of chemical in such primary treatment methods, other auxiliary units are employed, like

- Chemical feed units
- Mixing devices
- Flocculators
1.4.3.3 Secondary Treatment

Secondary treatment depends mainly on aerobic organisms, which biochemically decompose the organic materials to inorganic or stable organic solids and is comparable to the zone of recovery in the self-purification of a stream. The secondary treatment based devices are divided into four groups:

- Trickling filters with secondary settling tanks
- Activated sludge and modifications with final settling tanks
- Intermittent sand filters
- Stabilization ponds

1.4.3.4 Chlorination

Chlorination treatment has been employed for diverse purposes in all stages in wastewater treatment, and even prior to preliminary treatment. Chlorination is applying chlorine to the wastewater which serves the following purposes:

- Disinfection or destruction of pathogenic organisms
- Prevention of wastewater decomposition
  (a) odor control, and
  (b) protection of plant structures
- Aid in plant operation
  (a) sedimentation,
  (b) trickling filters,
  (c) activated sludge bulking
- Reduction or delay of biochemical oxygen demand (BOD)

Though chlorination has been routinely used over the years, especially for disinfection, there are other methods also like ozone treatment. Due to the toxicity of chlorine and chlorinated compounds for aquatic life fish as well as other living forms, ozonation may be more commonly used in the future.

1.4.3.5 Sludge Treatment

Wastewater sludge is the removal of wastewater from both primary and secondary treatment units, along with the water removed with them. Such treatment is needed to subject sludge to some treatment to prepare or condition it for ultimate disposal. These types of treatments generally has two objectives, the first will be to remove a part or all of
the water in the sludge to reduce its volume, and second to decompose the putrescible organic solids to mineral solids or to stable organic solids. Such processes are possible by a combination of two or more of the following techniques:

- Thickening
- Digestion with or without heat
- Drying on sand bed - open or covered
- Conditioning with chemicals
- Elutriation
- Vacuum filtration
- Heat drying
- Incineration
- Wet oxidation
- Centrifuging

1.4.3.6 Tertiary and Advanced Wastewater Treatment Process

The "primary" and "secondary" treatment processes are generally used to define a degree of treatment; like for instance, settling and biological wastewater treatment. Tertiary treatment has been used as a follow up treatment of secondary treatment process and describes the use of intermittent sand filters for enhanced removal of suspended solids from the wastewater and such treatment is also used for the removal of plant nutrients, primarily nitrogen and phosphorous, from wastewater. Improvement and upgrading of wastewater treatment units as well as the need to minimize environmental effects has led to the increased use of tertiary treatment. In general treatment of wastewater by methods other than primary or biological (secondary) treatment is advanced treatment processes, which is usually achieved by chemical (like coagulation) process and physical methods (flocculation, settling and activated carbon adsorption).

1.5 WATER TREATMENT METHODS

Water treatment methods as discussed below are called as Point of Use (POU) devices.
1.5.1 POINT OF USE (POU)

POU treatment routes treat water at the point of its usage like frequently at the kitchen sink. The water that is actually used for commodity use viz. drinking, cooking, beverage preparation, etc. is generally treated, which is advantageous on economic grounds because only a few hundred gallons of water is treated per annum rather than treating thousands if all of the water entering the home were to be treated. Users who consume water supplied by a municipal water company will need to be only concerned about POU treatment for the reduction of harmful contaminants as it is the water company’s responsibility to supply biologically and chemically safe water with taste and odor causing substances removed. The users of public water do not need to employ Point of Entry treatment devices or the more expensive POU devices like distillation and reverse osmosis. But still it is imperative to follow the annual water quality report that the water company is required to make available to the user. Some of the contaminants with public water likely to experience at harmful or unacceptable levels are:

- Adding Residual disinfectants (chlorine and/or chloramine) to keep water safe during distribution.
- Disinfection byproducts, like the trihalomethanes.
- Lead (in many homes leach lead into the water from pipes and/or fixtures).
- Biocontamination by microbes (E. coli, giardia, cryptosporidia, etc.) or other contaminants.
- In an agricultural region, unacceptable levels of nitrates or organic compounds (even if they are below regulated levels).

1.5.2 POINT OF ENTRY (POE)

Point of Entry (POE) based systems indicate complete house water treatment (where all water entering the home is treated) and it happens when the water has problems that affect all areas of the home. A typical example is water softening ion exchange system or the removal of calcium and magnesium ions from water. Hard water, while quite healthy to drink, cause building up of scales in pipes and on fixtures, interfere with the effectiveness of soap, and shorten the life of appliances, like dish washers and hot water heaters. There are other POE water treatment systems for the removal of iron and manganese, pH levels adjustment, addition chlorine or other disinfectant, etc. POE
treatment is more required for public using water from a private well, spring, or surface source. In general, a high quality POU treatment system is necessary to be connected with a well or water from a spring or surface source, as each type of POE treatment removes only one type contaminant type. Other type of contaminants like lead (from the home's plumbing and pipes) and chlorine residues could be removed by a POU device.

1.6 TYPES OF TREATMENT METHODS

1.6.1 BOILING METHOD

Out of all the methods reported, boiling is the best and simplest way to disinfect water that is not suitable and unsafe due to the presence of protozoan parasites, bacteria or viruses. In case if the water is cloudy, the same should be filtered prior to boiling. Filters used when camping, coffee filters, towels (paper or cotton), cheesecloth, or a cotton plug in a funnel are some of the effective ways to filter cloudy water. The water is boiled in a cleaned and closed container continuously over 3 minutes and if more than 5,000 feet above the sea level, boiling time must be at least 5 minutes (plus about a minute for every additional 1,000 feet).

Pros of boiling treatment

- Pathogens lurking in water would be killed with continuous water boiling.
- Volatile organic compounds (VOCs) would be removed with boiling.
- Boiling works well to make water contaminated with living organisms safe to drink, but due to the inconvenience, it is not routinely used to treat drinking water except in emergencies.

Cons of boiling treatment

- Boiling should be avoided if water is contaminated with toxic metals, chemicals (lead, mercury, asbestos, pesticides, solvents, etc.).
- Boiling may concentrate the harmful contaminants that do not vaporize as the relatively pure water vapor boils off.
- It is difficult for boiling in an emergency since energy is needed to boil the water.
1.6.2 DISTILLATION METHOD

In the process of distillation, water is usually boiled in a chamber or vessel for it to vaporize and the pure steam gets off the chamber leaving the nonvolatile contaminants behind. The steam coming out of the chamber is condensed back as liquid water by a different unit and the resulting distillate drips into a storage container. Matters that would not evaporate like salts, sediments, metals remain in the distiller and the same should be discarded. In the case of volatile organic compounds (VOCs), it will evaporate and get condensed with the water vapor and hence to eat it, a vapor trap like carbon filter, or other device must be used along with a distiller to ensure a more complete removal of contaminants.

Figure 1.2 Schematic diagram of distillation technique

Pros of distillation

- Very pure water is supplied by a good distillation unit and is one of the few practical ways for the removal of heavy metals, nitrates, chlorides, and other salts that carbon filtration cannot remove.
- Distillation removes pathogens in water, by killing and leaving them behind as the water vapor evaporates. If the water is boiled, or heated just short of boiling, pathogens would also be killed.
- As long as the distiller is maintained clean in good working condition, water quality will be maintained regardless of the incoming water and there will not be any drop in quality over time.
- There are no filter cartridges to replace, unless a carbon filter is used to remove volatile organic compounds.

**Cons of distillation**
- It is time consuming as distillation takes two to five hours to make a gallon of distilled water.
- Distillers require regular cleaning of the boiler, condensation compartment, and storage tank.
- Electricity consumption is one of the major disadvantages hindering its usage in an emergency situation when electrical power is not available.

1.6.3 REVERSE OSMOSIS (RO)

Reverse osmosis is the process of using water pressure to drive water molecules through a membrane with tiny pores and thus leaving the larger contaminants behind. The as purified water is collected from the clean side of the membrane, while the water with the concentrated contaminants is flushed from the other side to the drain. A simple RO system consists of a sediment/chlorine pre filter, a reverse-osmosis membrane, water storage tank, and an activated-carbon post filter (Sudilovskiy et al., 2008).

![Figure 1.3 Schematic diagram of reverse osmosis mechanism](image)
Pros of Reverse osmosis

- Reverse osmosis considerably reduces the concentration of salt, inorganic material and some organic compounds in water. In the presence of a quality carbon filter, organic materials that get through the filter could be removed and hence the purity of the treated water approaches the quality produced by distillation.
- Microscopic parasites (including viruses) are removed by proper functioning of the RO units, but a defect in the membrane would result in leaching of the organisms into the filtered water, which doesn’t allow its usage on biologically unsafe water.
- RO systems, though a slow process can purify a large quantity of water per day than distillers and are also less expensive to operate and maintain.
- Reverse osmosis systems generally does not require electricity, but as they require relatively high water pressure to operate, it may not work well in some emergency situations.

Cons of Reverse osmosis

- In terms of quantity, most of the point of use RO units makes 12 - 24 gallons of treated water a day for drinking or cooking purpose, which is acceptable for homes as it is stored in a tank for use.
- RO systems waste a large quantity of water with two to four gallons of wastewater being flushed down for each gallon of filtered water produced.
- RO systems don’t completely remove certain pesticides, solvents and other volatile organic compounds (VOCs) and to cater the same a good activated carbon post filter is recommended.
- RO membrane's efficiency gets affected by diverse ways like contaminant concentration, chemical properties of the contaminants, membrane type and condition, and operating conditions like pH, water temperature and water pressure.
- Though RO filters do not use electricity, a relatively high water pressure is needed to force the water molecules through the membrane. In this need, an electric booster pump is used to increase the water pressure but under an emergency
condition when water pressure is lost, these systems will not function. But with the use of a high quality activated carbon filter as a post filter, it could be disconnected and used to siphon water through in an emergency to reduce many contaminants.

- High maintenance is required in RO system where the pre, post filters and membranes must be changed according to the manufacturer's recommendation, along with the periodical cleaning of the storage tank.
- Damaged membranes are difficult to detect and thus it is hard to tell if the system is functioning normally and safely.

1.6.4 WATER FILTRATION

In water filtration, the contaminants are physically prevented from moving through the filter either by flushing them out with very small pores or in the case of carbon filters; the same is trapped within the filter matrix by attracting them to the surface of carbon particles. Broadly, there are three types of filters viz. sediment and activated carbon filters and the third type, reverse osmosis.

1.6.4.1 SEDIMENT FILTERS

Fiber Filters: Fiber filters contain cellulose, rayon or other material spun into a mesh with small pores and comes in a variety of sizes and meshes from fine to coarse, with the lower micron rating being the finer. The more finer the filter, the more particles are trapped. Fiber filters are generally used as pre-filters to decrease the suspended contaminants that clog carbon or RO filters. Fiber filters does not remove contaminants that are dissolved in water, like chlorine, lead, mercury, trihalomethanes and other organic or inorganic compounds.

Ceramic Filters: Ceramic filters are like fiber filters, where in water is forced through the pores of a ceramic filtration media, which is a kind of mechanical filtration. Ceramic filters does not remove contaminants that are dissolved in water, like chlorine, lead, mercury, trihalomethanes and other organic or inorganic compounds, nor will they remove viruses. Such filters may be used as a back-end to an activated carbon filter to provide a more thorough removal of contaminants.
1.6.4.2 ACTIVATED CARBON FILTERS

Activated carbon (AC) has treated carbon particles with a view of enhancing its surface area and increases their ability to adsorb a wide range of contaminants. Activated carbon based filters are generally good at adsorbing organic compounds. There are two basic kinds of carbon filters viz. granular activated carbon (GAC) and solid block activated carbon (SBAC). Regarding the mechanism for contaminant reduction by AC filters, it is happening by two processes, the first by physical removal of contaminant particles, via a blocking mechanism i.e. anything that are too large to pass through the pores (filters with smaller pores are more effective), and second by a process called adsorption in which a variety of dissolved contaminants are attracted to and held or adsorbed on the surface of the carbon particles. The characteristics of the carbon material like particle and pore size, surface area, surface chemistry, density, and hardness influence the efficiency of adsorption. (Jusoh et al., 2007; Kang et al., 2004).

AC is a highly porous material with high surface area suitable for contaminant adsorption. A high concentration of pores within a relatively small volume renders the material with a phenomenal surface area. The carbon source is from diverse materials like peanut shells, coconut husks, coal etc., The raw carbon source materials are heated in the absence of air to produce a high carbon material and the same is further activated by passing oxidizing gases through the material at extremely high temperatures. The latter activation process renders pores that result in such high adsorptive properties. The adsorption phenomenon depends on the following factors: 1) physical properties of the activated carbon materials like pore size distribution and surface area 2) chemical nature of the initial carbon source, or the quantity of oxygen and hydrogen associated with it; 3) chemical composition and concentration of the contaminant; 4) the temperature and pH of water; and 5) the flow rate or time exposure of water to AC.

Thus carbon filters effectiveness is affected by the above said factors and apart from it, three additional characteristics of the filter affects its performance like contact time between water and the carbon material, the amount of carbon in the filter, and pore size. The time period of contact between water and carbon material is mainly governed by the water flow rate and the quantity of activated carbon, which has a significant effect on adsorption of contaminants. More contact time results in greater adsorption. The
amount of carbon present in a cartridge or filter affects the amount and type of contaminant removed. Less carbon is required to remove taste- and odor-producing chemicals than to remove trihalomethanes.

Over time, activated carbon filter cartridges becomes less effective at reducing contaminants as the pores clog with particles thereby slowing the water flow and the adsorptive surfaces in the pores become filled with contaminants. Often, there is not a visible indication that a carbon filter has worn out and thus it becomes imperative to replace the cartridge according to the manufacturer's instructions. The overall water quality also affects the capacity of activated carbon to adsorb a specific contaminant.

1.6.4.3 GRANULAR ACTIVATED CARBON (GAC)

In GAC type filter, water flows through a bed of loose activated carbon granules, which could trap particulate matter, chlorine, organic contaminants, along with undesirable tastes and odors. The three main problems associated with GAC filters are: channeling, dumping, and an inherently large pore size.

Pros of GAC

- A normal GAC filter is typically used for aesthetic water treatment as it reduces chlorine and particulate matter as well as to improve the taste and odor of water.

- Loose granules of carbon do not restrict the water flow like solid block activated carbon (SBAC) filters, which enables its utility in places like whole house filters, where maintaining good water flow rate and pressure is important.

- The filters are simple, economical and inexpensive filter cartridge that could be changed every few months to a year, depending on water usage and the manufacturer's recommendation.

- Electricity is not required in GAC filters and it doesn’t waste water.

- Many dissolved minerals are not removed by activated carbon. In the case of calcium, magnesium, potassium, and other beneficial minerals, the taste of water can be improved and some (usually small) nutrient value can be gained from the water.

Cons of GAC

- Filtration is blocked as water flowing through the filter is able to channel around the carbon granules.
Like other carbon filters, GAC does not reduce the levels of soluble salts like
including nitrates, fluoride, arsenic and cadmium.

There is a formation of contaminated water pockets in a loose bed of carbon
granules. As water pressure and flow rates changes, such formed packets can
collapse, dumping the contaminated water through the filter into the filtered flow.

1.6.4.4 SOLID BLOCK ACTIVATED CARBON (SBAC)

In SBAC, activated carbon is the primary raw material but instead of carbon
granules, the carbon has been treated, compressed, and bonded to form a uniform matrix
with an effective pore size of 0.5 - 1 micron.

Pros of SBAC

- SBAC filters have a larger surface area than granular activated carbon (GAC)
  filters for better contaminant reduction via adsorption process.
- A longer contact time is provided with the activated carbon for more complete
  contaminant reduction.
- Small pore size, which could be utilized to physically trap particulates and as a
  consequence of it, trapping of bacteria as in GAC filters is avoided in SBAC
  filters.
- Channeling and dumping problems as in GAC filters are avoided in this type.
- SBAC filters are particularly useful in emergency circumstances where water
  pressure and electricity might be lost. Such filters do not require electricity and
  water can even be siphoned through them.
- There is no wastage of waste water in SBAC filters as like in reverse osmosis.
- With all such combined features, it provides a great potential for greater
  adsorption of diverse chemicals (pesticides, herbicides, chlorine, chlorine by
  products, etc.) and greater particulate filtration of parasitic cysts, asbestos, etc.
  than many other purification processes. With the combined use of other
  specialized materials along with specially prepared activated carbon, customized
  SBAC filters can be produced for specific applications or to achieve higher
  capacity ratings for certain contaminants like lead, mercury, arsenic, etc.
Cons of SBAC

- Like other carbon filters, SBAC filters do not reduce the levels of soluble salts like nitrates, fluorides, other potentially harmful minerals like arsenic and cadmium.
- As SBAC filters remove contaminants from water, they gradually lose effectiveness until they are no longer able to adsorb the contaminants. There is no easy way to determine when a filter is nearing the end of its effective life except that the 'filtered' water eventually begins to taste and smell like the unfiltered water.

1.6.5 ULTRA VIOLET LIGHT (UV)

In this technique, water through a clear chamber is exposed to ultra violet (UV) light, which effectively destroys bacteria and viruses. However, effectiveness of the UV system is based on the energy dosage that the organism absorbs and if the energy dose less, there is a chance that the organism’s genetic material cold be destroyed.

Pros of UV

- There is not any introduction of toxic substances.
- Organic contaminants are removed by this process.
- There is no smell or odor after filtration by this process.
- Requires very little contact time.
- The taste of water is improved as certain organic contaminants and microorganisms are destroyed.
- Many pathogenic microorganisms are killed or rendered inactive.
- Does not affect minerals in water.

Cons of UV

- UV radiation is not appropriate for water with high levels of suspended solids, turbidity, color, or soluble organic matter. Such materials can react with UV radiation, and reduce disinfection performance.
- UV light is not suitable for non-living contaminant, lead, asbestos, many organic chemicals, chlorine.
- Tough cryptosporidia cysts are fairly resistant to UV light.
- Organic compounds are degraded by UV radiation to harmful byproducts.
- Requires electricity to operate, which is the main drawback since it cannot be operated as power is out.

1.6.6 WATER SOFTENERS AND DEIONIZERS

In this technique, it operates on the ion exchange process specifically a cation exchange process where positive ions are exchanged, wherein water passes through sulfonated polystyrene beads. The beads are supersaturated with sodium ion and ion exchange process takes place as hard water passes through the softening material. The hardness minerals viz. positively charged calcium and magnesium ions attach themselves to the resin beads while sodium on the resin beads is released simultaneously into water. As the resin gets saturated with such ions, it is recharged, which is done by passing a brine solution through the resin. During the process, sodium ions replace the trapped calcium and magnesium ions, which are discharged into the waste water. Softened water is not recommended for watering plants, lawns, and gardens because of its high sodium content.

Several factors govern the efficiency of a cationic softener:

- Type & quality of resin used
- Amount of salt per cubic foot of resin for regeneration
- Brine concentration in the resin bed during regeneration
- Brine flow rate through the resin bed (contact time) during regeneration
- Raw water hardness
- Raw water temperature - softeners perform better at higher temperatures and
- Optimal flow rate of hard water through the resin bed.

Potassium chloride is used as the salt brine for softeners, where in the potassium rather than sodium is exchanged with calcium and magnesium. Before softening process, the hardness and iron content is generally checked. (Alyuz et al., 2009).

Pros of water softeners and deionizers

- The nuisance factor of hard water is reduced.
- This process could be used for the reduction of cations like barium, radium and iron.
Cons of water softeners and deionizers

- The process of regenerating the ion exchange bed dumps salt water into the environment.
- The elevated sodium concentration of most softened water can affect the taste and may not be good for people on low sodium diets, although sodium concentrations are typically quite low relative to sodium levels in most food.
- Cation exchange does not reduce the level of anions (like nitrates), or biological contaminants (bacteria, viruses, cysts); nor does the process reduce the levels of most organic compounds.
- Typically, approximately 50 gallons of rinse water per cubic foot of resin is required to totally remove hardness and excess salt from the resin after each regeneration.

1.6.7 OZONATION

The formation of oxygen into ozone occurs with the use of energy. This process is carried out by an electric discharge field as in the CD-type ozone generators (corona discharge simulation of the lightning), or by ultraviolet radiation as in UV-type ozone generators (simulation of the ultra-violet rays from the sun). In addition to these commercial methods, ozone may also be made through electrolytic and chemical reactions. Ozone is a naturally occurring component of fresh air. It can be produced by the ultraviolet rays of the sun reacting with the Earth's upper atmosphere (which creates a protective ozone layer), by lightning, or it can be created artificially with an ozone generator.

The ozone molecule contains three oxygen atoms whereas the normal oxygen molecule contains only two. Ozone is a very reactive and unstable gas with a short half-life before it reverts back to oxygen. Ozone is the most powerful and rapid acting oxidizer and will oxidize all bacteria, mold and yeast spores, organic material and viruses given sufficient exposure.

Advantages

- Ozone is primarily a disinfectant that effectively kills biological contaminants.
- Ozone also oxidizes and precipitates iron, sulfur, and manganese so they can be filtered out of solution.
• Ozone will oxidize and break down many organic chemicals including many that cause odor and taste problems.
• Ozonation produces no taste or odor in the water.
• Since ozone is made of oxygen and reverts to pure oxygen, it vanishes without trace once it has been used. In the home, this does not matter much, but when water companies use ozone to disinfect the water, there is no residual disinfectant, so chlorine or another disinfectant must be added to minimize microbial growth during storage and distribution.

Disadvantages
  o Ozone treatment can create undesirable byproducts that can be harmful to health if they are not controlled (e.g., formaldehyde and bromate).
  o The process of creating ozone in the home requires electricity. In an emergency with loss of power, this treatment will not work.
  o Ozone is not effective at removing dissolved minerals and salts.

1.7 OBJECTIVE AND SCOPE OF THE WORK

In view of the above said importance of the carbon based materials towards heavy metal ions adsorption, this research has been focused on development of carbon based materials viz carbon nanomaterials and graphene based materials. Initially, carbon nanotubes were grown and further tested for its adsorption capacity. The latter part was focused on graphene based materials and it’s composite with magnetic compounds with a view of increasing its adsorption capacity towards the removal of heavy metal ions.

The aim of this research work is to investigate the adsorption efficiency of heavy metal ions onto carbon based materials. Overall, the objectives of the thesis work are as follows.

1. Growth of carbon based materials (CNTs, and graphene ferrites nanocomposites) using chemical vapour deposition and solvothermal process.
2. Investigation of the as-prepared materials using the analytical and microscopic techniques such as X-ray diffraction (XRD), Field Emission Scanning Electron Microscope (FE-SEM), High Resolution Transmission Electron Microscope (HR-
TEM), Vibrating Sample Magnetometer (VSM), X-ray Photo Spectroscopy (XPS) and Atomic Absorption Spectroscopy (AAS).


4. Investigating diverse experimental parameters using batch mode adsorption process, various parameters such as effect of contact time, initial concentration, pH, adsorbent dosage and temperature.

5. Equilibrium adsorption isotherm and kinetic study analysis, using various models to evaluate the adsorption capacity of the heavy metal ions onto to as-prepared materials.

**1.8 STRUCTURE OF THESIS**

In view of the objectives discussed above, the thesis is organized in the following way. This thesis is composed of 5 chapters as follows.

Chapter 1: This chapter deals about the introduction of water treatments and waste water treatment methods and also presents the detailed introduction about the proposed research work. The objective and thesis structure are also included.

Chapter 2: It discussed about the details of various materials reported so far for heavy metal ions adsorption and techniques used for the removal of heavy metal ions with up to date literature review.

Chapter 3: The detailed experimental section of the material synthesis and characterization techniques has been discussed in this chapter.

Chapter 4: In this chapter it details about the results and discussion of the as-prepared materials for heavy metal ions adsorption and their interpretation onto various adsorbents.

Chapter 5: Finally, the conclusion of the entire work of this thesis and also possible future directions have been outlined in Chapter 5.