Mesopo. Environ. j., Special Issue E :1 -28, 2018
ISSN 2410-2598
proceeding of 2nd International conference of science and Art
University of Babylon and Liverpool John Moores
University, UK
Mesopotemia Environmental journal
journal homepage:www.bumej.com

The Most Practical Treatment Methods for Wastewaters: A Systematic Review

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To cite this article:

AlJaberi, F. Y. and Mohammed, W. T., The most practical treatment methods for wastewaters: A systematic review *Mesop. environ. j.*, 2018, Special Issue E;1-28.

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Abstract

Numerous techniques such as physical, chemical, biological, and physicochemical methods were used for the treatment of the aquatic system in order to remove various pollutants such as organics, inorganics, and heavy metals from domestic and industrial effluents. The aim of the present study is to review the most practical wastewater treatment techniques such as the chemical precipitation, ion exchange, adsorption, membrane filtration, and electrochemical methods which are used for heavy metals removal. Many of published studies and dissertations were reviewed in this paper to evaluate the general specifications of these processes and their advantages and disadvantages. The results revealed that electrochemical methods have a wide attention among other techniques due to their capabilities of overcoming most of the problems that occur in the conventional methods from the environmental and economic view.

Keywords: Water and wastewater treatment, Chemical precipitation, Ion exchange, Adsorption, Membrane filtration, Electrocoagulation.

Introduction:

The rapid development of industrial segments has led to a series of complex ecological contamination in the world [1]. The continuous use of water by industries and urban, produces wastewater effluents containing undesirable and sometimes toxic pollutants which pose complex and extremely varied problems related to each particular situation [2]. Therefore, wastewaters should be treated before being discharged into the aquatic environments by using efficient trends of removing heavy metals to protect people and the environment.

A huge amount of industrial wastewaters are discharged daily in the modern society [3;4] into environment system [5] as a result of the continuous development and advancment in technologies which substantially caused the degradation of the aquatic environment. Numerous types of wastewater which are directly or indirectly discharged into the aqueous environment, such as landfill leachate, textile, restaurant, carwash, laundry, tannery, and industrial wastewater [2;6].

The pollutants in industrial wastewater are classified into two types, bio-degradable and non-degradable [7]. The former type is represented by the domestic wastewater which is released in the residential area that is recognized as heavily contaminated with various organic and inorganic pollutants [8]. The latter type of industrial wastewater contains several types of toxic contaminants such as arsenic, pesticides, cyanides, and heavy metals. The increment of water usage leads to release huge of wastewaters that added more of impurities into the aquatic system which must be treated by the treatment processes. Several industries in Iraq such as the chemical and petrochemical industries have consumed, in 2014 only, more than 44300 cubic meters of fresh water per day and have released more than 17500 cubic meters of wastewater per day [9] that contain various kinds of organic and inorganic pollutants. The following table lists details of fresh water consumed and wastewaters discharged from Iraqi industries according to the Central Statistical Organization (CSO) report for the year 2014.

Table 1. Daily amounts of fresh water used and wastewater released from Iraqi industries in 2014 [9]

Type of industry	Fresh water consumed		wastewaters discharged	
	m^3/day	%	m^3/day	%
Chemical and petrochemical	44338.1	43.4	17554.8	38.8
Engineering	20689.2	20.3	11534.5	25.5
Food and medication	3476.0	3.4	1611.5	3.6
Textile	4844.7	4.7	3388.0	7.5
Construction and industrial services	28743.7	28.2	11155.3	24.7
Mixed sector companies	0.0	0.0	0.0	0.0
Total	102100.6	100.0	45244.0	100.0

Heavy metals are highly electronegative elements [10] having atomic weights higher than that of Fe (55.8 g/mol) [11] or a specific gravity greater than 5.0 [2;6], and their ions are toxic or poisonous at low concentration [12;13]. They are non-biodegradable contaminants [11;14] which tend to accumulate in living organisms and are the most serious environmental threats in recent years because of the wide applications of heavy metals and their components in processes [6;15]. Heavy metals could be released from soils into the aquatic system when these soils are broken down because of acid rain [16]. Table 2 shows the distribution of heavy metals in the industries effluents.

Table 2. Toxic heavy metals in industrial wastewaters [4;10]

Heavy metals	Manufacturing Industries
Copper	Electrical, plating, rayon
Nickel	Electroplating, iron, steel
Mercury	Chlor-alkali, chemical, scientific instruments
Zinc	Plating, Galvanizing, iron, steel
Arsenic	Phosphate fertilizer, metal hardening, paints and textile
Cadmium	Electroplating, phosphate fertilizer, pigments
Lead	Battery, paints
Chromium	Metal plating , tanning, rubber, photographic

Heavy metals and their components are usually presented in the aquatic system in trace amounts but many of these metals are toxic and carcinogenic even in low concentrations [6;17]. The following table lists the concentration of toxic metals in the discharged wastewater. While Table 4 explain the regulatory limits of these metals in water.

Table 3. Concentration limits of toxic metals in the discharged wastewater [18;19]

Toxic metals	MCL (ppm)
Arsenic	0.050
Mercury	0.00003
Cadmium	0.010
Lead	0.0060
Chromium	0.050

Table 4. Regulatory limits in water of some of toxic metals [11;20]

Toxic metals	EPA	OSHA*	WHO
Arsenic	0.01 ppm	10 microg/m^3	0.010 ppm
Mercury	0.02 microg/m^3	0.05-0.1 millig/m^3	0.006 ppm
Cadmium	5.00 microg/m^3	5 microg/m^3	0.003 ppm
Lead	0.15 microg/m^3	-	0.010 ppm
Chromium	0.15microg/m^3	-	0.050 ppm

*It is measured for an 8-hour workday, 40-hour workweek.

There are several techniques used for the treatment of wastewaters to remove heavy metals such as the chemical precipitation, ion exchange, adsorption, membrane filtration, and electrochemical processes. All of these kinds of treatment processes have advantages and disadvantages from the practical and economic insight.

2. Techniques for heavy metals removal

Heavy metals pose the greatest toxicity that causes serious damage to the ecosystem [21] and the purification of wastewater from highly toxic contaminants had the most consideration in recent years. Therefore, effective methods are required to accomplish the removal of toxic elements such as Cadmium, Chromium, Lead, Mercury, and Arsenic. The conventional techniques used for that purpose are described as follows.

2.1 Chemical precipitation

This is one of the widely used methods for the removal of heavy metals from the contaminated water and wastewaters [2]. Its mechanism depends on the change in form of the ionic constituents of pollutants dissolved in wastewater into solid particles by the addition of counter-ions to reduce the solubility [22]. There are several types of this process, and one or a combination of these types may occur to complete the precipitation operation in a water environment.

Hydroxide precipitation is one of these types and most commonly used an alkaline agent to remove heavy metal ions physically as hydroxide by sedimentation or filtration. The increment of pH of water or wastewater in the range of 8-10 causes the decreasing of solubility of various pollutant ions and thus sediments out the solvent because the enhancement of nucleation rate in higher pH values which enhance the distribution of the resulting particle size . It's relative simplicity in operation and low cost precipitant (such as lime which is more economical than other kinds of alkalis) make it more widely used than other types of chemical precipitation. Whereas, in some cases of heavy metals treatment, 2-4 hours are needed to complete the operation while it works slow and not complete for other metals removal especially mercury, cadmium, and lead [23]. Moreover, such method is caused complex agents in wastewater then incomplete process and a large sludge amounts as a secondary pollution is produced that may be reached 50% of the treated wastewater volume and then they will be difficult to dewater due to the amorphous particle structure [22;24].

Other types of this technique used such as the carbonate precipitation and sulfide precipitation which are not different so more than the hydroxide precipitation except the range of pH of the pretreated solution and the agents required to accomplish the precipitation of the contaminant ions.

Practically, coagulation and flocculation processes often occur together and in cooperation or subsequent to the precipitation operation to remove pollutants ions by converting them to an insoluble form [22]. Therefore, the consequence of these serial operations involves the formation of a solid phase by precipitation, coagulation, where the containment is trapped by the formation of a precipitate, and flocculation is the agglomeration of a coagulating chemical [25]. The following equation explains the conceptual mechanism of heavy metal removal via chemical precipitation [18]:

$$\mathbf{M^{+2} + 2(OH)^{-} \Leftrightarrow M(OH)_2 \downarrow} \qquad \textbf{(1)}$$

Where M^{2+}, OH, and $M(OH)_2$ represent the dissolved metal ions, the precipitant, and the insoluble metal hydroxide respectively. The following figure shows a simple schematic of a chemical precipitation process.

Mesopotamia Environmental Journal
Mesop. environ. j. 2018, Special Issue E.;1-28
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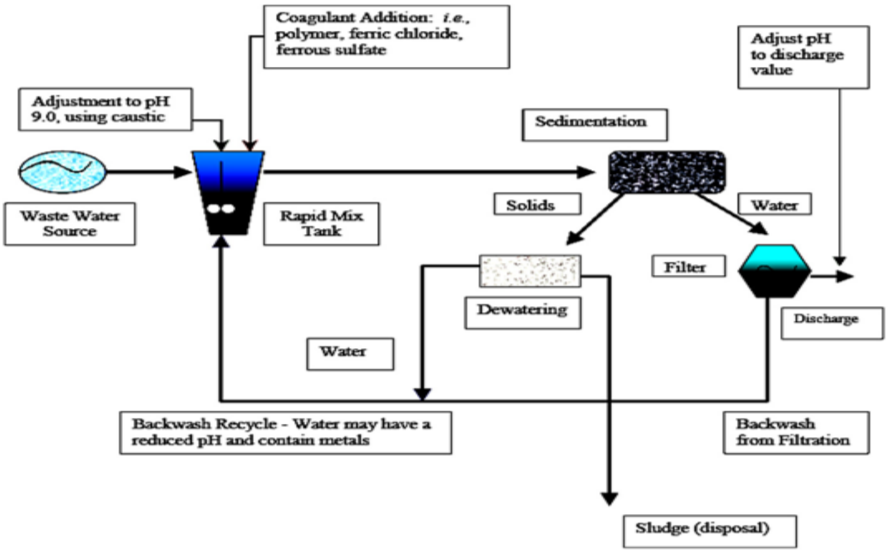

Fig. 1. Schematic of a conventional metals precipitation treatment process [18]

2.2 Ion exchange

A conventional chemical process used for removing pollutants from wastewaters by the changing of the chemical form of these pollutants through the attraction of soluble ions from the liquid phase to the solid phase which is held by mixed anionic or cationic groups [24;25]. Therefore, the ion exchangers are classified into a cation exchanger when it possesses cations such as hydrogen and sodium ions, and correspondingly anion exchanger is a type that involves anion exchange such as hydroxyl and chloride ions [24]. The following reversible equations represent the major difference between this technique and other adsorption phenomena [26]:

Cation exchange:

$$\mathbf{M^-A^+ + B^+ \Leftrightarrow M^-B^+ + A^+} \qquad (2)$$

Anion exchange:

$$\mathbf{M^+A^- + B^- \Leftrightarrow M^+B^- + A^-} \qquad (3)$$

Ion exchange technique, as is shown in Fig. 2, use organic ion exchange resins which are water-insoluble solid substances and they can be distinguished into natural and synthetic resins (i.e., cationic, anion, and chelating exchange resins) that can be easily regenerated using a regenerative solution such as NaOH after recovering and then it can be reused [18;27;28].

Usually, polymeric resins are employed such as zeolite, purolite, amberlite, etc. However, they are so complex and should have several important properties to be efficient such as the particle size, moisture content, resin capacity and selectivity, and distribution coefficient [26].

The ion exchange process has some advantages like the treating aqueous solutions with only low concentration of heavy metals [28], and convenient operations. Otherwise, the drawbacks involve the onerousness in elution of toxic metals from the chelating ion exchangers [29], which are too expensive, inefficient to remove some metals such as cadmium from water [30;31], highly sensitive to the value of solution pH [24], and inoperative of handling the concentrated metal solution [18].

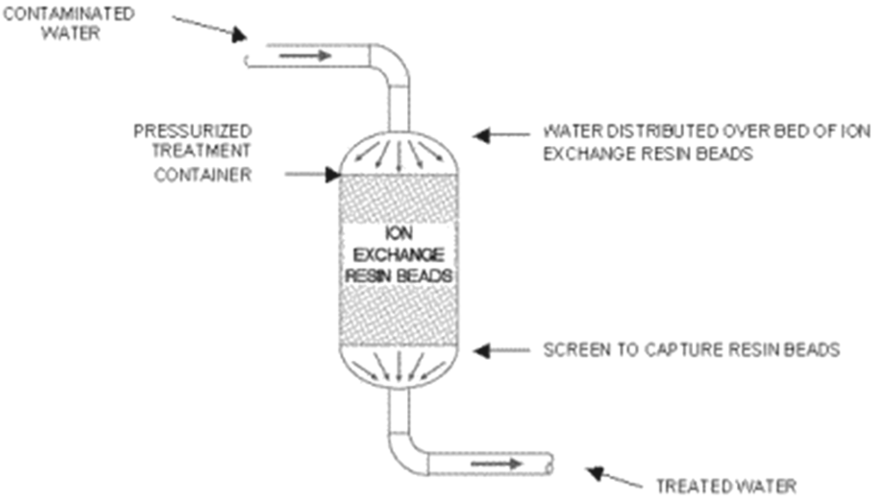

Fig. 2. Schematic of ion exchange treatment process

2.3 Adsorption

Another highly effective physico-chemical treatment technique which is widely used to remove various kinds of contaminants from pollutant water and wastewater is adsorption. The main principle of this method is the mass transfer of ions from the liquid phase to the surface of the solid phase bounded by physical and/or chemical interactions [18;24]. Therefore, all of the adsorption methods are depending on solid-liquid equilibrium and on mass transfer which relies on the diffusion of either intra-particle or film formation or both [19].

The adsorption process is classified into physical adsorption and chemical adsorption according to the kinds of the intermolecular attractive forces, which caused precipitation of adsorbents from solution into the molecular scale pores. The former type occur due to the forces of attraction which originated between the adsorbent and the adsorbate, i.e. belongs to Van der Waals forces. Meanwhile the chemical adsorption, as otherwise known, the activated adsorption, involves a chemical reaction between the adsorbent and the adsorbate. Therefore, new kinds of electron bonds are formed such as the covalent and ionic bonds upon the strong interaction between the adsorbent and the adsorbate.

Generally, adsorption occurs in three serial steps starting from the transport of the contaminate from the solution to the adsorbent surface the adsorption on that surface and finally transport within the adsorbent particle [18].

There are several types of sorbents that must possess a large surface area, micro-porous character and chemical nature of their surface [32] (i.e., mineral, organic, or biological) such as the zeolites, industrial byproducts, agricultural waste, biomass, and polymeric materials [19;24;33].

Bisorption uses the biomass adsorbents that are produced from the agriculture byproducts due to the involving of cellulose, carbohydrate, silica, and lignin. This passive adsorption kind, which is fast and reversible, belongs to the rule of physicochemical interaction effect, but the selectivity tends to be low. On the other hand, bioaccumulation adsorption kind

ISSN 2410-2598

is more preferred than biosorption as is shown in the comparison between these two types in Table (5) upon to some parameters.

Table 5. **The comparison between biosorption and bioaccumulation adsorption types [11]**

Parameter	Biosorption	Bioaccumulation
Cost	Usually low. Biomass can be obtained from industrial waste. Cost associated mostly with transportation and production of biosorbent.	Usually high. The process occurs in the presence of living cells that have to be supported.
pH	The solution pH strongly affects the sorption capacity of heavy metals. However, the process can occur within a wide pH range.	Significant change in pH can strongly affect living cells.
Selectivity	Poor. However, this can be increased by modification/ biomass transformation.	Better than in the case of biosorption.
Rate of removal	Most mechanisms occur at a fast rate.	Slower rate than in the case of biosorption because intercellular accumulation takes a long time.
Regeneration and reuse	Biosorbents can be regenerated and reused in many cycles.	Reuse is limited due to intercellular accumulation.
Recovery of metals	With an adequate eluent the recovery of heavy metals is possible.	Even if possible, biomass cannot be used for other purposes.
Energy demand	Usually low.	Energy is required for cell growth.

Numerous low-cost adsorbents are investigated to remove heavy metals from wastewaters as shown in Fig. 3, such as the aquatic plant [34], yeast [35], pomegranate pall [36], commercial powder activated carbon (CPAC) [32], sawdust [37], granular activated carbon (GAC) [38], rice husk [39], peel sunflower [40], coconut activated carbon [41], date stone activated carbon [42], beans pall [43], egg shell [44], olive leaves [45], palm tree waste [46], etc. In practical, these adsorbents should have high selectivity to provide thermal and chemical stability, mechanical strength, fouling resistance, regeneration capacity, and low solubility in the solution in contact [11;18;19].

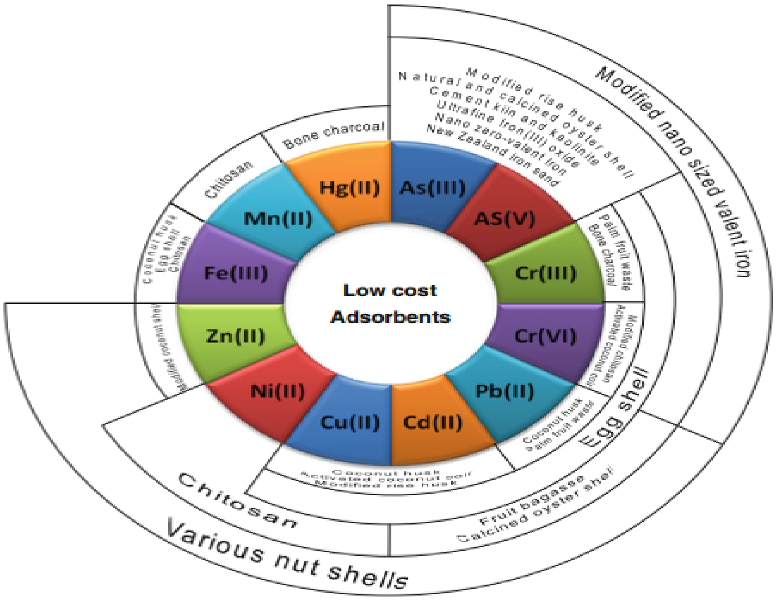

Fig. 3. Low-cost adsorbents and their corresponding ability of heavy metals removal [19].

The higher equality of activated carbon the greater consumption of the cost beside the addition of larger cost of chemical and thermal regeneration of the spent carbon [41]. Moreover, low-cost adsorbents are usually not readily available and must be cleaned and pretreated in order to eliminate the residue of pollutants present on the adsorbent's surface. Moreover, some of these adsorbents are not ready to use in case of their nature form, therefore they need to be modified and enhanced to change their original states to be active adsorbents.

2.4 Membrane filtration

This is a general term used to describe a number of different separation physicochemical processes, continuous and batch modes [47-49] which are very modern innovation than thermal procedures [50] and more applicable to remove suspended solid, organic compounds, and inorganic contaminants such as heavy metals [6;24].

There are numerous kinds of membrane filtration technique which are classified belongs to the size of particle that must be retained [24;51] and they are used for the aquatic environment treatment processes such as Microfiltration (MIF), Ultrafiltration (UF), Nano-filtration (NF), Reverse osmosis (RO), and Electrodialysis (ED) [20;52;53]. They are utilizing with a high efficiency, easy operation, and space saving [6;14] and they could be run as pressure driven, concentration gradients, or electrical potential gradients [48]. The following figure shows a general schematic of membrane filtration technique.

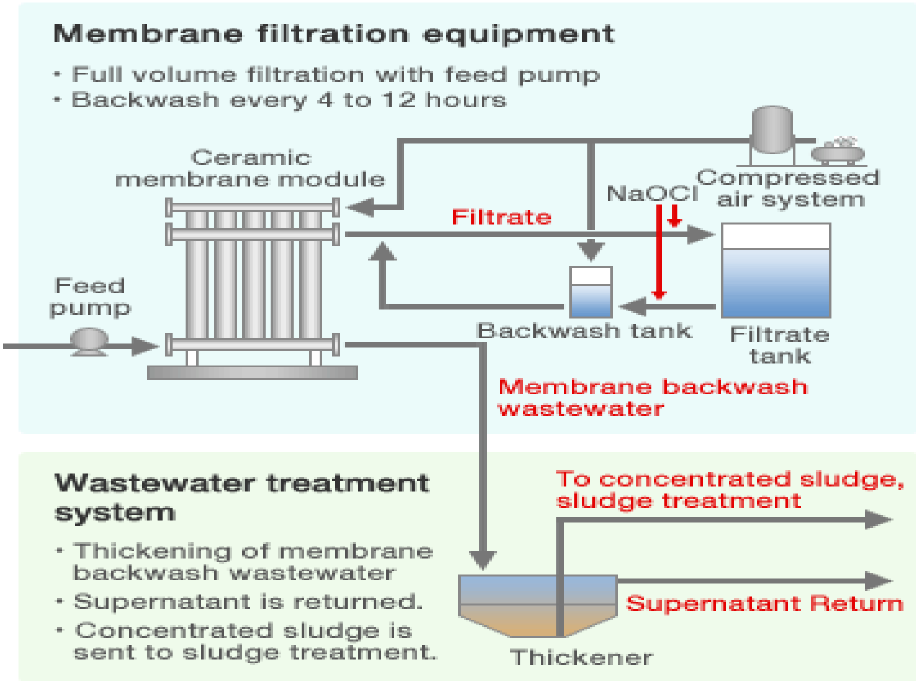

Fig. 4. Schematic of membrane filtration technique

Membranes are usually made of polymer, ceramic, or inorganic materials which consist of a lot of very small pores [51] and have a molecular weight in the range of 100 to 1000 Dalton (e.g., 1 Da=1.66x10^{-24} g or 1 g/mol) [48]. Therefore, a membrane should be a semipermeable and dense barrier layer in the polymer matrix [24]. These membranes are manufactured according to the type of filtration and then to the kind of contaminants as shown in Fig. 5.

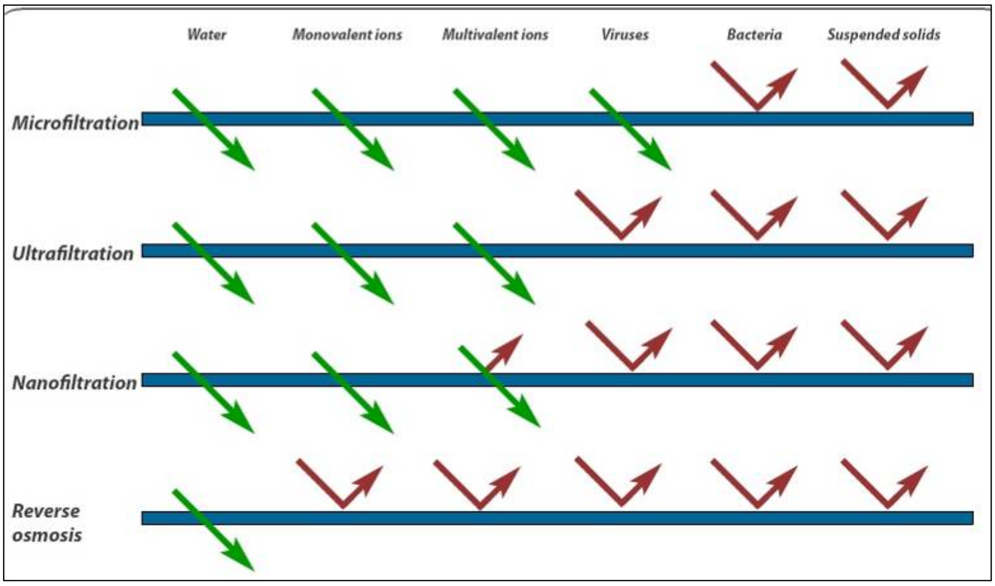

Fig. 5. Characteristics of membrane filtration processes [54]

Microfiltration method (MIF) is practically applied to remove microorganisms from water that is used in some medical applications requirements [20].

While Ultrafiltration process (UF) is working at low trans membrane pressure in which the membrane has a pore size ranging (5-20nm) larger than the dissolved metal ions. It's metal removal efficiency achieves more than 90% if the range of the metal concentration is 10 to 112 ppm at a pressure supplied (2-5 bar) and (5-9.5) of the pH value. Polymer-supported ultrafiltration (PSUF) and the complexation-ultrafiltration (CUF) techniques are low energy demands and they have a higher selectivity due to the use of selective binding [6;24;55] but the important threat is the generation of sludge [33].

Both Microfiltration and Ultrafiltration are low pressure membrane applications [49] which are characterized by their ability to remove pollutants particles upon the size of the membrane pores [48], and they are traditionally applied together in membrane bioreactor (MBR) [51].

Another conventional type of membrane filtration technique is reverse osmosis process (RO) [51;56;57]. It consists of a semi-permeable membrane and uses high pressure to force a solution through the membrane that conserves the solute on one side and the pure solvent will be passed into other side of the membrane [6;24;49]. Reverse osmosis efficiency depends on several parameters such as the solute concentration, pressure supplied, and the rate of water flux [24;57].

The Nanofiltration (NF) process is utilized for the elimination of toxic metal from wastewater [14;48]. It is a reliable and comparatively low energy consumption [6].

Many of the treatment systems use the Reverse osmosis and the Nanofiltration techniques to deal with each other in order to treat the wastewater that containing toxic metals [6;14].

Electrodialysis (ED) is an electrochemical process using membrane filtration technique to eliminate heavy metals ions from wastewaters across a selective charged membrane belongs to the driving force of the electrical field. The polyelectrolyte membrane is classified into two types, cation exchange and anion exchange, that are inserted between anode and cathode electrodes [6;48-50]. This technique is more effective than the reverse osmosis method, therefore, it is generally applied for the desalination of industrial effluents that containing TDS which ranges 500 to 1500 ppm [50]. The main influential parameter on its performance is the voltage applied [24].

Other types are employed the concept of membrane technique such as the forward osmosis (FO) that do not require high pressure like reverse osmosis method [58]; and the phytofiltration process that dependent on employing the plant roots or seedling pieces for hazardous metals removal from the aqueous wastes [53].

In general, the problematic points in many applications, which affects the efficiency of these methods, are the fouling, membrane life, high initial and maintenance costs, and low flow rate of the treated solution [16]. Table (6) explains distinctly the average membrane pore size of these techniques of membrane filtration processes.

Table 6. Membrane pore size characteristics

Membrane process	average membrane pore size (nm)
Microfiltration (MIF)	200
Ultrafiltration (UF)	2-50
Nanofiltration (NF)	<2
Reverse osmosis (RO)	<1

ISSN 2410-2598
(proceeding of 2nd International conference of science and Art –University of Babylon and Liverpool John Moores University, UK).

Photocatalytic reduction-oxidation (PCR or PCO) is also used for destruction of pollutants in wastewaters which is induced by the consumption of cheap photons from the UV light and sensitized by a semiconductor photo catalyst such as TiO_2 to convert the metal ions into metal oxides [17;18;59] as is shown in the following figure.

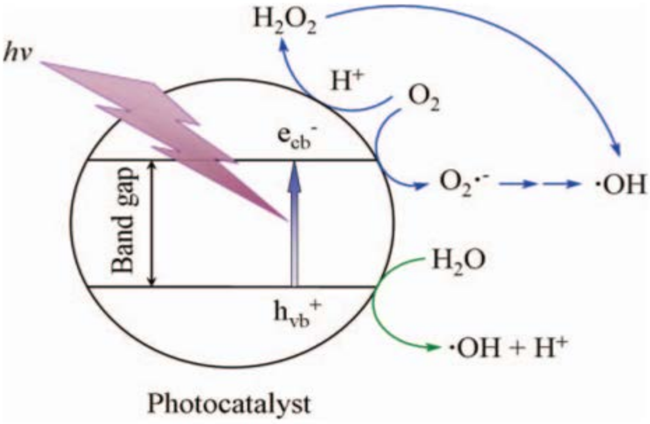

Fig. 6. Mechanism of photocatalytic process acting on the semiconductor photocatalyst [60]

The main advantages and drawbacks of the previous treatment techniques could be summarized in the following table.

Table 7. The main advantages and drawbacks of the previous treatment techniques of heavy metal in wastewaters

Treatment method	Advantages	Drawbacks
Chemical precipitation	• Low capital cost • Simple operation	• Additional operational cost to disposal the huge sludge
Ion exchange	• Treating wastewaters with low concentration of heavy metals • Convenient operations	• Difficult in elution of toxic metals from the chelating type • Too expensive • Highly sensitive to pH value of solution
Adsorption	• Easy operating conditions • Applicable for wide range of the pH • High metal binding capabilities	• Low selectivity • Generation of waste products
Membrane filtration	• Small space requirement • High selectivity	• High operational cost due to membrane fouling
Photoctatlysis	• Removal of metals and organic pollutant simultaneously • Less harmful by-products	• Long duration time • Limited applications

2.5 Electrochemical technique

This is another aquatic treatment technique that has the successive ability to remove various kinds of contaminants from wastewaters such as toxic metal ions, organics, and inorganics [61-63]. This method is more reliable and economical when compared to other treatments techniques [64] due to its capability to make several contributions to ecological treatment, recycling, and monitoring [63;65]. The schematic of electrochemical cell is shown in the following figure.

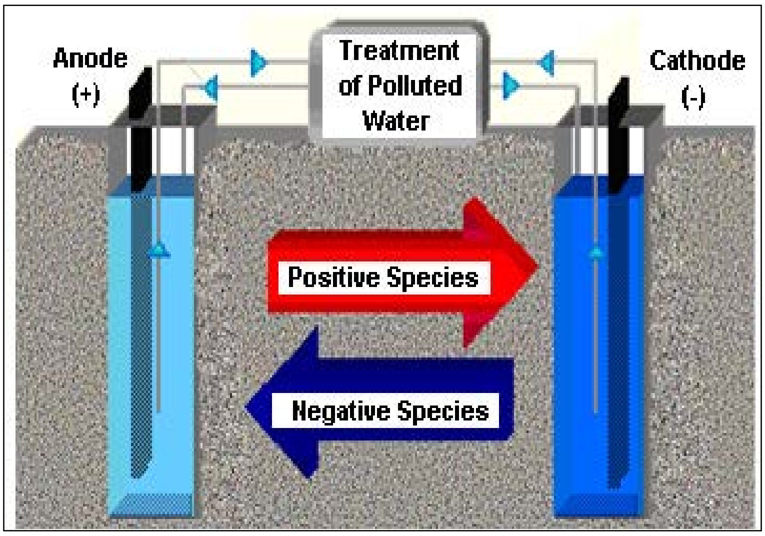

Fig. 7. Schematic of electrochemical cell

During the last two decades [66], electrochemical technologies have been developed in water and wastewater treatment with higher efficiency than other conventional methods due to their eco-friendliness by controlling pollution [12], versatility through the ability to treat a variety of pollutants via redox reactions [14], energy efficiency due to the minimizing of non-homogeneously in current applied distribution then the voltage drop [63;67], safety, selectivity, and cost effectiveness [14;66;68].

Moreover, electrochemical technologies are simple, easily operable, and the treated wastewater is potable, colorless, and odorless with low sludge production without the generation of secondary pollution [2]. Besides, they are smaller systems which allow controlled and rapid reactions [68] depending only on the releasing ions formed "nascent" colloids in much more controlled way without using any chemical or microorganisms that may prove the simplicity of electrochemical unit design without solution dosing [61;68]. There are still few drawbacks which may limit their application such as short lifetime of electrodes materials and low current efficiency [63].

The main and important parameter of all electrochemical technologies performance is the current density supplied which it is more effective variable to control the rate of reaction in the electrochemical reactor. Electrochemical technique involves electro-oxidation, electrochemical reduction, electro-flotation, and electrocoagulation.

2.4 Electrocoagulation method

Electrocoagulation term is involved in a couple of procedures, electricity and chemical coagulating [61], which used to produce a clean electrochemical technique with various application of treating water and wastewater without the generation of second pollution [69;70].

It is a simple method and fast, unlike biological treatment methods which required a specific condition to generate coagulants then the inapplicability of dealing with high toxicity components [2;62], therefore, and for that challenge, among the different methods of wastewater treatment, electrocoagulation technique has the capability to overcomes this problems due to various reasons such as ecological compatibility, ingrained safety, energy, and cost efficiency [71].

ISSN 2410-2598

Electrocoagulation is derived from the coagulation-flocculation process in the theory of the destabilizing negative colloidal particles via the addition of some metal salts such as alum ($Al_2(SO_4)_3$), ferrous sulfate ($FeSO_4$), and ferric chloride ($FeCl_3$) [62;72] where these colloidal particles will be surrounded by the electrical double layer compressed by the positive charge of cations [30;47]. But, the extra development of this electrochemical technique is the production of the coagulating agents which occurs in situ and belongs to the process of electro-oxidation at the anode electrode [3;30] and depending on the hypothesis that states: "the pollutants present in the wastewater are maintained in a solution by electrical charges"[2]. Moreover, hydrogen gas is released from cathode electrode to assist the natural buoyancy of the flocculated particles to the surface of the treated wastewater [62;71;73] by another benefit process called electrofloatation [74] which is combined with electrocoagulation process for contaminants removal.

Fundamentally, the main responsible effect of the electrocoagulation performance is the production of flocs $Al_2(OH)_3$ as a result of the electrodeposition of aluminum ions from both of electrodes [75] depending on the time and applied current which measure the generation of coagulants, and the rate and size of bubbles released, and hence influence the evolution of flocs [3]. Therefore, it uses electricity to control the destabilization mechanism according to the following summary [2;30] and Fig. 8:

- Due to the current supplied to the electrocoagulation cell, the interactions of ions released by oxidation of the artificial anode compresses the diffusion double layer around the charged particles.

- At the anode electrode with metal M:

$$M_{(S)} \rightarrow M^{+n}_{(aq)} + ne^- \qquad (4)$$

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \qquad (5)$$

- At the cathode electrode:

$$2H_2O + 2e^- \rightarrow H_{2(g)} + 2OH^-_{(aq)} \qquad (6)$$

- Ionic species presented in wastewater are neutralized by the counter ions produced via the electrochemical dissolution of the artificial anode which leads, this charge neutralization issue, to enhance the Van der Waals attraction force and minimize the electrostatic inter-particle repulsion then zero net charge result and coagulation process occurs.

$$M^{+n}_{(aq)} + ne^- \rightarrow M_{(S)} \qquad (7)$$

- Consequently, the flocs formed create a sludge blanket of colloidal particles. These flocs are relatively larger, heavier, and contain less bound water then precipitate out easily better than in traditional chemical precipitation method [2].

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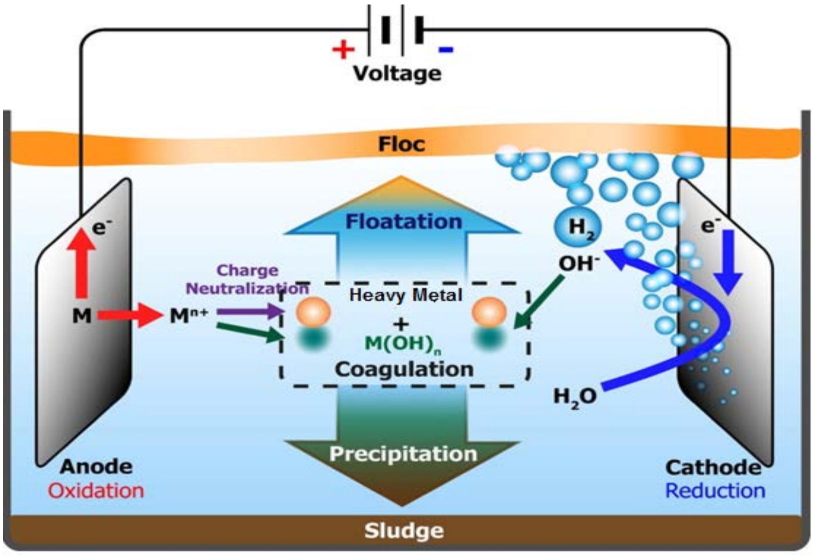

Fig. 8. General schematic of electrocoagulation technique [76]

Iron and aluminum materials are mostly used for electrodes due to their availability and relatively low cost [3;74] but, the electrochemical of dissolution of iron anode is more complex owing two oxidation states of iron species Fe^{+2} (Ferrous) and Fe^{+3} (Ferric) as explained clearly in the following equations [71]:

$$Fe \rightarrow Fe^{+2} + 2e^{-} \quad (8)$$

$$4Fe^{+2} + O_2 + 4H^{+} \rightarrow 4Fe^{+3} + 2H_2O \quad (9)$$

$$Fe^{+3} + 3H_2O \rightarrow Fe(OH)_3 + 3H^{+} \quad (10)$$

The electrodeposition of aluminum in the electrocoagulation cell is the main reason for the electrodes consumption along the duration of the experiments done [77].

Despite the mechanisms of electrocoagulation included, they are not yet clearly understood [2] but, in general, the electrocoagulation method involves two essential processes, the first one is the electrodeposition of aluminum electrodes and formation of flocs due to the polymerization of aluminum oxy-hydroxides as shown in the following equations:

$$2Al \rightarrow 2Al^{+3} + 6e^{-} \quad (11)$$

$$Al^{+3} + 3OH^{-} \Leftrightarrow Al(OH)_3 \quad (12)$$

While the second essential process is the simultaneous production of hydrogen at the cathode electrode [76] as shown in equation (6).

Different hydroxo-complexes including monomers and polymers will be formed such as $Al(OH)^{+2}$, $Al(OH)_2^{+}$, $Al_2(OH)_2^{+4}$, $Al_6(OH)_{15}^{+3}$, $Al_7(OH)_{17}^{+4}$, $Al_8(OH)_{20}^{+7}$, $Al_{13}O_4(OH)_{24}^{+7}$, and $Al_{13}(OH)_{34}^{+5}$ which have high affinity for dispersed particles as well as counter ions to produce very effective coagulating agents [47;73].

$$n\ Al(OH)_3 \rightarrow Al_n(OH)_{3n} \quad (13)$$

Therefore, the electrocoagulation method could be considered as an autocoagulating or electrocatalysis method without further addendum of chemicals then less amount of sludge produced if compared with other conventional techniques [2].

Various researchers have used the electrocoagulation method in their studies for several pollutants removal such as heavy metals [47;65;71;73], paint [70;74], detergents [62]; TDS [78], COD and TSS [31], etc.

Conclusions

The rapid development in the countries of the world with regard to the establishment of factories of various kinds as well as the expansion of cities has caused many environmental problems and the most important problem of water pollution because of the disposal of these facilities as wastewater. The present research has reviewed some of the specifications of these polluted water as well as the most important pollutants that contain it. Among these pollutants are toxic metals, which have a significant impact on the aquatic environment and therefore the health and safety of the human as well as the economic aspects associated with it. Thus, the methods of wastewater treatment that have been widely used have been presented. It has been shown that the electrochemical methods of treatment are characterized by their very practical nature and the low generation of new pollutants unlike others. The results found that electrochemical methods have a wide attention among other techniques of wastewater treatment due to their capabilities of overcoming most of the problems that occur in the conventional methods from the environmental and economic view. The main and important parameter of all electrochemical technologies performance is the current density supplied which it is more effective variable to control the rate of reaction in the electrochemical reactor. Electrochemical technique involves electro-oxidation, electrochemical reduction, electro-flotation, and electrocoagulation. Electrocoagulation is a simple method and fast, unlike biological treatment methods which required a specific condition to generate coagulants then the inapplicability of dealing with high toxicity components

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