

Electrochemical Water Treatment Technology in Viet Nam: Achievement & Future Development

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Abstract: Electrochemical technology is a promising technique for water and wastewater treatment in the world. This technology has many advantages as compact model, saving area, highly removal efficient of non-biodegradable compounds, reduction of secondary by-products. There are some different electrochemical techniques such as electroflotation; electrocoagulation using sacrificial electrodes; direct or indirect electrochemical oxidation using Dimensionally Stable Anodes (DSA) and electrodialysis to separate ions in water. In Vietnam, some researches on water and wastewater treatment by electrochemical technology have been studied in the recently year. In this paper, notable results of studies in the application of water and wastewater treatment by electrochemical technology in Vietnam are reviewed in detail. The researching trends of the authors mainly focused on the laboratory scales and the simulated wastewater. Therefore, there are not enough scientific basis to apply for real treatment plants. In the future, electrochemical methods should be used to study the different types of wastewater at the pilot scales, especially difficult handling wastewater and toxics that biological methods cannot handle effectively.

Keywords: Water Treatment, Electrocoagulation, Electroflotation, Electrooxidation, Electrodialysis

1. Introduction

Nowadays, the industrial development has achieved many significant goals for the economic growth in Viet Nam. In addition, this process discharged waste into the environment in general and water resource in particular. At present, common methods used for treating wastewater are physical, chemical and biological methods. However, these methods have not always achieved satisfactory results with increasingly stringent discharge regulations. The wastewaters containing heavy metals, phenolic compounds, and non-biodegradable pollutants are very difficult to handle and easily retained in the receiving source, which affect human health. On other hand, traditional physical and chemical methods have relatively high process costs, ineffective or can lead to secondary pollution [1]. Therefore, how to eliminate

these biodegradable components in wastewater are essential.

Over the last two decades, electrochemical technology has been studied in the field of wastewater treatment in the world. Many studies have been conducted in the laboratory and some good results have been commercialized. Electrochemical treatment has the following advantages: direct or indirect oxidation flexibility; space saving; high-performance processing and can be integrated with environmentally friendly methods [2]. Some types of wastewater have been studied such as: tanning [3, 4], pharmaceuticals [5, 6], toilet wastewater [7], textile [8, 9], sugarcane [10, 11], carwash [12], dairy [13] and some other wastewater types.

In Vietnam, over the past ten years, electrochemical techniques in water and wastewater treatment have also been studied. However, this issue is relatively novel and limited in the application. In this article, the current state and evaluation

of water treatment results in Vietnam by electrochemical will be summarized in detail. Then the suitable future research direction in this field in Viet Nam will be proposed.

2. Electrochemical Methods for Water Treatment

2.1. Electrocoagulation

Electrocoagulation is technology that is used long-standing and popular today. In this process, when current density is applied, the coagulants are created inside the reactor using sacrificial electrodes, usually iron or aluminum. The metal ions dissolved at the electrode will react to form hydroxide, polyhydroxide compounds that produce a coagulation processing. Chemical reactions in this process can be summarized below [14]:

- a. The metal is oxidized into cations at the anode, according to the equation:



- b. Water is reduced into hydrogen gas and hydroxide anions at the cathode:



- c. General reaction:



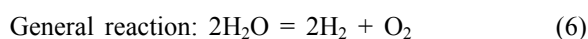
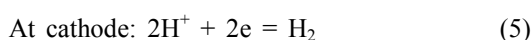
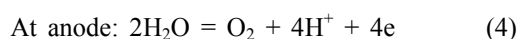
The advantages and disadvantages of this process are shown in Table 1.

Table 1. Advantages and disadvantages of the electrocoagulation method [14].

Advantages	Disadvantages
Ability to treat drinking water and wastewater	Maintenance required regularly
Combination of oxidation and coagulation processes	The electrode breaks down over time
Reduced demand for chemicals (replaced by aluminum and iron electrodes)	Wastewater must has high conductivity
Reduce operating costs	
Reduce the risk of secondary pollutions	
Less generated sludge	
Low energy requirements	
Ability to use solar energy	

2.2. Electroflotation

Electroflotation is a process that pollutants are loaded on the reactor surface by hydrogen and oxygen microbubbles produced by electrolysis of water at the cathode and anode. Generation of the hydrogen and oxygen bubbles are simulated by the equations below:



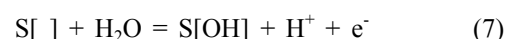
Several studies have combined electroflotation and electrocoagulation in a reactor tank. The coagulation processes occur at the anodes generated aluminum hydroxide ions or iron hydroxide ions which combined to the hydrogen and oxygen bubbles are generated at the anodes and cathodes to increase the efficiency of the process. [15].

2.3. Electrooxidation

2.3.1. Direct Oxidation

In order to reach high performance of direct oxidation process, the anode needs two characteristics: high oxidation potential and corrosion resistance. The oxidation of an organic compound at the anode is simulated in three steps [2]:

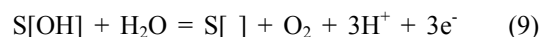
- a. Discharge of water forming an adsorbed hydroxyl species:



- b. The adsorbed OH is the 'activated state' of water in O-transfer reactions to the organic molecule R:

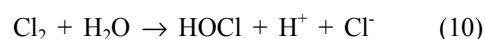


- c. Co-evolution of O₂ by oxidation of water diminishing the current efficiency:



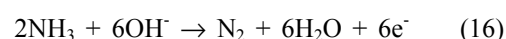
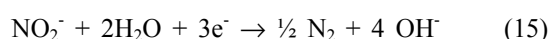
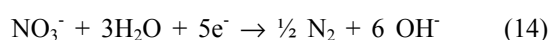
2.3.2. Indirect Oxidation

Oxidants such as chlorine, hypochlorite, Fenton's reagent, peroxide, peroxodisulphate and ozone are used for indirect oxidation at the anode [14]. The chlorine and hypochlorite are often used because they are easily generated at the anodes. The indirect oxidation mechanisms of the (R) organic compounds are described by the following equations [16]:



2.3.3. Electroreduction

Similar to electrooxidation method, the electroreduction also has two groups: direct and indirect. The advantages of this direct process are the reducing nitrate at the cathode to generate nitrogen gas and hydroxide ions. However, some undesirable byproducts such as nitrite and ammonia are also produced during the nitrate reduction process. These two byproducts are also involved in the process in which the nitrite is reduced at the cathode, ammonia is oxidized at the anode according to the following equations [16]:



The electroreduction is often used for the treatment of

organic dyes that are insoluble in water and poor contact with the electrode surface. It dissolves some chemical substances such as Anthraquinone, Fe-TEA and Glucose to enhance the solubility of dyes and decomposition by indirect reduction. [12].

2.4. Electrodialysis

Electrodialysis (ED) is an electrochemical process. This process involves the movement of ions through selective ion-exchange membranes, which are the results of electrostatic attraction between the ion and the two electrodes. In addition to the desalination function, ED can also remove contaminants in water as soluble ions by electrostatic attraction [17].

The advantage of ED is that the recovery rate of water is higher than the Reverse osmosis (RO) process, leading to lower wastewater treatment costs and increased water using efficiency. In addition, the life of the ion-exchange membrane is relatively high. The ED technology will require less energy than the RO when the salinity is less than 5000 mg/l [17].

3. Results of Water Treatment by Electrochemical Methods in Viet Nam

3.1. Electroflotation and Electrocoagulation

3.1.1. Electroflotation

The electroflotation technology in Vietnam was investigated for pre-treatment of wastewater before aerobic steps. The wastewater output has a COD removal efficiency as 70-80%, Nitrogen removal efficiency as 50-60%. Although this quality has not reached the standard for direct discharge to receiving sources, it is generally feasible for the thorough treatment process of pollution compounds in the next units. Dinh Quang Du *et al.* (2015) [18] was investigated electroflotation process for pre-treatment of pesticide production wastewater. In this study, the operating parameters of the electroflotation model include: 45° of angle electrode, aluminum electrode with 486 cm^2 square, 1 cm of electrode gap, retention time was 30 minutes and 12 V electrolytic voltage, H_2O_2 concentration was 80 mg/L and 30 mg/L FeCl_3 concentration. The results showed that SS, COD, BOD_5 , TKN, TP removal efficiency were obtained as 83%, 76%, 57%, 53% and 82%, respectively. After the flotation process, the dissolved oxygen (DO) value in water increases. Compared with the results of using aerobic bioreactor rollers, the pre-treatment of electroflotation is more effective, which satisfies the requirements for the next biological treatment. Similarly, electroflotation process is applied at the pre-treatment stages, Le Hoang Viet *et al.* (2015) [19] evaluated the technical feasibility of applying this method for wastewater treatment system in catfish processing facilities. The experimental conditions are similar to the research of Dinh Quang Du. Under these experimental conditions, the SS, COD, BOD_5 , TKN, TP removal efficiencies were obtained as 83.2%; 76.8%; 68.3%; 66.9% and 71.4%, respectively. The

electroflotation process showed that during the reaction, the metal material on the electrode is decomposition at same performances. Therefore, the bigger the electrode size, the higher removal efficiency.

3.1.2. Electrocoagulation

Comparison of anthraquinone dye by two methods: electrocoagulation and electro-Fenton processes. The electrocoagulation uses an aluminum electrode with 0.5 mA/dm^2 current density, anodic area is twice cathode sizes, the stirring speed in the reaction is 1000 rpm, 0.5 g/L NaCl solution. During electrochemical reaction, aluminum anode dissolves to generate aluminum hydroxide which remove COD from wastewater. The COD removal efficiency decreased when increasing COD concentration. At the influent COD concentrations were 600 mg/l and 1040 mg/l for 97.33% and 86.92% performances respectively in 40 minutes. With the ratio of $\text{H}_2\text{O}_2:\text{FeSO}_4 = 5:1$ added to the Fenton reaction, the input COD concentrations were 600 mg/l and 1040 mg/l for 69.5% and 40% performances, respectively. This results illustrate when the dye concentration increase, the Fenton compounds are not sufficiently decomposed causing reduced efficiency. The comparative dyes removal time of two methods are shown in Figure 1, in the same time COD removal efficiency of electrocoagulation was higher than electro-Fenton reached approximately 90% performances after 25 minutes. The study also tested on the anthraquinone dye, the electro-Fenton processing efficiency is relatively better at 85% when the input dye concentration is 458 mg/l. The performance would depend on the types of dye and input concentration (Nguyen Thi Huong, 2009 [20]).

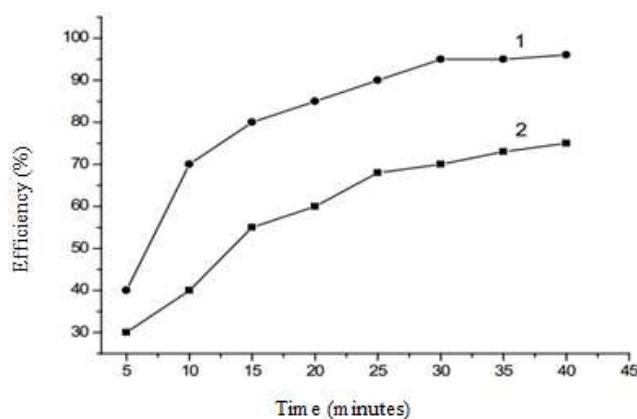


Figure 1. COD removal performance of dyes wastewater (1. Electrocoagulation; 2. Electro-Fenton process [16]).

Evaluating and comparing the performance of electrocoagulation process between AC (alternating current) and DC (direct current). Ho Van Khanh (2004) [21] has investigated to use aluminum electrode to treat dye wastewater with the conditions: 1 – 1.5 A/dm^2 of current density, a range of 0.5–1 g/L NaCl concentration and dye concentration less than 80 mg/L. The results indicated relatively high removal efficiency, rapid separation rate (2-5 minutes per phase), relatively low dissipation of aluminum

electrode and less power wastage. With a small dissipation (12% -15%) while the processing time is quite fast. That demonstrate not only effects of the aluminum colloidal particles but also effects of electric field force between the electrodes. The treatment performance of aluminum electrodes with AC may be similar to DC. However, the DC could remove more types of dyes than the AC.

Electrocoagulation combined between hollow iron electrode and aeration were studied to remove contaminants in plating wastewater. The Cr, Ni, Cu, Zn removal efficiencies were 99.48%, 99.96%, 99.91%, 99.88% with input concentrations of 350 ppm, 105 ppm, 40 ppm, 5 ppm, respectively. The hollow electrode has treatment performance the same to rectangular electrode. The dissipation of iron electrode was investigated by cyclic voltammetry and Tafel extrapolation methods. The results showed that the dissipation of iron electrode is low but may be apply for the real model with the supports of oxidation of Fe^{2+} into Fe^{3+} by oxygen providing. Compared with other technologies for treating of plating wastewater such as RO, ultrafiltration, nanofiltration. The electrochemical process with hollow electrode has relatively similar efficiency in the range of 99 – 100%. The optimum conditions for this process are: a 2 liters tank, two hollow iron electrodes with a diameter of each is 7.5 cm and 6 cm, 10 cm of height, 3 mm of thickness, and 99% oxygen gas jetted from the bottom of the tank with flow rates of 4 L/min, pH = 5, 8.79 mA/cm² of current density, electrolytic time of 30 minutes. Power consumptions were 10 kWh/m³ and this method has potential to apply with real wastewater treatment plant (To Thi Hien et al. (2016) [22]).

The electrocoagulation was investigated in combination with micro electrochemical to remove simultaneously Pb^{2+} , Zn^{2+} , Cu^{2+} and F^- ions in wastewater by Vo An Khue (2014) [23]. The optimum parameters for this method are as follows: initial pH value 5, 5V of voltage, removal time is 30 minutes, 60g of Fe-C, 20~27 mesh of size Fe-C. Under this condition and the initial concentration of ions is 50mg/L, Pb^{2+} , Zn^{2+} , Cu^{2+} and F^- removal efficiency are obtained 99.76%, 99.26%, 99.78%, 94.03%, respectively. After treatment, the wastewater is very clean and water quality is better than discharge standard, could be discharged directly to the receiving source. The mechanism of fluoride removal is mainly due to the formation of $\text{AlF}_x(\text{OH})_{3-x}$ precipitate and a small fraction of the fluoride absorption of iron hydroxide.

Nguyen Ngoc Anh et al. (2010) [24] was carried out the integration of two technologies including USBF (Up-flow Sludge Blanket Filtration) and EC (Electrocoagulation) into once of aquatic wastewater treatment system. A total of eight experiments were conducted, and determined to parameters for design and operation of batch electrochemical tank combined to the USBF with subtracts inside and without subtracts. The results indicated that at 10 h of total retention time, the USBF performances without subtracts were obtained as: 89.96%, 96.33%, 97.52%, 89.34%, 71.95% for SS, COD, BOD₅, TKN, TP of parameters, respectively; the USBF performances were combined with subtracts as: 92.63%, 97.16%, 98.00%, 92.69%, 75.85% for SS, COD, BOD₅, TKN,

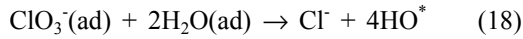
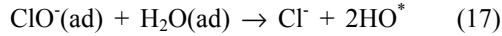
TP of parameters, respectively. The SS, COD, BOD₅, TKN parameters meet QCVN 11: 2008/BTNMT (column A). The optimum conditions of this process are as follows: Anode should be made of aluminum material and cathode should be made of iron material, batch retention time for electrocoagulation tank works at 45 minutes, the distance between the two electrodes is 2 cm, electrode area: 100 cm², 24 V of voltages, 1.6 A of current density.

3.2. Electrooxidation

Nguyen Thi Lan Phuong et al. (2016) [25] studied on wastewater containing reactive dye by electrochemical method with 304 stainless steel anode. Under conditions of pH = 6, 30 mA/cm² of current density. After only 6 minutes of treatment, this method had COD and color effluents were achieved the QCVN 13: 2008/BTNMT (column B) standard with color influents as a range of 34–8453 Pt-Co and COD < 170 mg/l. The color removal efficiency during this study was relatively high, but the COD removal efficiency was dependent on the original concentration. The input COD concentration of 806 mg/l was achieved 17% removal efficiency. However, the input COD concentration less than 806 mg/l was achieved 70%. With anode and cathode as 304 stainless steel, the oxidation processes occur directly on the electrode surface or indirectly in solution through the OH^* radicals. In addition, the 304 stainless steel electrode also was dissipated during the process to form Fe^{2+} ions which involved in the electrochemical and electro-Fenton processes increasing the color removal efficiency of draw wastewater. The results of UV-Vis spectroscopy of influent and effluent showed that the azo groups and aromaticity of dye dissolved into simpler compounds, resulting in loss of color and reduced toxicity of the reactive dye.

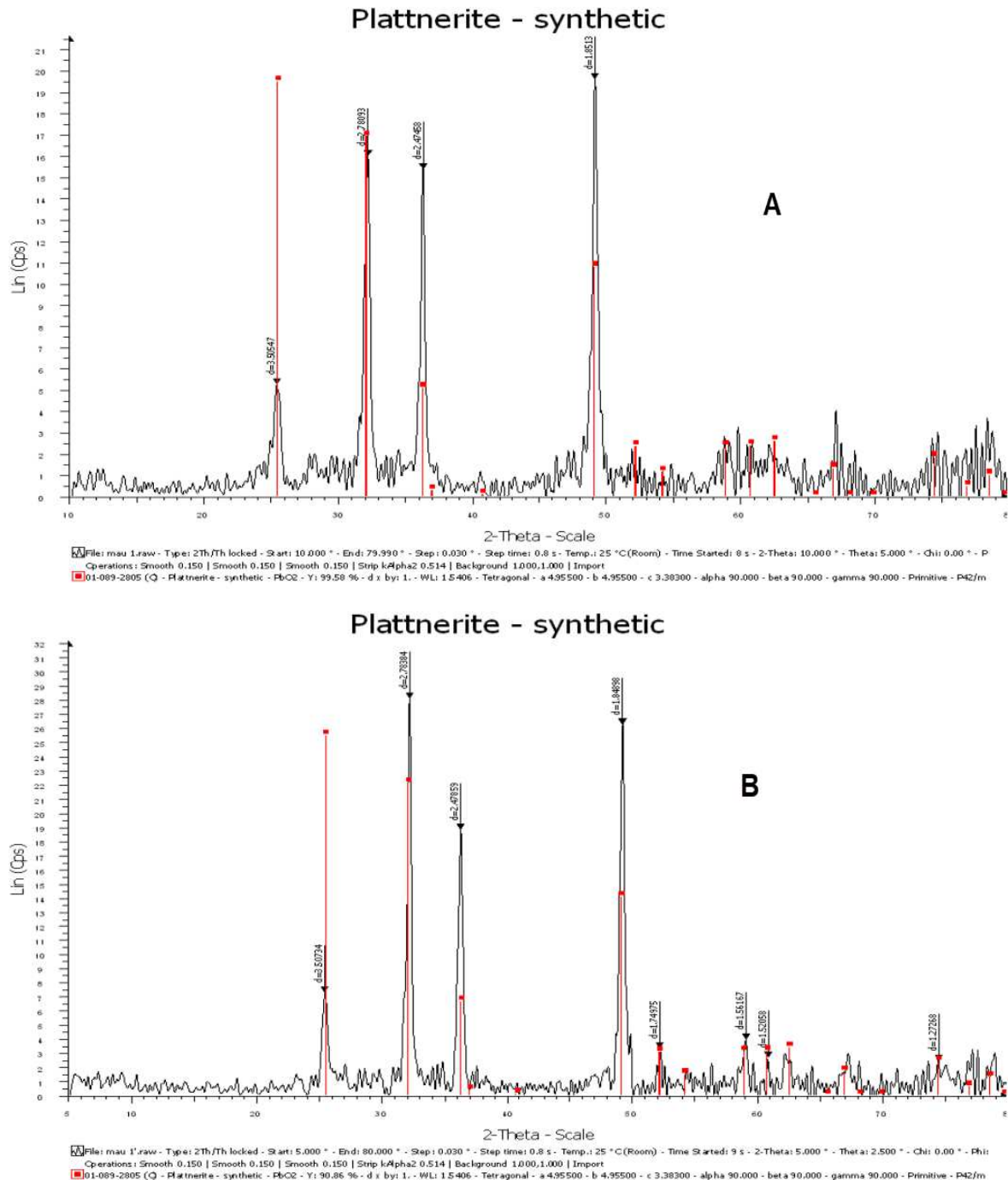
Research on producing new electrodes on Titanium substract is also being done in Vietnam. Under the manufacturing conditions are a mixture of 0.5 M SnCl_4 + 0.5% SbCl_3 in $\text{C}_2\text{H}_5\text{OH}$ + HCl solutions with 1:1 of rate and they are heated to 450°C. Dinh Thi Mai Thanh et al. (2007) [26] have successfully manufactured the working electrode of $\text{SnO}_2\text{-Sb}_2\text{O}_3/\text{Ti}$. Study on the Phenol removal efficiency in wastewater, after 7 hours of electrolysis with 10 mA/cm² of current density was obtained low performance at 39%, 62.7% of COD removal efficiency. Compared with some other electrode materials, the treatment efficiencies of this electrode type are not high. Based on this research, Chu Thi Thu Hien (2014) [27] has successfully developed the $\text{Ti/SnO}_2\text{-Sb}_2\text{O}_3/\text{PbO}_2$ inert anodic electrode by combining the decomposition of SnCl_4 , SbCl_3 solutions at 480°C temperature and was covered by PbO_2 at 120 minutes. Electrode life is approximately 290 hours. The simulated phenol of 500 mg/l concentrations showed the highest efficiency of electrochemical treatment as conditions: pH = 8, 50 mA/cm² of current density, 7.5 g/l Na_2SO_4 concentrations, 1% NaCl solution. The phenol removal efficiency was 99.60% at 360 minutes. The results of electrode application have been manufactured to treat real textile wastewater showed that COD removal efficiency was 95.17% after 360 minutes with

constant current intensity of 50 mA/cm². The Cl⁻ ions not only a reducing passivity role and activating the electrode but also contributes to the formation of ClO⁻, ClO₃⁻ and HO* radicals are phenolic oxidation agents and intermediate products, according to the equations below:



Similarly, research by Nguyen Ngoc Kien (2013) [28] produced PbO₂ anode on carbon graphite substrate combined with 304 stainless steel cathode. The optimum conditions for the

synthesis of anode in this study are: 20 ml/l of HNO₃ solution, 0.6 M of Pb(NO₃)₂ concentration, 0.4 M Cu(NO₃)₂, 1 g/l of gelatin, 25°C - 30°C temperature, the current density for electrodialysis is 40 mA/cm². The study investigated the phenol removal ability as conditions: pH = 8, 0, 7.5 g/l of NaCl solution, 1000 mg/l of input phenol concentration. The results showed that at the current density of $i = 75 \text{ mA/cm}^2$ which reached 92.7% removal efficiency at 210 minutes. The results of the X-ray diffraction pattern of the PbO₂ electrode show in figure 2 illustrated the line represents the unaltered tetrahedral structure, which indicates that the strength of the electrode is very high.



The issue of ammonium removal of wastewater is great interested today. In this field, Pham Cong Minh et al. (2015) [29] has conducted to research on removing of ammonium ($\text{NH}_3\text{-N}$) for synthetic wastewater by indirect electrochemical oxidation using Platinum anode and stainless steel for cathode. Synthetic wastewater was prepared in a laboratory by dissolving 99% (NH_4)₂SO₄ solution. The surface areas of each electrode are 100 cm². The model uses circulating pump with 5 liters per minute and stirred at 150 rpm. The study conducted to the ammonium removal in direct and indirect electrolyte conditions. The direct electrolysis (input wastewater without chloride addition) of ammonium removal efficiency is very low, approximately 8% after at 80 minutes. Meanwhile indirect electrolysis (chloride added to wastewater) concentrated that chloride productions are generated at the anode while presence of chloride ions and chlorination of the critical point between chlorine and ammonium to converting to nitrate and N₂. Ammonium removal efficiency was above 99% with indirect electrolysis conditions as: 25 mg/l of input ammonium concentration, 0.03% of NaCl solution, pH= 7.5, 20 mA/cm² of current density with removal time at 70 minutes.

Lam Hoa Hung et al. (2017) [30] investigated the p-Nitrophenol ability of degradation by electro-Fenton process using bar graphite electrode. Pt/Ti anode type of grid was used and a graphite rod with 9.5 mm diameter of cathode. This study was carried out considering of reducing Fe³⁺ to Fe²⁺ ions and deoxygenation generated to H₂O₂ under electrolysis conditions are separated by salt bridges of 1.0M Na₂SO₄ that remove the effects of the anode on the reduction products. Reducing process of Fe³⁺ to Fe²⁺ ions conducted in 0.001 M Fe₂(SO₄)₃ and 0.05 M Na₂SO₄ solutions. The result of the reducing process Fe³⁺ to Fe²⁺ on the graphite electrode occurs relatively easily, the reaction was occurred when applied to 1.0 V voltage and saturated at 3.0 V. However, Fe³⁺ ions removal efficiency decreased over time as a result of under-voltage condition. When the voltage is constant, the current density supplied to electrodes decrease over time, so the equilibrium voltage at the electrodes surface fall. However, at 75 minutes electrolysis, the Fe²⁺ ion concentration was accumulated at 2.74x10⁻⁴ M which are enough to join the electro-Fenton reaction. The H₂O₂ is generated more difficult because the activity of graphite electrodes is relatively low. The voltage applied to generate H₂O₂ a range of 4.0–7.0 V. The H₂O₂ concentration is generated in the range of 9.5x10⁻⁵-11x10⁻⁵ M at 30 to 120 minutes. Upon these conditions may be only enough to handle p-nitrophenol concentration about 5 mg/l. The p-nitrophenol decomposition experiments were performed on a non-membrane electrolyte model with 5 mg/l input p-nitrophenol concentrations and 0.05 M Na₂SO₄ solution. The results illustrated input voltage of 7 V, pH = 3, the p-nitrophenol removal efficiency was greater than 90% at 120 minutes. However, influent p-nitrophenol concentration of this study was too small because of low active electrode. Therefore, it is necessary to improve the performance of the graphite electrode for applying in real.

Dinh Thi Mai Thanh et al. (2009) [31] used graphite anode to treat the Phong Khe paper wastewater by electro-Fenton

method. The anode and cathode electrodes are graphite materials with 8 cm² surface areas, 15 mA/cm² of current density, pH = 3, 1 mM Fe²⁺. Under those conditions, COD concentration has removed from 1280 mg/l to 160 mg/l at 35 minutes. This study showed that when pH value increases to causing H⁺ ion concentration decrease, the H₂O₂ producing reaction is good but Fe²⁺ ion concentration reducing. Therefore, the OH* radical is generated that caused to decrease the organic decomposition efficiency. The research has compared the performance between three methods: electrochemical, electro-Fenton and Fenton's reagent technologies on paper industry wastewater. The results showed that high-to-low removal efficiency are electro-Fenton, Fenton's reagent and electrochemical respectively. Electrochemical method was the least performance because the only oxidation agent is electrolysis process but the graphite electrode has low decomposition efficiency. Fenton's reagent method has the disadvantage that generated Fe²⁺ is low because the H₂O₂ concentration decreases over time. The presence of strong oxidizing agents are OH* and HO₂* radicals so removal efficiency of Fenton electrochemical is higher than other two methods. Nguyen Duc Dat Duc et al. (2016) [32] conducted the same study to use graphite anode to remove color of real textile wastewater by electro-Fenton process. The results showed that optimal conditions of the process were as: pH = 3.11, 1.82 mM Fe²⁺ (this concentration is higher than the research of Dinh Thi Mai Thanh, 2009), 19 V of current density. The color removal efficiency reached over 96% at 30 minutes and color concentrations reduce from 1500 Pt-Co to 46 Pt-Co. This research was contradictory to the study by Lam Hoa Hung (2017) when the voltages above 7 V do not increase the p-nitrophenol treatment efficiency.

Azodyes from textile wastewater most commonly have complex carbonaceous structures that are difficult to decompose using traditional methods such as physiological and biological methods. Nguyen Thi Le Hien et al. (2009) [33] carried out removing Red metyl by electro-Fenton method with working anode is graphite covered Cu_{1.5}Mn_{1.5}O₄ and without covered Cu_{1.5}Mn_{1.5}O₄ (5 cm² electrode area). Cathode is platinum grip and Calomel saturated KCl is reference electrode. In this study, the reaction was concentrated in the cathode with deoxidation process produces H₂O₂. Fenton's reagent process is formed from H₂O₂ combined to Fe²⁺ ion which create to OH* radicals to destroy pollutants. Under optimal conditions as: -0.6 V/SCE cathodic voltage, oxygen flow as 1 L/m, pH =3, 1 mM Fe₂SO₄, 0.1 M Na₂SO₄ of electrolyte solution, 0.185 mM of Red - Methyl. Effluent COD concentration is 50 mg/l after at 24 hours electrolysis when the input COD concentration of 1300 mg/l. Investigation effect of H₂O₂ generated by cathode with aeration and no aeration. The results showed that reducing of dissolved oxygen available in water without aeration is not high performance. However, performance unchanged if aeration is greater than the saturation level of reaction at 1 L/m flow rate. A amount of Fe²⁺ added also has a great influence on processing. The amount of

Fe^{2+} less than 1mM concentration is not enough to total creating H_2O_2 generated, but if Fe^{2+} more 1mM that decreases efficiency. A mount of Fe^{2+} ion concentration redundancy is oxidized to create Fe^{3+} ion at anodic electrode, the pair of $\text{Fe}^{2+}/\text{Fe}^{3+}$ oxidation-reduction reaction redundancy will occur consecutive reaction on anodic and cathodic electrodes that decrease electrical efficiency. The results illustrated to $\text{Cu}_{1.5}\text{Mn}_{1.5}\text{O}_4$ (C/Ppy/ $\text{Cu}_{1.5}\text{Mn}_{1.5}\text{O}_4$) anode has the highest processing efficiency. In the same study, Nguyen Thi Le Hien *et al.* (2010) [34] repeated the study on Orange-Methyl by C/Ppy/ $\text{Cu}_{1.5}\text{Mn}_{1.5}\text{O}_4$ anode. The results showed that, at 1 mA/cm^2 of current density, pH = 3, aeration flow rate of 0.5 L/m, 1 mM Fe^{2+} . Orange-Methyl has lost its color completely after 15 hours treatment. The UV-Vis spectroscopy at the treatment sites showed that peak characterization of the Orange-Methyl was lost. At 229 nm wavelength there is a new peak which indicates the presence of OH^* radicals involved in the decomposition of the azo color group.

3.3. Electrodialysis

Electrodialysis is a relatively high efficiency of desalination technology in parallel with Reverse Osmosis technology (RO). However, there are some disadvantages compared to RO technology, so it is not widely to use. Nguyen Hoai Chau *et al.* (2005) [35] have applied this technology to remove salinity, hardness and suspended solid in ground water with the experimental model scale of 100 l/h capacity. The research has compared the performance of three different membranes: Vietnamese membrane made from cellulose acetate; Russian membranes and US membranes. The cylindrical membrane is 200 mm of diameter and 12.56 cm^2 area of each. The working electrode is made of Titanium covered an anti-corrosive layer. The results showed that three membranes had similar performance that reached as 83%, 66%, 65% performance for hardness, suspended solid, desalination removal efficiencies respectively. This study demonstrates that electrolysis technology has potential in field of desalination with low power consumption, not over 1 kWh per 1 kg salt to be removed. However, this method still has some limitations that affect the performance by osmosis and electro-osmosis process, the fouling membranes by presence of organic and inorganic substances.

In addition to desalination, the electrodialysis is also investigated for the treatment of nitrogen compounds in groundwater. Model of 30–60 l/h capacity included titanium electrodes covered by noble metal oxide layer for anti-corrosive, 53 VDC of voltage, a range of 0.75–1.5A current density. The results illustrated over 99% ammonium removal efficiency when input ammonium concentration was 10.4 mg/l. The nitrite and nitrate removal efficiency were 80% and 60%, respectively. The power consumption for this process ranged from 1.2 to 2.5 kWh/m^3 (Nguyen Thu Tra, 2005 [36]).

4. Conclusion

In conclusion, the electrochemical methods in Vietnam to treat water and wastewater have been investigated and applied but quantities and quality also exceeded. Those technologies

have also been studied to combine with other methods that achieved the desired treatment performance. However, the researching trends of the authors mainly focused on the laboratory model scales and the simulated raw water. Therefore, overall efficiency of specific indicators have not been evaluated and applied of real wastewaters. However, the results also provided the technical and economic feasibility of this approach. Previous studies focused on electrocoagulation, although this approach is cheap costs but it was generated secondary sludge which is harmful to environment. So research on electrochemical oxidation should be applied in the future, especially the advanced electrodes that the world is using today. In the future, electrochemical methods should be used to study the different types of wastewater at the pilot model scales, especially difficult handling wastewater and toxics that biological methods cannot handle effectively. In addition, it is necessary to find the optimal operating parameters to saving treatment costs as well as to reusing resources for sustainable development. On the other hand, the electrodialysis technology for desalination is applied to treat salty water in the Mekong Delta also interested in situation affected by climate change. That is also mainly research trends to environmental technology faculty of the Vietnamese – German University at the present.

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