

FEASIBILITY STUDY FOR MAKE-UP WATER QUALITY FOR COOLING TOWER  
BY ELECTRO-COAGULATION PROCESS

การศึกษาความเป็นไปได้ในการปรับปรุงคุณภาพน้ำสำหรับหอผึ่งเย็น  
ด้วยกระบวนการรวมตะกอนด้วยไฟฟ้า

Sasipim Manasilp<sup>1</sup> and Cattaleeya Pattamaprom<sup>1\*</sup>

<sup>1</sup> Chemical Engineering, Faculty of Engineering, Thammasat University, Patumthani 12120, Thailand

ศศิพิมพ์ มานะศิลป์<sup>1</sup> และ แคทลียา ปัทมพรหม<sup>1\*</sup>

<sup>1</sup> ภาควิชาวิศวกรรมเคมี คณะวิศวกรรมศาสตร์ มหาวิทยาลัยธรรมศาสตร์ ปทุมธานี 12120 ประเทศไทย

received : April 29, 2011

accepted : June 28, 2011

### Abstract

Cooling Tower was a type of heat transfer equipment which was used to enhance heat rejection to the environment by increasing the surface contact between water and air. Water used in the cooling tower system had to be pretreated to prevent scaling and corrosion. As most factories in the northern part of Bangkok utilized both tap water and groundwater, which was known to contain large amount of minerals and suspended solids, water pretreatment was crucial before entering cooling towers or the heat-exchanging systems. Typical water pretreatment system consisted of sand filtration, carbon adsorption and ion-exchange resin adsorption to remove particles and minerals from water. Beside this, some research paper had reported the use of electro-coagulation technique in various applications to remove unwanted suspended and dissolve matter from water. Nevertheless, the utilization of this

technique in water treatment for cooling water/ heat-exchanging systems was not widespread. Hence, the aim of this feasibility study was to investigate technical, economic and energy-conservation feasibilities by using aluminum sheet connected with DC power supply with its voltage was adjustable between 0 – 30 volt as well as the water resource optimization for electro-coagulation technique in cooling water system when using in combination with or replacing the conventional treatment process. We found that this technique is considered appropriate to replace some parts of the water treatment unit without adding chemical into the process. It helps reduce operating cost and water usage in softener regeneration process with less amount of wastewater.

**Keywords:** electro-coagulation, hard water, cooling tower, total hardness, turbidity

---

\* corresponding author

E-mail : cattalee@engr.tu.ac.th

Phone : +66-2564-3002 ext 3125,3040

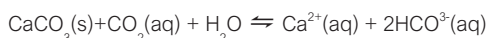
## บทคัดย่อ

หอผึ่งเย็น (Cooling Tower) เป็นอุปกรณ์สำหรับระบายความร้อนออกสู่แหล่งรับความร้อนภายนอกโดยใช้หลักการเพิ่มพื้นที่ผิวสัมผัสในการแลกเปลี่ยนความร้อนระหว่างน้ำกับอากาศ ซึ่งน้ำที่ใช้สำหรับระบบหอผึ่งเย็นนั้นจำเป็นต้องมีการปรับสภาพก่อนเข้าระบบเพื่อป้องกันการเกิดตะกอนและการกัดกร่อน เนื่องจากน้ำที่ใช้ในโรงงานอุตสาหกรรมตอนเหนือของกรุงเทพมหานครเป็นน้ำประปร่วมกับน้ำบาดาลซึ่งน้ำบาดาลเป็นน้ำที่มีแร่ธาตุต่างๆ และสารแขวนลอยเจือปนอยู่มาก ดังนั้น จึงมีความจำเป็นต้องปรับปรุงคุณภาพน้ำเบื้องต้นก่อนเข้าสู่หอผึ่งเย็น วิธีที่ใช้ในการปรับปรุงคุณภาพน้ำในปัจจุบันประกอบด้วย การกรองด้วยทราย การดูดซับด้วยคาร์บอน และการแลกเปลี่ยนประจุด้วยเรซิน (Ion exchange resin) นอกจากนี้ยังมีรายงานวิจัยในอดีตบางส่วนได้นำเสนอการประยุกต์ใช้กระบวนการรวมตะกอนด้วยไฟฟ้า ในการกำจัดอนุภาคและสารละลายต่างๆ ออกจากน้ำ แต่ปัจจุบัน ยังไม่ค่อยพบการนำมาใช้งานอย่างแพร่หลายในการปรับสภาพน้ำในระบบแลกเปลี่ยนความร้อน ดังนั้น งานวิจัยนี้จึงนำเสนอการศึกษาสภาวะที่เหมาะสมด้านเทคนิค เศรษฐศาสตร์ และการประหยัดพลังงาน รวมถึงการประหยัดทรัพยากรน้ำ ในการนำเทคนิคกระบวนการรวมตะกอนด้วยไฟฟ้ามาใช้เพื่อกำจัดความขุ่นและความกระด้างของน้ำบาดาล โดยใช้อลูมิเนียมแผ่นเป็นขั้วไฟฟ้าต่อเข้ากับแหล่งจ่ายไฟฟ้ากระแสตรงที่สามารถปรับระดับแรงดันได้ 0-30 โวลต์ จากการศึกษาพบว่า การรวมตะกอนด้วยไฟฟ้าสามารถกำจัดความขุ่นและความกระด้างได้เป็นอย่างดี นอกจากนี้ยังมีค่าใช้จ่ายในขั้นตอนการปรับปรุงคุณภาพน้ำที่ต่ำกว่าการกรองด้วยทราย คาร์บอน และเรซิน ไม่มีน้ำเสียจากกระบวนการล้างย้อน และการฟื้นฟูสภาพเรซิน เป็นการลดภาระของระบบบำบัดน้ำเสียได้อีกด้วย

**คำสำคัญ:** กระบวนการรวมตะกอนด้วยไฟฟ้า, น้ำกระด้าง, หอผึ่งเย็น, ความกระด้างทั้งหมด, ความขุ่น

## Introduction

Hard water, which is a cause of scale, is originated from mineral dissolved in water. Main causative minerals are  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and positively charged metal always found in a form of  $\text{CaCO}_3$  that dissolved in water or caused by  $\text{Ca}^{2+}$  in water reacting with bi-carbonate as a reversible reaction. <sup>(1)</sup>



When there is not enough water for the production, most of industrial factories rely on other alternative water sources, mostly the groundwater that mixed with much of several minerals and suspended particle, it therefore influences on water quality improvement before use in order to prevent the scale in heat-exchanging system that drops efficiency in heat exchanging. Currently, there are many processes of water pretreatment system such as sand filtration, carbon adsorption and ion-exchange resin adsorption. From many of previous researches, Electro-coagulation is an interesting method and there is a report that this technique can decrease turbidity and hardness of water. Electro-coagulation technique consists of 3 principles<sup>(2)</sup>, which are 1) anode electrode producing 2) losing stability of foreign matters in water 3) gathering to form scale. In the past, Nabil et al.<sup>(3)</sup> studied and

treated groundwater's quality with Electro-coagulation technique and found that if connected a direct current with stainless steel electrode, the turbidity of groundwater could reduce 95% within 5 min using 1A current, however there was no study on hardness reduction. Recently Malakootian and Yosefi<sup>(4)</sup> have studied the elimination of hardness in sample water at Kerman University located in southern of Iran by using aluminum as electrode as well as controlling pH level. It was found that at pH of 10.1 while applied 20V direct current, the water hardness could be 95.6% reduced within 60 min but at pH neutral, which is the scale of our interest, could get rid of the hardness for only 80.6% in 60 min. Besides Malakootian et al.<sup>(5)</sup> researched the use of Electro-coagulation to improve drinking water quality connecting with iron electrode using 12V direct current. They found out that this technique could remove 97.4% of water hardness in 60 min, but caused rust therefore it required the process in eliminating rust as well.

For cooling tower, Langelier Saturation Index (LSI) and Ryznar Stability Index (RSI) <sup>(6)</sup> are popular indices indicating occurrence's possibility of scale and corrosion in heat-exchanging system within

water filling in cooling tower. These indices are supposition that base on measurable pH scale comparing to pH level of water saturated with limestone ( $\text{CaCO}_3$ ) that has high pH. Water saturated with limestone can dissolve limestone no more and if it is high potential the limestone will crystallize and become scale, nevertheless if water isn't saturated with limestone or able to dissolve in water, the pH is quite low and could bring to opposite result: water tends to erode.

The researchers of this research are interested in studying Electro-Coagulation system in order to remove suspended particles and water hardness of groundwater used in heat-exchanging process of cooling tower to replace the systems of sand filtration, carbon adsorption and ion-exchange resin adsorption as shown in Figure 1 since this technique has a tendency in decreasing chemical applying, plastic ion-exchange resin and water using, wastewater from backwash and water that needed to be disposed of from regenerating filter media in water softener treatment. The study focuses on appropriate condition in applying Electro-coagulation technique as well as economic evaluation and the use of power occurred.

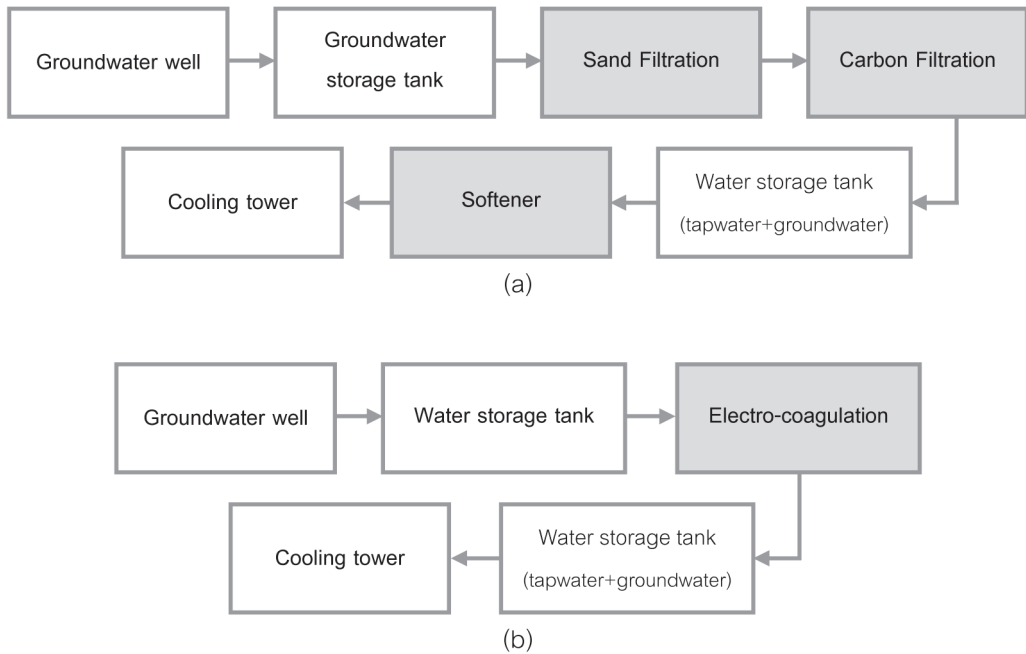


Figure 1 (a) Groundwater treatment system of a factory in Pathumthani and (b) Flow chart of water treatment with electro-coagulation technique described in this research

**Objective**

To study a tendency of groundwater treatment for cooling tower in industrial factory with electro-coagulation technique to replace conventional water pretreatment processes such as sand filtration, carbon adsorption and softener, lessen water used in backwash sand and carbon filter and softener regeneration process, decrease chemical applying and economic evaluation.

**Materials and Methods**

Groundwater was used and taken from an electronic-producing-factory in northern part of Bangkok with its characteristics is shown on Table 1. Electro-coagulation equipment comprised a DC power supply with adjustable volatage (0-30 volt) designed to be connected to 4 pieces of 8x12 cm<sup>2</sup> aluminum electrodes with 2 cm apart to each other. These electrodes are

suspended in a acrylic 12.5x12x10 cm<sup>3</sup> tank. The experiment start DC power supply for 60 min and set the volatage at 5, 10, 15 and 20 volt. Each batch of 1 L groundwater was collected to analyze for conductivity and pH every 10 min and let for sedimentation for at least 60 min. Turbidity was measured using turbidity meter, EUTECH model TN100. Hardness analyzed using APHA/AWWA/WEF 2340C method<sup>(7)</sup>. Aluminium concentration obtained after sludge dewatering process was analyzed using Atomic Absorption Spectrophotometer, Perkins Elmer Analyst 800. Shortest time that electro-coagulation technique would allow and its voltage was

selected to calculate the electricity consumption. The tank was then designed for industrial scale (120 m<sup>3</sup>/d) with 8640 working hr/yr to investigate economic value using present values technique. Sensitivity analysis was employed in some parameters (Electricity, Water and Aluminum sheet price) that might affect a break-even point of water treatment with Electro-coagulation technique comparing to a combined unit (sand filtration, carbon adsorption and softener treatment systems) by referred to MLR at 6.12% /yr from Siam Commercial Bank as of December 3<sup>rd</sup>, 2010<sup>(8)</sup> and expand electric energy usage's proportion of Electro-coagulation technique

**Table 1** Quality of groundwater used compares with standard quality of tap water specified by Provincial Waterworks Authority<sup>(9)</sup>

Parameter	Groundwater	Standard Tap Water
Conductivity (µS/cm)	3,380	-
Turbidity (NTU)	38.7	5
pH	7.27	6.5 – 8.5
Temperature (°C)	28.7	-
Total hardness (mg/L as CaCO <sub>3</sub> )	302	300
Total dissolved solid (mg/L)	1,701	600
Aluminum (mg/L)	1.237	-

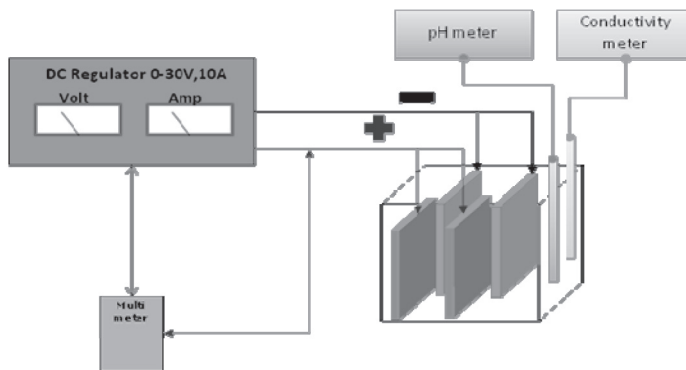
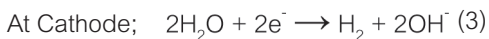
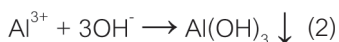


Figure 2 Experimental diagram

**Result and Discussion**

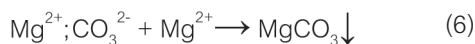
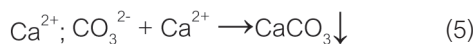
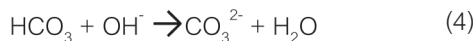
Figure 3 showed water hardness decreased with time. The reaction occurred at electrode could be described as follows;



The reaction mentioned above resulted in a floc formation (Equation 2) of aluminum hydroxide,  $Al(OH)_3$ . This floc contacted other suspended particles, pollutants in water and  $H_2$  gas which was generated from the reaction at the Cathode as shown on Equation 3. This floating  $H_2$  gas played an important role to increase contact and merger between suspended particles, pollutants and  $Al(OH)_3$ . Apart from this, electric current between two electrodes also influenced on lessening

stability of suspended particles resulting in binding with floc. After leaving it to precipitate water sample in the tank was collected to examine turbidity. The turbidity was dropped and stayed 38.7 to <1 NTU.

Since, groundwater naturally contains  $Ca^{2+}$ ,  $Mg^{2+}$  and  $HCO_3^{-}$ .  $OH^{-}$  produced from reaction in Equation 3 reacted with bi-carbonate base ionize to form carbonate (Equation 4). Further reaction occurred when carbonate binded with  $Ca^{2+}$  and  $Mg^{2+}$  to form  $CaCO_3$  and  $MgCO_3$ . As shown in Equations 5-6. Both  $CaCO_3$  and  $MgCO_3$  precipitated from water and resulted in lower water hardness<sup>(4)</sup>.



Moreover, it was also found that turbidity, conductivity and total dissolved

solid (TDS) of water passing through Electro-coagulation subsided at initial condition because of Al ion ( $\text{Al}^{3+}$ ) from Anode resulted in a compound with  $\text{OH}^-$  and/or pollutants having charge in water combined becoming a floc, which was neutral in electricity. Even though, the dropped-down conductivity benefited the usage of water for cooling tower, it revealed that electric current in systems was also lower and this mattered to decrease in efficiency of removing several substances from water.

For the left over after the combination of  $\text{OH}^-$ , of which occurred at Cathode, with Al was a compound that had an effect on high pH due to increasing time. This result agreed with the study of Malakootian et al. <sup>(5)</sup> who reported that pH of water after the Electro-coagulation process was always higher than initial condition. Furthermore, a research of Mouedhen et al. <sup>(10)</sup> stated that raising pH happened because normally, water contains  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$ , which would ion exchange with  $\text{Al}(\text{OH})_3$  so  $\text{OH}^-$  was more independent, pH scale then increased.

Figure 4 shows a comparison of effectiveness in water treatment through Electro-coagulation technique with electric voltage varied from 5 – 20 volts. The results showed that a test of 10 volt direct current for 50 min could get rid of 82.12% total hardness (from 302 mg/L to 54 mg/L), 18.46% TDS (from 1,701 mg/L to 1,387 mg/L) and lessen 16.57% of water's conductivity (from 3,380 to 2,770  $\mu\text{S}/\text{cm}$ ). While 10 volt of direct current testing for 40 min could eliminate 80.79% total hardness (from 302 mg/L to 58 mg/L), 17.16% TDS (from 1,701 mg/L to 1,409 mg/L) and 16.57% reducing water's conductivity (from 3,380 to 2,820  $\mu\text{S}/\text{cm}$ ). These two results implied that there was no significant difference in efficiency, thus in order to save time and energy, the researchers decided to use 10 volts of direct current with 40 min of reaction time that equals to 41  $\text{amp}/\text{m}^2$  in current density for calculating many equipment using in water treatment by Electro-coagulation method for water flow of 120  $\text{m}^3/\text{d}$ .

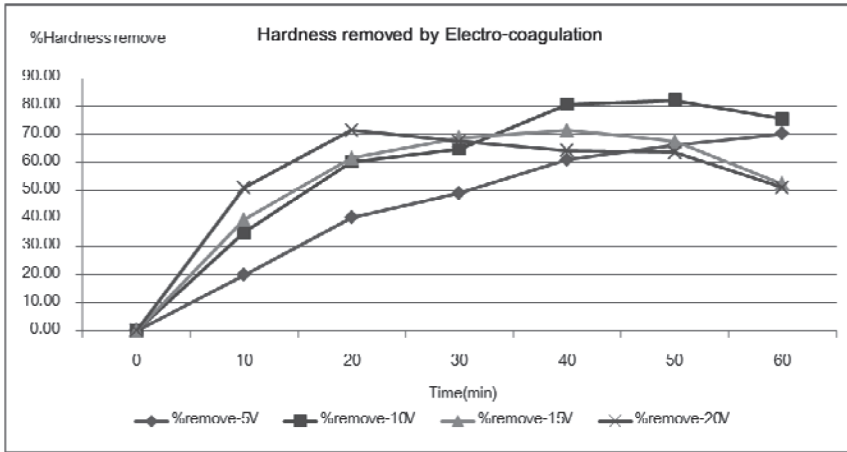


Figure 3 Efficiency of hardness's removal with electro-coagulation technique

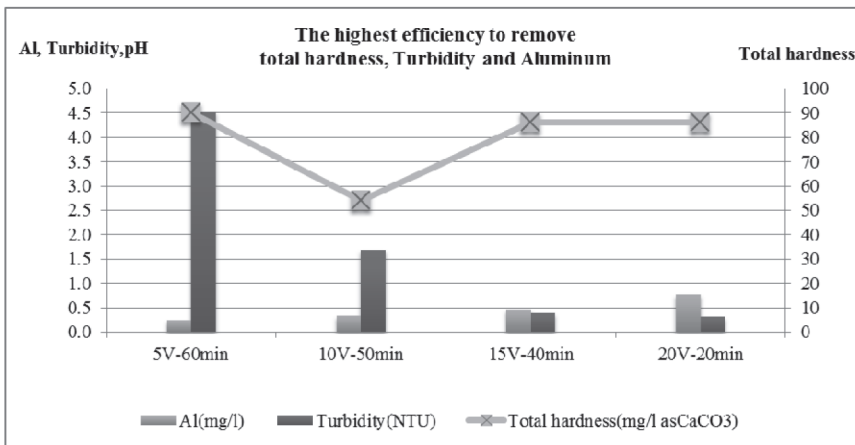


Figure 4 The highest efficiency at different voltage after electro-coagulation technique

After the tank calculation, an appropriate reaction tank of Electro-coagulation was 20.8 m<sup>3</sup> cylinder type and 13.52 m<sup>3</sup> rectangular the for sedimentation tank, of which was also adjusted its bottom at 45 degree angle at ground level. A

groundwater tank should have capacity of 25 m<sup>3</sup>. While using 4 m<sup>2</sup> of an aluminum piece to connect to 12V/200 amp direct current power supply as demonstrated in Figure 5.



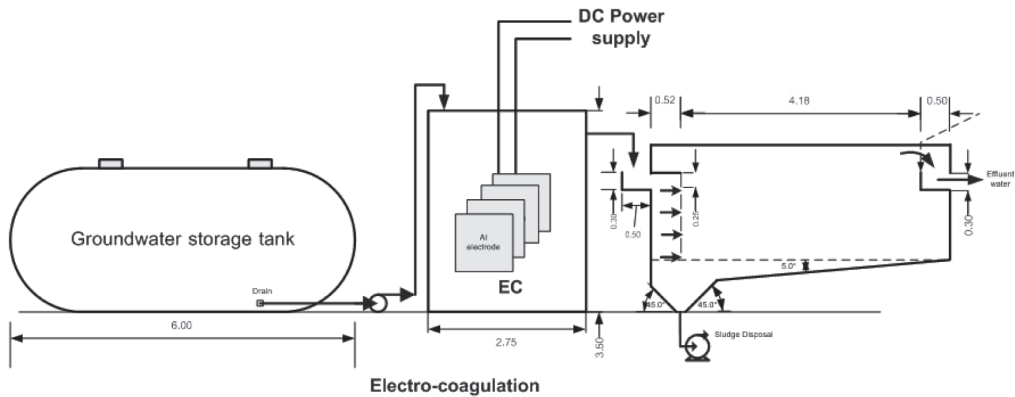


Figure 5 Diagram of water treatment system: electro-coagulation

To analyze the suitability for using cooling tower, water that processed via Electro-coagulation technique with 10 volts current for 40 min of reaction time was examined with Langelier Saturation Index (LSI) and Ryznar Stability Index (RSI), it revealed that LSI equaled to 1.972 and RSI was 5.695. This result implied the potential of thin scale in water due to increasing intensity. Water from Electro-coagulation process was able to circulate to utilize cooling tower for 5.17 cycles with 2.61 m<sup>3</sup>/hr of wastewater.

For economic analysis, using 6.12% of interest per year, it is assumed that the equipment had 7 yr of tool life and 8,640 working hr/yr. The calculation of present value cost included water treatment process and maintenance such as cost of groundwater, tap water, water for backwash and softener regenerate, electricity for

water pump of Electro-coagulation reaction tank and control equipment, various filter medias, carbon, ion exchange plastic resin, salt solution for softener regenerate, wages, and payment on floc's and worn out electrode's elimination.

For traditional processes, i.e. filtration of sand, carbon and ion exchange resin, the operating cost of traditional process is 3,709,968 THB while Electro-coagulation technique is 3,007,095 THB at 7 yr service. It estimated the operating cost of traditional process was 18.94% higher than our process. The break-even point of Electro-coagulation technique was at 1.81 yr, at capital cost of 1,272,093 THB and residual value of zero.

The sensitivity analysis on the change of cost on electricity, water for washing electrode, equipments and aluminum

pieces with the break-even point of water treatment with Electro-coagulation method for is shown in Figure 6. It showed that the break-even point of Electro-coagulation process mostly depended on electricity expense since electricity energy was required for water treatment (52.27%) than filtration process. However, the method

save water as there was no use of either filter media or ion-exchange substance; it was therefore not necessary to maintain filter system by backwash and ion exchange resin. Water was used only for cleaning electrode and equipment but require salt solution resulted in decreased expense on wastewater treatment.

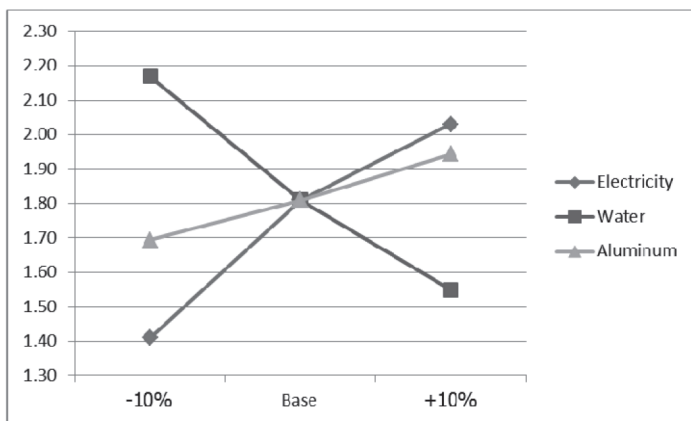


Figure 6 Sensivity of change of cost on electricity, tap water and aluminum piece to the break-even point of Electro-coagulation method

**Conclusion**

Water treatment with Electro-coagulation technique of 10 volt electric current for 40 min could remove suspended particles and solution in water. The analysis as compared to LSI and RSI, found out that the output water of electro-coagulation process had a tendency in creating thin scale. Practically it was more acceptable for water to consist of scale

rather than corrosion because most equipment such as water pipe, cooling tower's structure and heat exchanger were made of copper ingot and iron; the corrosion inevitably affected equipment's structure more than scale.

The result of feasibility study found that Electro-coagulation was able to replace conventional water treatment processes like sand filtration, carbon

adsorption and ion exchange resin in order to supply water to cooling tower. Besides, Electro-coagulation technique was also suitable both for industrial factories located in area of insufficient water or no wastewater treatment system to backwash water from sand filtration and carbon adsorption and salt solution from ion exchange resin process, and the factory that could self supply electricity to use within the factory. This is because the expense on water treatment's maintenance was 1.47 time lower than conventional treatment therefore it was slight electric energy cost.

#### Acknowledgement

It is a pleasure to thank Engineering Faculty, Thammasat University for a research fund, location and test equipment.

#### References

- (1) Wurts, W..A. and Durborow, M.R. .1992. Interaction of pH, Carbondioxide, Alkalinity and Hardness in Fish Ponds, SRAC Publication No. 464.
- (2) Emamjomeh, M.M. and Sivakumar, M. 2009. Review of pollutants removed by electrocoagulation and electrocoagulation/ flotation processes, J. Environ. Manage. 90:1663–1679.
- (3) Abuzaid, N.S., Bukhari, A.A. and Al-Hamouz, Z.M. 2002. Ground water coagulation using soluble stainless steel electrode. Advance in Environmental research. 325-333.
- (4) Malakootian, M. and Yousefi, N. 2009. The Efficiency of Electrocoagulation Process Using Aluminum Electrodes in Removal of Hardness from Water, Iran. J. Environ. Health Sci. Eng. 6(2):131-136.
- (5) Malakootian, M., Mansoorian, H.J. and Moosazadeh, M. 2010. Performance evaluation of electrocoagulation process using iron-rod electrodes for removing hardness from drinking water, Desalination. 255(1-3): 67-77.
- (6) Rafferty K. 1999. Scaling in geothermal heat pump systems, U.S. Department of Energy Idaho Operations Office. 1-4.
- (7) APHA /AWWA /WEF 2340C. 1989. Standard method for examination of water and wastewater, 17<sup>th</sup> Edition, Washington DC.
- (8) Siam Commercial Bank interest rate effective on December 3, 2010.
- (9) Standard tap water from Provincial Waterwork Authority. Available online at [www.pwa.co.th](http://www.pwa.co.th) [Jan 29, 2011]
- (10) Mouedhen, G., Feki, M., Wery, D.M. and Ayedi, H.F., 2008. behavior of Aluminum Electrodes in Electrocoagulation Process, J. Hazard. Mater. 124-135.