Iranian Journal of Energy & Environment
Journal Homepage: www.ijee.net
IJEET an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Water Purification by Solar Powered Electrocoagulation System

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PAPER INFO

Paper history:
Received 25 October 2017
Accepted in revised form 17 December 2017

Keywords:
Water purification
Electro-coagulation
Photovoltaic system

ABSTRACT

This paper demonstrates technique of water purification using electro-coagulation method. This system is composed of DC electric source 200 V 30 A connect to the anode and cathode terminals. The DC power supply can be received from utility or solar energy. The sample of raw water from reservoir is used to conduct experimental reaction with electrocoagulation system in order to improve water quality. The water purification experimental was implemented by batch processing with varying electrolysis time. The parameter of electro-coagulation and water quality parameters are collected such as electric voltage, electric current, water temperature, pH, dissolved oxygen (DO), total dissolved solid (TDS) and electro-conductivity. The result found that the water quality has improved with the standard of domestic water supply and also drinking water standard.

***doi**: 10.5829/ijee.2017.08.03.07*

INTRODUCTION

The water purification is composed of physical, chemical and biological process to remove the contaminated, hardness, chemical and bio-infective out of the raw water. The conventional method of water purification process is performed by chemical reaction with quick stirring and adding lime and alum for pH adjust. The next stage of the particle in water is removed by sedimentation and filtration. However, the drawbacks of conventional water purification is use of chemical such lime and alum. The disadvantage of high amount of alum and lime may affect to human health. The other limitations of classical water purification are time consuming and space consuming. There are other technologies for water purification such as ozone, filtration, distillation, irradiation and electrochemical [1, 2]. Among these methods, electrocoagulation is one of attractive method which use electrochemistry for treatment such as flocculation, coagulation and floatation by adjust parameter of electrocoagulation process. The advantage is this method has capability to treat the sediment, solid suspend, particle, chemical substance and also biological organisms such virus [3]. The plenty of electrocoagulation application for water treatment and purifications is illustrated [4]. The tap water and drinking water is removed turbidity by electrocoagulation (Malini, 2012). The removal of metal[5] such as iron [6], cadmium [7], lead, chromium is applied with electrocoagulation [8]. Nevertheless, this method still use energy supply for generation of DC power supply to the electrode such aluminium, iron or copper to generate the electrochemistry, electrocoagulation, electro-flotation, precipitation or sedimentation. The evaluation of electrocoagulation efficiency process is considered by water quality standard from purification process with water index parameter. The other aspect of electrocoagulation process is energy efficacy which calculated by ratio of quantity of water treatment and energy input. The energy input of electrocoagulation system can be received from AC utility via rectifier circuit, in addition DC renewable energy sources such photovoltaic system can be applied especially in the rural area which no electricity from utility [9, 10],In this paper, the combination of benefit of electrocoagulation and photovoltaic for water purification is proposed. The water purification and water quality parameter and standard are studied. Then experimental of water purification process by electrocoagulation is performed, and then result and discussion are presented.

Principle of electrocoagulation

The principle of electrocoagulation composed of DC power supply source, two electrodes for anode and cathode, which oxidation reaction is occur at anode and reduction reaction of water at cathode. In this system, water is separated to generate H_2 and OH. After reaction for a while the water is transform to base and the sediment of aluminium ion which sediment color, particle in the water. The bubble gas is attached to

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sediment and float to the surface which call "electro-floatation".

The reaction equations of electrocoagulation are composed of redox and oxidation reaction. Both anode and cathode electrode are aluminium and reaction in each electrode is shown in Fig. 1. The low density particle is floated on the surface and the heavy particle is sediment in to the bottom.

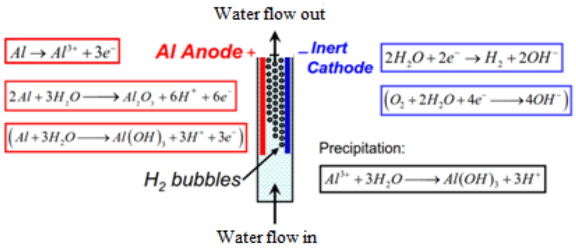

Figure 1. Redox – Oxidation of electrocoagulation process

Effect of Electrocoagulation

a) Type of electrode: In most studies reported in the literature, aluminium (Al), iron (Fe), mild steel and stainless steel (SS) electrodes are used as electrode materials. The aluminium is one of the attractive electrodes which has appropriate characteristic for electrocoagulation. A plenty of aluminium is found as the third rank of metal at earth crust, it has white color, light weight, hard, no brittle and easily transform in any form. The aluminium can make fast response reaction with other metal and give oxidation number +3. When Al^{3+} is in the water, it has capability to occur hydration reaction and hydrolysis. In this experiment, two electrode of aluminium is designed for anode and cathode of electrocoagulation reactor. The size of the cation produced (10-30µm for Fe^{3+} compared to 0.05-1 µm for Al^{3+}) was suggested to contribute to the higher efficiency of iron electrodes [11].

b) Current Density: The most critical operation parameters in electrocoagulation which have integral effect on process efficiency is current density. The current density is calculated the ratio of current and area of electrode as shown in equation (1)

$$J = I/A \tag{1}$$

where A is cross section area and I is current (A) and when the potential voltage occur between electrode then current density and electric field are generated as shown in equation (2)

$$J = \boldsymbol{\sigma} E \tag{2}$$

where $\boldsymbol{\sigma}$ is electrical conductivity and E is electromotive force.

c) Effect of water conductivity and supporting electrolyte: The high water conductivity has increase the efficiency of electrocoagulation. Sodium chloride is usually employed to increase the conductivity of the water or wastewater to be treated.

d) Effect of pH: The value display the positive potential of the hydrogen ions (pH) is express the concentration of H^+ or Hydronium ion (H_3O^+) which use for indicate acid or base of solution. The pH of the reaction solution changes during the EC process, and the final pH of the effluent actually affect the overall treatment performance. It is generally found that the aluminium current efficiencies are higher at either acidic or alkaline conditions than at neutral.

e) Inter-electrode spacing and configuration: The space between electrodes will increase treatment efficiency but it increase the capital cost of material. The electrode configuration connection is up to requirement of treatment method. If the system want to remove the suspend solid by float particle, the electrode should line in vertical in order to make a gas bubble from chemical reaction take the particle with float sediment. If the system want to remove suspend solid with sedimentation, the electrode should be layout in horizontal which anode is line below and cathode is line upper.

f) Electrolysis time: Increasing of electrolysis time leads to an increase in coagulant concentrations that has been reported to reduce the floc density, then to reduce their settling velocity [12].

g) Efficiency: The dissolution of the anode metal is based on Faraday's law as shown in equation (3)

$$m_{metal} = \frac{ITM}{zM} \tag{3}$$

where I is the applied current (A), t is the treatment time, M is the molar mass of the electrode material (M_{AL} = 26.982 g/mol, M_{FE} = 55.845 g/mol, z is the valency of ions of the electrode material (z_{AL} = 3, z_{FE} = 2) and F is the Farday's constant (96485 g/mol)

The removal efficiencies (R%) have been calculated with the Equation (4)

$$\boldsymbol{R\%} = \frac{\boldsymbol{C_0 - C_1}}{\boldsymbol{C_0}} \boldsymbol{x100} \tag{4}$$

where c_0 and c_1 are pollutant concentrations before and after EC treatment, respectively. Hydraulic retention times (HRT, min) were calculated with equation (5)

$$HRT = \frac{V}{Q} \tag{5}$$

where Q is the flow rate (liter/min) and V is Volume of water (liter)

The electrical energy consumption (EEC, kWh/m^3) has been calculated with the equation (6)

$$EEC = \frac{UIt}{60V} \tag{6}$$

where U is the applied voltage (V), t is the treatment time (min), and V is the volume of the treated water (m^3). Operating cost (OC, THB[2]/m^3) have been calculated with the equation (7)

[2] Thai Baht

$$OC = a \times EEC + b \times EMC \quad (7)$$

where a and b are the current market price of electricity (THB/kWh) and electrode materials (THB/kg), respectively. The EMC (kg/m^3) is the electrode consumption.

Water quality measurement

Water quality parameter that use for examine the supply water in this paper are temperature, pH, DO, TDS and conductivity (EC) respectively.

a) pH of pure water is 7. In general, water with a pH lower than 7 is considered acidic, and with a pH greater than 7 is considered basic. The normal range for pH in surface water systems is 6.5 to 8.5, and the pH range for groundwater systems is in the range of 6 to 8.5.

b) Dissolved Oxygen is amount of oxygen dissolved in water. DO is the most important indicator of the health of a water body and its capacity to support a balanced aquatic ecosystem of plants and animals. The DO of waste water has less than 3 mg/L.

c) Total dissolved solids (TDS) Dissolved solids refer to any minerals, salts, metals, cations or anions dissolved in water. Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and some small amounts of organic matter that are dissolved in water. The unit of mg/L is equal to ppm and the TDS of each type of water are shown in Table 1.

TABLE 1. Type of water classified by TDS

Water type	Value (ppm)
Rain water	0
High quality RO drinking water	3-12
RO drinking water	13-29
RO from high TDS water 500-900 ppm	30-39
RO from high TDS water 1000-1200 ppm or poor efficiency RO	40-49
Mineral water or poor drinking water	60-100
High quality tap water	100-150
Tap water	151-200
Village supply water	201-250
Supply water from ground water	251-500

d) Electro-conductivity (EC)**,** The electrical conductivity of the water depends on the water temperature: the higher the temperature, the higher the electrical conductivity would be. The electrical conductivity of water increases by 2-3% for an increase of 1 degree Celsius of water temperature. The conductivity is also directly related to the concentration of salts dissolved in water, and therefore to the total dissolved solids (TDS). Salts dissolve into positively charged ions and negatively charged ions, which conduct electricity. Since it is difficult to measure TDS in the field, the electrical conductivity of the water is used as a measure. EC can be converted to TDS using the following calculation

$$TDS\ (ppm) = 0.5 \times EC\ (\mu S/cm) \quad (8)$$

This relation between TDS and EC is provides an estimate only it may increase or decrease around 0.4-0.6 up to condition of water. The water hardness is one of water quality indicator to show how much of calcium and magnesium dissolved in the water which can expressed as equivalent of calcium carbonate. Total permanent water hardness is expressed as equivalent of $CaCO_3$ in mg/L.

TABLE 2. Classification of water by TDS, conductivity and hardness

TDS (ppm)	Conductivity (μS/cm)	Hardness	Type of water
0-75	0-120	Very soft	Rain **or disti**l
75-150	120-235	Soft	Drinking water
150-250	235-390	Slightly hard	Tap water
250-350	390-500	Moderately hard	Agriculture water
320-420	500-655	Hard	Raw water
Above 420	Above 655	Very hard	Ground water
Above 3000	Above 4690	Too hard	Waste water

MATERIAL AND METHODS

In this work water purification with electrocoagulation, using aluminium electrode was performed. In this method, the particle is lighter than water molecule due to gas generation in electro-cell (EC); the particle is floated to the surface. The electrode is positioned vertically and connected to power supply as shown in Fig. 2. The 200 V_{DC} voltage supply can be used from AC source via rectifier or from photovoltaic via DC/DC converter. The treatment electrolysis time of electrocoagulation is performed by batch processing. The electrode spacing was varied from 0.5 cm to 2 cm in order to find an optimum distance for high efficiency of the EC system.

The two electrodes of aluminium have size of 20x40 cm with appropriate electrode spacing (0.5 cm) between anode and cathode. The voltage level was 200 V_{dc} which can be supplied by AC utility via rectifier circuit or DC source from solar panel and DC converter. The DC supply can be energized with alternating electrode of cathode and anode to be more effectiveness. When electrode act as anode it supply electron and the cathode act as receiving electrode. From the surface of cathode hydroxide ion is generated. Then hydroxide has opportunity to be detached from electrode and react with aluminium ions to form aluminium hydroxide.

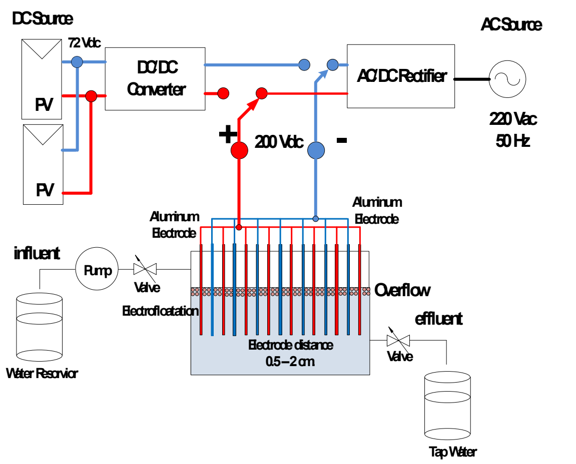

Figure 2. Electrocoagulation configuration

The water from reservoir was used to be treated by electrocoagulation. 10 liters of water was experimented by electrocoagulation reactor in 6 batch processes time from 0 to 60 minutes. After the system was energized through electrical power, the oxidation and electro floatation was performed, then sediment and particle is floated to the surface of the cell. The dirty particle on surface was washed off by overflow to the sedimentation tank and the treated water is separated from the clarification tank (see Fig. 3). The treated water was very clear and had no particle by visual inspection. Water sample was collected every 10 minute in order to measure water pH, DO, TDS and EC. Also electrical voltage, current and water temperature were continuously recorded in the entire course of experiments.

Figure 3. Electro-floatation process

RESULTS AND DISCUSSION

The water treatment by electrocoagulation is experimented by adjusting the distance of electrodes. The current density was affected by electrode spacing. The electrical parameters such as voltage and current; water process parameters such as temperature, TDS, DO, conductivity and pH were monitored. The temperature of water was measured while the electrode spacing distance and time of reaction varied as data are shown in Fig. 4. Based on this figure for long reaction time the temperature increased for 0.5 cm of electrode spacing.

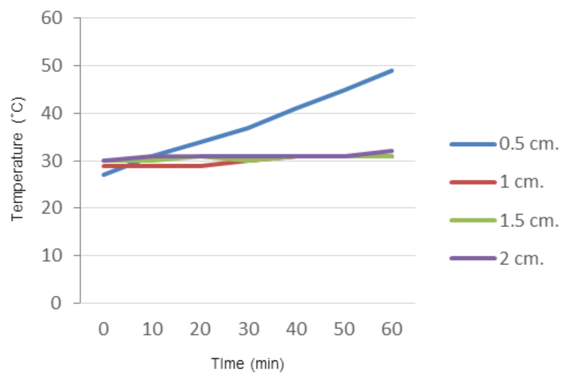

Figure 4. Temperature profiles vs. time of reaction at different electrode spacing

Figure 5 presents electrical current generated in the course of electrochemical reaction time. If one has to neglect any current fluctuation in electrical system we should consider the highest current density was obtained from 0.5 cm of electrode spacing.

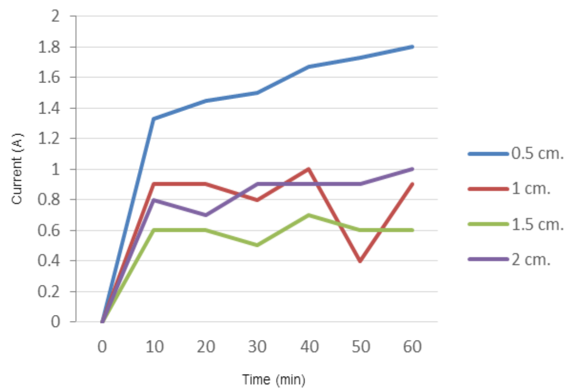

Figure 5. Electrical current with respect to reaction time at different electrode spacing

For electrochemical reaction no significant pH changes was observed unless slightly changes from 7-7.5 to alkaline condition; that was due to formation of hydroxide ions (see Figure 6). Table 6 Dissolved Oxygen (DO) in the water which use to indicate the quality of water. As it was found the minimum distance of electrode (0.5 cm) was effective to increase DO from 6 mg/L to 13 in 40 minute and then DO values was saturated. The relations between distance of electrode with respect to reaction time of reaction and DO are shown in Fig. 7.

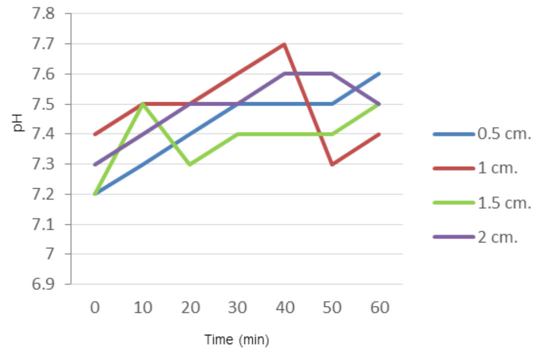

Figure 6. pH vs. reaction time

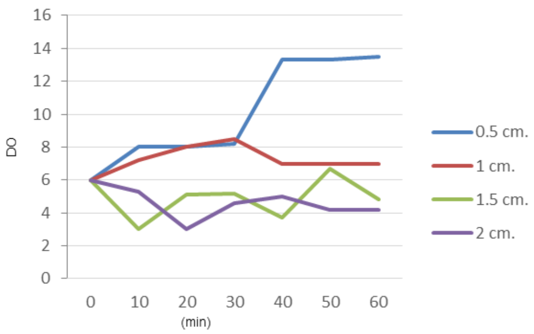

Figure 7. DO of EC water purification

Figure 8 depicts electrical conductivity of the treated water. As total suspended solids significantly decreased, electrical conductivity reduced. For the electrode spacing of 0.5 cm minimum amount of EC was obtained.

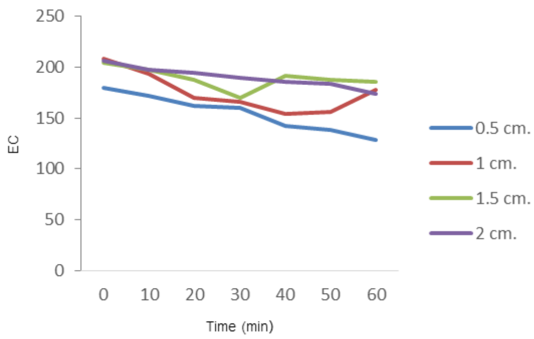

Figure 8. **C**onductivity of water purification

TDS of treated water was in the range of mineral drinking water. Fig. 9 shows the reducing trends of TDS as the distance for electrode spacing was reduced more TDS was removed. The distance 0.5 cm was more efficient in TDS diminishing to 63 mg/L.

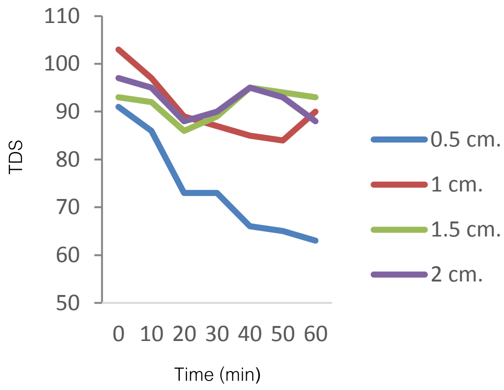

Figure 9. TDS of EC water purification

CONCLUSION

This paper demo**n**strates the application of electrocoagulation process for water purification. The aluminium material is applied for electrode of electrochemical reactor. The DC power supply 200 V is energized from rectifier circuit from AC utility and also DC-DC converter from Solar Panel. The current density is varied by distance of electrode. The efficiency of EC system was proportional to the time of reaction and current density. The time of reaction can adjust by flow rate of water inlet and outlet. The current density can adjust by DC voltage or distance of electrode. The electrocoagulation reactor was more efficient than conventional chemical system. The result of experimental found that the best of distance is 0.5 cm with has high DO, low TDS, low EC which appropriate for produce drinking water. The time of reaction is appropriate for good result at 20-40 minute, this information is useful for adjusting the flow rate of continuous system in the future.

Acknowledgement
The author would like to express their appreciation to Rajamangala University of Technology Lanna for providing necessary instrument and place to conduct experimental work.

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Persian Abstract

DOI: 10.5829/ijee.2017.08.03.07

چکیده

این مقاله روش خالص سازی آب را با استفاده از روش انعقاد الکترونی نشان می دهد. این سیستم از منبع برق DC 200 V 30 A متصل به پایانه های آند و کاتد است. منبع تغذیه دیجیتال را می توان از انرژی خورشیدی یا انرژی دریافت کرد. نمونه ای از آب خام از مخزن برای انجام واکنش تجربی با سیستم الکتروکواگولاسیون جهت بهبود کیفیت آب استفاده می شود. آزمایش تصفیه آب با پردازش دسته ای با زمان الکترولیز متفاوت انجام شد. پارامترهای الکترو انعقاد و پارامترهای کیفیت آب از جمله ولتاژ الکتریکی، جریان الکتریکی، دمای آب، pH، اکسیژن محلول (DO)، جامد محلول جامد (TDS) و الکترو هدایت جمع آوری شده است. نتیجه این است که کیفیت آب با استاندارد تامین آب خانگی و همچنین استاندارد آب آشامیدنی بهبود یافته است.