

Biofouling Management in the Cooling Circuit of a Power Industry Using Electrochemical Process

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(Received on 5th May 2010, accepted in revised form 6th September 2010)

Summary: Biofouling is one of the major issues in the power industry using seawater for cooling and other purposes. Presence of biological organisms such as bacteria and algae that could foul pipes and expensive equipments need to be managed from economical and safety point of view. Generally, the biofouling problem is aggravated in hot climate regions. Various means of disinfection processes are available for this purpose, such as chlorination, UV or ozone. In the present study electrochemical technology for the production of sodium hypochlorite was evaluated for onsite disinfection of seawater for applications in a nuclear power industry. A continues flow laboratory scale experimental setup was fabricated and influence of various operating parameters such as electrode material, applied current density, power consumption, surface area of electrode and interelectrode spacing were evaluated. It was found that efficiency of the electrochemical disinfection process was strongly dependent on these studied operating parameters. It was concluded that the production of sodium hypochlorite on site using an electrochemical process is a feasible and promising option for the power industry using seawater as cooling and/or process water. An optimum design of the electrochemical cell was also suggested.

Introduction

It is feasible to build a power industry near the seashore or adjacent to a water body. This will facilitate to meet the cooling water requirements of power plant. Naturally, seawater is abundant and provides desired flow rates. However, the saline seawater contains high biological organisms such as bacteria and algae, which may cause biological fouling in the seawater inlet structure and relevant equipments of the industry. This may further damage and obstruct the piping system and equipments due to the bacterial and other biological slime formation. It is generally considered that the hot climate regions could aggravate the problem since microbial activity will be greatest in that region where the temperature of the water will be higher than in the other regions [1]. In order to keep the power plant in operation heat transfer surface and cooling circuit must be clean and free from any obstruction. This is a challenging task for the operators to keep cooling water circuits operating efficiently in environments where biofouling threatens the heat transfer surfaces. Macro fouling (mussels, clams, oysters) and micro fouling (bacteria, slime, algae) from seawater intake systems forms deposits on condenser tubes, tube sheets, and piping systems resulting in unexpected plant downtime for maintenance and/or equipment replacement. Generally, biofouling can affect the condenser performance in a number of ways [1-3].

1. Reduction in the internal diameter of the condenser tubes and intake pipes.

2. An increase in the fluid resistance that requires pumping system/operation to be modified; in some cases high pumping heads may be required.
3. Reduction in the thermal conductivity, as the outer shell of biofouling has poor thermal conductivity than metal.

Disinfecting the influent seawater is one of the options to get rid of biofouling. The objective of disinfection is to destroy or inhibit the growth of biological organisms that could grow and form deposits that foul equipments and other accessories [4]. Disinfection can be accomplished through chlorination, ultra-violet (UV) sterilization, ozone or biocide. Chlorine is an effective and well understood disinfectant [5]. Use of liquid or gaseous chlorine for disinfection involves many safety hazards during transportation, storage as well as application period. It has great potential for unintended large releases involving equipments such as tanks, valves, and pipelines which may result in harmful health effects or even fatality [3].

Use of electrochemically generated chlorine from seawater in the form of sodium hypochlorite may be an economical option [6, 7]. The approach is the use of electrolysis to generate sodium hypochlorite from seawater since the main components, electricity and salt water, are readily available in costal operations.

Rational of Present Study

A traditional chlorination system has been provided at Karachi Nuclear Power Plant (KANUPP) to control marine biological growth that usually get stuck inside heat exchanger (HX) tubes while they are in their larval stage. Later, they grow up and choke the tube, which results in a decrease in the effective cooling, and the temperature of process water may increase significantly as a consequence [2]. The chlorination system was installed in the year 1990 and had a capacity of 500 lbs chlorine per day by electrolysis of seawater using two cells. The daily requirement of chlorine in the plant ranged between 145 kg to 227 kg [8]. With the extensive use of the system and corrosive nature of seawater, various components of the chlorination system became deteriorated and required replacements such as electrodes. Unfortunately it has not been possible to maintain and run the chlorination plant in safe operation, due to unavailability of critical spare parts.

As a result of the above mentioned problems a new chlorination system was employed by storing chlorine gas in cylinders. However, gaseous chlorine handling could be hazardous and requires strict regulatory compliance to protect workers and environment. Specific safety devices need to be provided to personnel handling chlorine gas tanks and cylinders [9].

Stored sodium hypochlorite can also be used but it is highly corrosive and industrial grade hypochlorite undergoes rapid decay in concentration during storage [10]. Table-1 shows data available from sodium hypochlorite decay studies. The data generally indicates that decay rates are higher at higher concentration and higher temperature.

Table-1: Half-life of NaOCl at different concentrations and temperatures [11].

Half life constant(Days) Initial (%) of available chlorine	Temperature			
	100 °C 212 °F	60 °C 140 °F	25 °C 77 °F	15 °C 59 °F
10.0	0.079	3.5	220	800
5.0	0.25	13.0	790	1500
2.5	0.63	28.0	1800	N/A
0.5	2.5	100	6000	N/A

For both of these options, security of supply can result in unplanned shutdowns of power plant due to cooling problems. On-site generation of sodium hypochlorite is the trusted and preferred method of providing effective chlorination since it is safe, effective, and uses only seawater and electricity, both of which are available in abundant supply at costal power industry KANUPP. Electrochemical

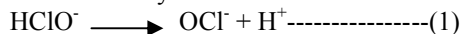
process is preferred because it provides sodium hypochlorite as and when required in the required concentration.

Present study was carried out to evaluate the electrochemical process for the production of sodium hypochlorite as a disinfectant. Production efficiency was an important consideration in the study. Therefore, effect of various critical operating parameters on the process efficiency was evaluated. Present study helps in selecting an electrode material to be used in the electrochemical process having a high current efficiency and superior durability as compared to the previous material. Material should carryout the electrochemical process at low temperature and at a low concentration of brine such as seawater. The effects of critical operational parameters on the process performance such as electrode material, applied current density, power consumption, surface area ratio of electrode and inter-electrode spacing were evaluated.

Sodium Hypochlorite as a Disinfectant

Sodium hypochlorite is a strong oxidizer. Products of the oxidation reactions are corrosive. Hypochlorous acid is a weak acid and dissociate into OCl⁻ and H⁺ [12].

Ionization may be defined as



The quantity of OCl⁻ is called as free available chlorine and a strong oxidizer. It is effective not only against bacteria, but also against viruses and fungi. Sodium hypochlorite disinfects in the same way as chlorine does. The effectiveness of chlorine against some bacteria and protozoan is presented in Table-2 and 3.

Table-2: Effect of chlorination on inactivating selected bacteria [13-19].

Bacteria	Cl ₂ Residual (mg/L)	Temp. (°C)	pH	Contact Time (min.)	Reduction (%)
Campylobacter jejuni	0.1	25	8.0	5	99.99
Escherichia coli	0.2	25	7.0	15	99.99
Legionella pneumophila	0.25	21	7.6-8.0	60-90	99
Mycobacterium chelonae	0.7	25	7.0	60	99.95
Mycobacterium fortuitum	1.0	20	7.0	30	99.4
Mycobacterium intracellulare	0.15	25	7.0	60	70
Pasteurella tularensis	0.5-1.0	10	7.0	5	99.6-100
Salmonella Typhi	0.5	20	7.0	6	99
Shigella dysenteriae	0.05	20-29	7.0	10	99.6-100
Staphylococcus aureus	0.8	25	7.2	0.5	100
Vibrio cholerae (smooth strain)	1.0	20	7.0	< 1	100

It can be seen from these tables that the reduction percentage due to chlorination is significant

against most bacteria and protozoa, if residual concentrations about 1 mg/L and contact time in the order of 30 min. are provided. Recent studies found that production of sodium hypochlorite by saline or seawater is an attractive option in the coastal industries required disinfectants for cooling water as well as saline wastewater discharging from industries and required to treat before discharging into the environment [22].

Table-3: Effect of chlorination on inactivating selected protozoa [20, 21].

Protozoa	Cl ₂ Residual (mg/L)	Temp. (°C)	pH	Contact Time (min.)	Reduction (%)
<i>Cryptosporidium parvum</i>	80	25	7.0	90	90
<i>Entamoeba histolytica</i>	1.0	22-25	7.0	50	100
<i>Giardia lamblia</i>	1.5	25	6.0-8.0	10	100
<i>Naegleria fowleri</i>	0.5-1.0	25	7.3-7.4	60	99.99

Results and Discussion

Electrochemical technique was applied to produce sodium hypochlorite for disinfection purpose using seawater at KANUPP. The effect of critical operating parameters such as electrode material, applied current density, applied voltage, surface area ratio of electrode and interelectrode spacing were evaluated. Results obtained during the experimental study are discussed in the following section. Some of the properties of seawater used in this experimental study are given in Table-4.

Table-4: Characteristics of seawater adjacent to study site.

Parameter	Units	Minimum	Maximum	Mean
Temperature	°C	16	31	28
pH at 25 °C		8.0	8.3	8.2
Turbidity	NTU	--	30	16
Conductivity	mS/cm	--	--	52.0
Total Hardness as CaCO ₃	mg/l	6,350	7,580	6,800
Total Dissolved Solids (TDS)	mg/l	35,000	41,500	39,500
Total Solids (TS)	mg/l	--	--	46,200
Calcium as Ca ²⁺	mg/l	400	610	615
Magnesium as Mg ²⁺	mg/l	1,300	1,470	1,200
Sodium as Na ⁺	mg/l	10,800	15,800	14,660
Potassium as K ⁺	mg/l	380	480	450
Chloride as Cl ⁻	mg/l	19,360	25,000	24,000
Sulfate as SO ₄ ²⁻	mg/l	2,700	3,300	3,000
Oil	mg/l	Nil	Nil	Nil

Electrode Material

The selection of electrode materials for electrochemical treatment must take into account issues such as cost, accessibility, lifetime of anode, stability at the required potentials, selectivity, composition and pH of the reaction medium, nature of intermediate substances and products and

environmental compatibility. Care has to be taken in proper selection, since most electrodes are useful in only a limited range of potential and pH. With conventional metal electrodes, electrochemical treatments are unsuitable because of the low stability of the anodes and the poor current efficiency. Regarding stability at the required potentials, the selected electrode material must be such that it will not corrode under the application of these potentials [4]. However, in the present study the process efficiency was a major consideration due to the importance of uninterrupted plant operation. In the electrode material investigation stainless steel, lead, zinc, copper, aluminum and titanium were tested as candidate materials. However, finally titanium with Dimensionally Stable Electrode (DSA) coat was selected due to its better performance.

Temporal variation in the production of sodium hypochlorite using different electrode materials is presented in Fig. 1. It can be seen that the production of sodium hypochlorite was insignificant even after a run of 90 minutes when copper and aluminum were used. Copper and aluminum are good conductors and easily available and are commonly being used in the electrolytic industry. However, the process efficiency for the production of sodium hypochlorite is very low. In the case of zinc and stainless steel some amount of sodium hypochlorite was produced; stainless steel was being used as cathode in chlor alkali cells. It is quite stable in alkaline catholyte, having a lifetime in excess of 20 years. Similarly zinc may also be used in electrolytic industry but it has high corrosive nature and may corrode quickly. Both stainless steel and zinc showed low production of sodium hypochlorite.

Titanium is used as a cathode in cells manufacturing chlorates and hypo chlorites. However, titanium readily forms hydrides while evolving hydrogen thereby slowly flaking off the cathode, resulting in a lifetime of only 1 to 2 years. In the present study production reached about 750 ppm of sodium hypochlorite when titanium electrode was used and the electrode was found to remain stable. When lead electrode was used production of sodium hypochlorite reached near 1100 ppm after 30 min of run however, lead was found to be highly unstable overall and gray colored precipitates were formed as a result of formation of chlorides of lead. The surface of the anode became covered with this scale which further slowed the consumption of the anode; however, this effect also reduced the production of sodium hypochlorite.

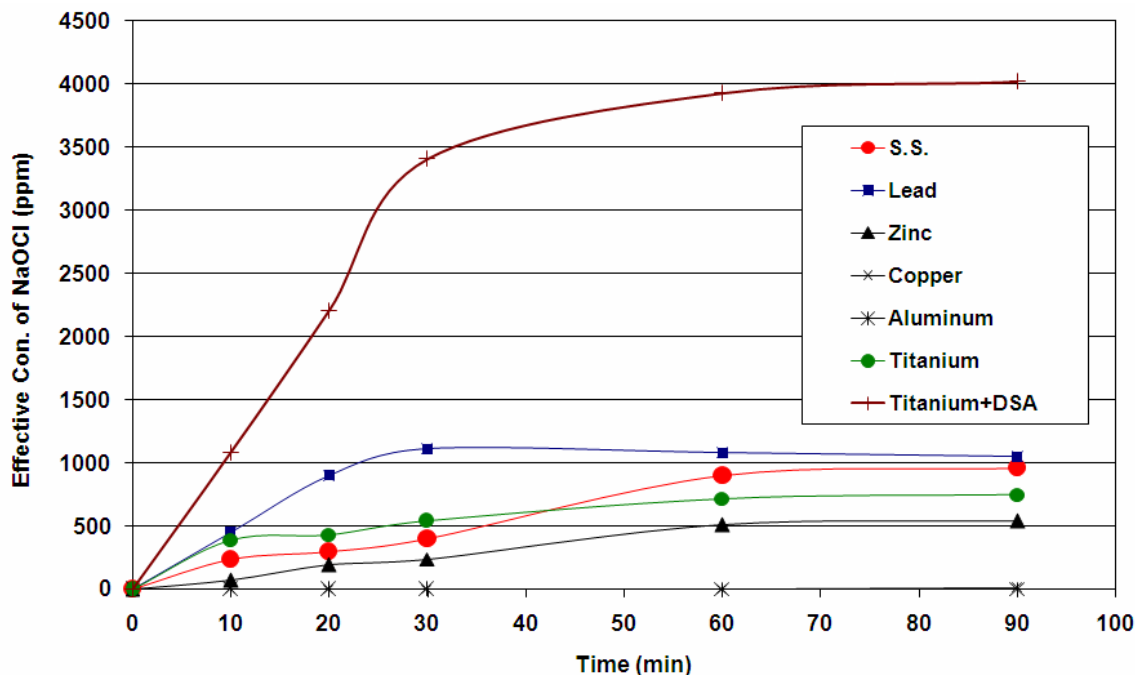


Fig. 1: Temporal variation in the production of NaOCl using different electrodes.

Results show that if stability of electrode material is considered along with the production of sodium hypochlorite titanium is better than other materials. Titanium is the material of choice for the substrate because of its excellent chemical resistance, its high breakdown potential and its reasonable cost. Titanium has a very low resistivity of $55 \times 10^{-6} \Omega \text{ cm}$ as compared to graphite, which has a resistivity of about $1 \times 10^{-3} \Omega \text{ cm}$ and also has stability problems [23]. Finally, titanium electrode with DSA coating was tested for stability and sodium hypochlorite production. Titanium + DSA electrode showed excellent stability and production of sodium hypochlorite reached to about 4000 ppm. In all subsequent experiments titanium + DSA electrode was used.

Effect of Current Density on Process Efficiency

Effect of current density on the production of sodium hypochlorite was investigated using titanium + DSA electrodes. In this part of study supplied DC current was adjusted in a controlled manner to achieve current density ranging from 3.8 to 12.8 A/dm^2 in four experimental runs. The results of the temporal variation of sodium hypochlorite at different current densities are presented in Fig. 2. Fig. 2 depicted that the production of sodium hypochlorite is increasing with run time. It is also depicted in Fig. 3 that the production increased with the current

density however; when current density increased beyond an optimum value of 9.8 A/dm^2 efficiency of the process decreased. It was found that at a current density of 9.8 A/dm^2 the production of sodium hypochlorite reached to 3000 ppm. As an increase in current density augment the cost of production one may use an optimum value of current density for efficient production and minimum cost. Therefore, result in Fig. 2 shows that the current density of 9.8 A/dm^2 is a reasonable value for an efficient production of sodium hypochlorite. As the cost of treatment is a crucial issue in the industry effect of current density (applied current) on the cost have been studied.

Effect of Surface Area Ratio of Anode to Cathode

In this phase influence of the ratio of surface areas of anode to cathode on the process efficiency for the production of sodium hypochlorite has been studied. In this investigation surface area ratio was varied by gradually removing the submerged cathodes from the solution while keeping the submerged area of anodes constant. Results of the six runs are presented in Fig. 3. Fig. 3 shows the relation between produced sodium hypochlorite concentration in the seawater and the anode to cathode surface area ratio after 30, 60 and 90 minutes of runs. It is to be noted that by increasing surface area ratio, the production of sodium hypochlorite rose

almost linearly up to a ratio of unity and after that the rate of increase appeared to decline slightly. However, slow increase in the production of sodium hypochlorite was observed. These findings are in a reasonable agreement with the results reported in literature, claiming that a larger S_a to a larger S_c

would enhance the production of sodium hypochlorite [24]. Results show that changing the surface area ratio affects the amount of sodium hypochlorite produced. This attribute may be due to the inhibition of some of the side reactions involved.

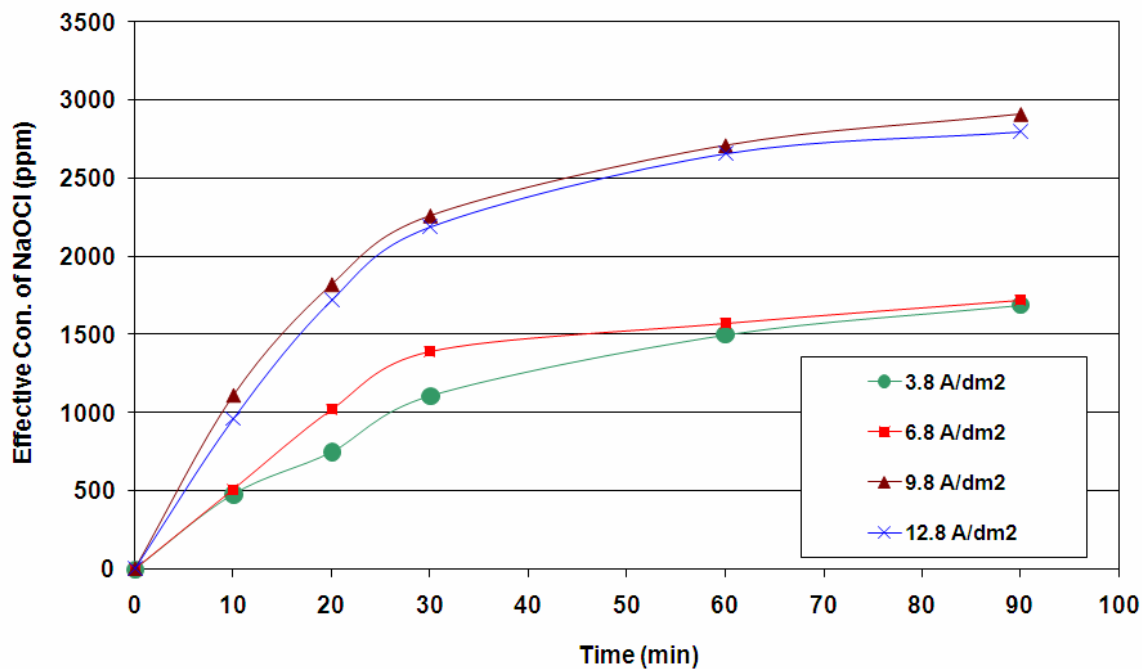


Fig. 2: Temporal variation in NaOCl production at different current densities.

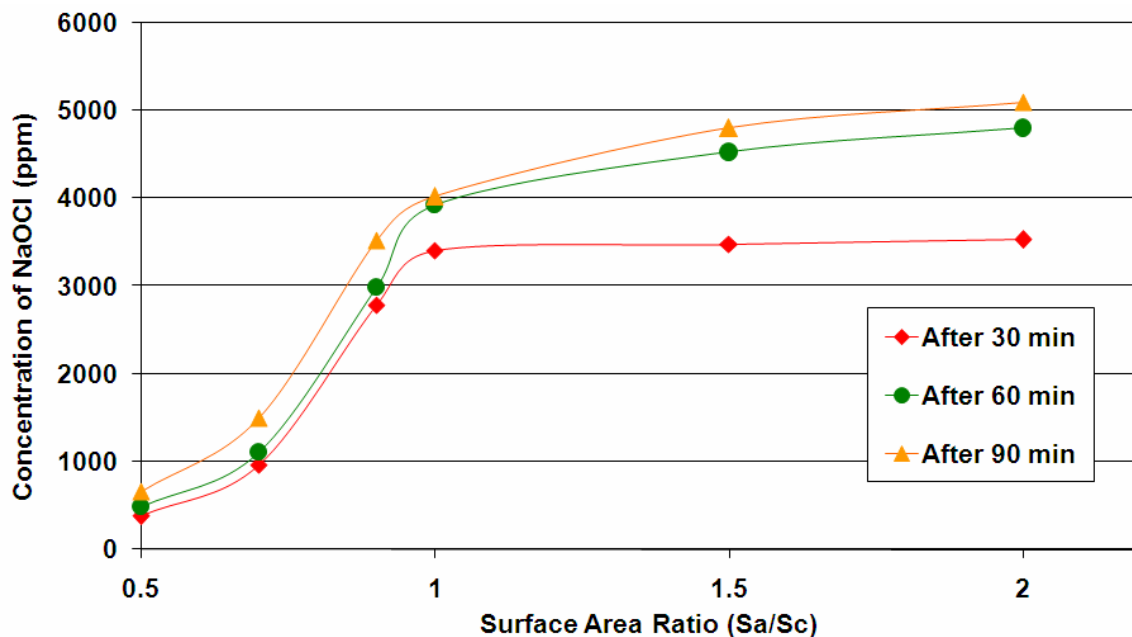


Fig. 3: Effect of anode to cathode surface area ratio on NaOCl production efficiency.

One of the causes of the reduction in amount of available chlorine at lower values of S_a/S_c is that the hypochlorite ion is electrochemically reduced at the cathode according to the following reactions:



Furthermore, the production of magnesium hydroxide precipitates at cathode may also hinder the process [25].



Therefore, result in Fig. 4 shows that the anode to cathode surface area of unity is an optimum value for an efficient production of sodium hypochlorite.

Effect of inter Electrode Spacing

Inter-electrode spacing is a vital parameter in sodium hypochlorite production using electrochemical process. Increasing the electrodes spacing will reduce the capital cost of treatment but may reduce the treatment efficiency. Hence, an optimization of this parameter is critical. Temporal

variation of sodium hypochlorite production as a function of inter-electrode spacing is presented in Fig. 4. Analysis of Fig. 4 revealed that the rate of sodium hypochlorite production increased as the inter-electrode spacing decreased. Maximum production of sodium hypochlorite was achieved for spacing of 8 cm. However, further reduction in inter electrode spacing does not increase the process efficiency. It can be seen from Fig. 4 that production of sodium hypochlorite at a spacing of 6 cm is approximately equal to the spacing of 10 cm. Therefore, beyond a gap of 8 cm, the production of sodium hypochlorite dropped and is inauspicious.

The brine solution whose electrolysis is being carried out contains the sodium (Na^+) and Chloride (Cl^-) ions distributed throughout the solution. When two oppositely charged electrodes are immersed in the solution, the sodium (Na^+) and Chloride (Cl^-) ions move towards the oppositely charged electrodes. Both the electrodes are separated uniformly to maintain a critical uniform distance from each other. This critical distance in case of sodium hypochlorite production is 8 cm. This distance is maintained for optimum operation and for the quick removal of hydrogen from cell [8].

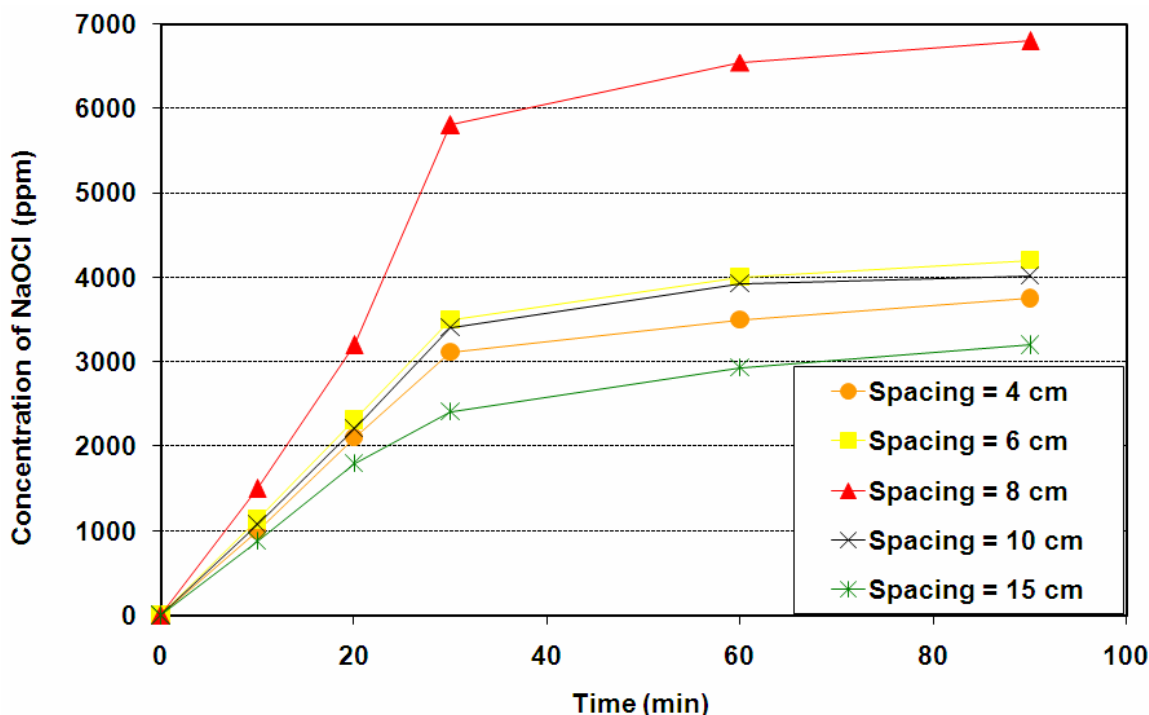
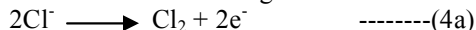


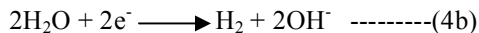
Fig. 4: Effect of inter-electrode spacing on NaOCl production efficiency.

Main reaction:

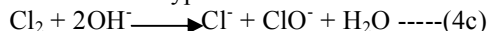
At the anode: chlorine generation



At the cathode: hydrogen evolution and hydroxide formation



Chemical reaction: Chlorine and Hydroxide ions react to form hypochlorite



Mass balance: production of hypochlorite



The overall reaction can then be represented as:



This observation is in line with the idea that a shorter gap would favor the minimization of the potential drop, and lead to a higher current density. This phenomenon has also been pointed out by other researchers [26]. One may conclude that for the studied operational conditions an inter electrode spacing of 8 cm is feasible for the production of sodium hypochlorite.

Cost Analysis

Cost of the treatment is one of the most important parameters that affect the application of electrochemical process. In addition to the cost of electrode and other accessories of cell, the major

operation cost is the power consumption during operation in the electrochemical process. In the present study parallel electrodes were placed in the electrochemical cell and powered by a DC power supply. The energy consumption in the process can be written as [27]:

$$E = (U_t * I_t) / (1000 * Q) \text{----- (5)}$$

where,

U_t is the total electrolysis voltage (V)

I_t is the total electrolysis current (A)

Q is the volumetric flow rate (m³/h)

In order to see the cost effectiveness of electrochemical process for the production of sodium hypochlorite from seawater, the performance of process evaluated in terms of energy consumption rate. It was observed that with the increase in applied current density the process efficiency can be increase which at the other hand increase the treatment cost. A plot between the power consumption and the applied current density is presented in Fig. 5. It can be seen from Fig. 5 the power consumption is increasing with the increase in the applied current density which generally improves the process efficiency. However, there is insignificant increase in the power consumption when applied current density increases beyond 7 A/dm². It is therefore, important to select a best suited applied current density to achieve an economical process.

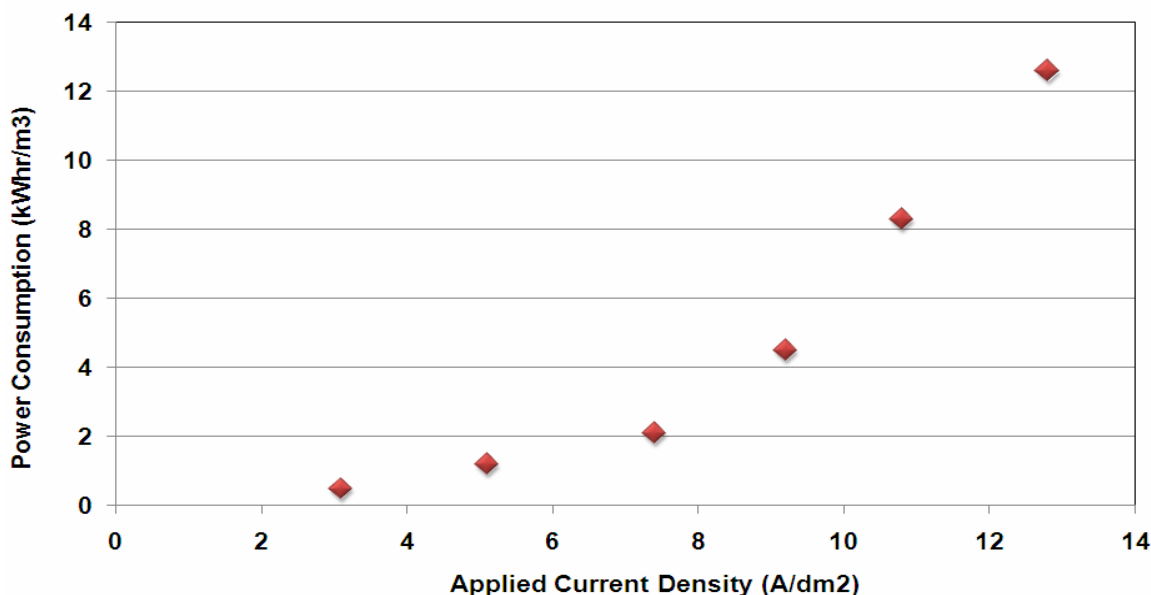


Fig. 5: Relation between applied current density and power consumption.

It was also observed that to achieve a similar concentration of sodium hypochlorite the power consumption rate decreased as the contact time increased (see Fig. 6). For example, to produce 3500mg/l of sodium hypochlorite, the power input was around 0.03 kWh/m³ with an electrolysis time of 52 min, in comparison to a higher power consumption of 0.10 kWh/m³ with an electrolysis time of 23 min. Thus, cost effective electrochemical wastewater disinfection should use a proper combination of contact time and current input.

Experimental

The present study evaluates the electrochemical process efficiency for the production of onsite sodium hypochlorite at KANUPP, Karachi. In order to simulate the sodium hypochlorite production in a continues flow cell using seawater an experimental setup using Plexiglas having dimensions of 420 mm × 250 mm × 250 mm was fabricated and checked for any leakage. The schematic sketch of experimental setup is shown in Fig. 7. The electrochemical cell is a rectangular box with four electrodes; each having a thickness of 2 mm and size of 200 mm × 220 mm. Electrodes were placed in the electrolyte (seawater) and connected to an uninterrupted DC power supply MAXIREG 761 along with a rheostat and multi-meter. Inter-electrode spacing was kept at 10 cm in each run except during studies of inter-electrode spacing.

Gravity controlled flow rate of 0.8 l/min (0.048 m³/hr) was provided as shown in Fig. 7. Under the experimental conditions (temperature lower than 40 °C and pH greater than 8), species such as Cl₂⁻, ClO₂⁻, ClO₄⁻ were not detected and the chlorates ClO₃⁻ were found to be negligible. Thus, the active chlorine is totally in the form of hypochlorite ClO⁻.

In addition, some cations, which are present in seawater, such as calcium, and magnesium may form hydroxides and carbonates in the form of suspended solids. During experimental runs precipitates of these hydroxides observed on the electrode surface, which are carried away by the seawater stream, but some of which cause scaling on the electrodes. This scaling was removed by flushing the electrodes after each run with dilute hydrochloric acid solution.

Each experimental run lasted for at least 1.5 hours. During experimental runs samples of seawater were collected at predefined time intervals and analyzed for sodium hypochlorite concentration following the procedures outlined in “Standards methods for the examination of water and wastewater”[28]. During the study of electrode material in order to improve the sodium hypochlorite production a Dimensionally Stable Anode (DSA) coating over titanium electrode was carried out. Titanium after being washed and cleaned thoroughly, the titanium sheet was defatted with acetone, and submerged in a 90 °C, 10% (w/w) acetic acid solution for 1–2 h to remove its compact oxide layer and produce a micro porous structure on its surface. Then the sheet was washed with distilled water and was placed in dehydrated alcohol to protect it from being oxidized again before the coating operation. The coating liquid was prepared to the specification given in Table-5.

Table-5: Reagents used in formation of DSA coating [22].

Reagents	Amount
RuCl ₃	1 g
36% HCl	0.5 ml
n-butanol	17 ml
Iso-propanol	10 ml
Ti(OC ₂ H ₅) ₄	3 ml
Ti:Ru	1:3.46

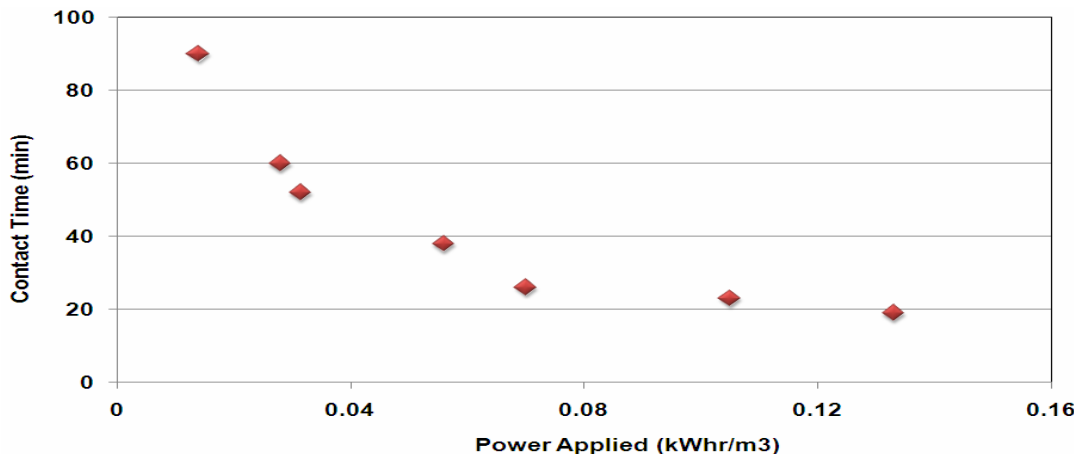


Fig. 6: Relation between applied power and contact time to produce 3500 mg/l product.

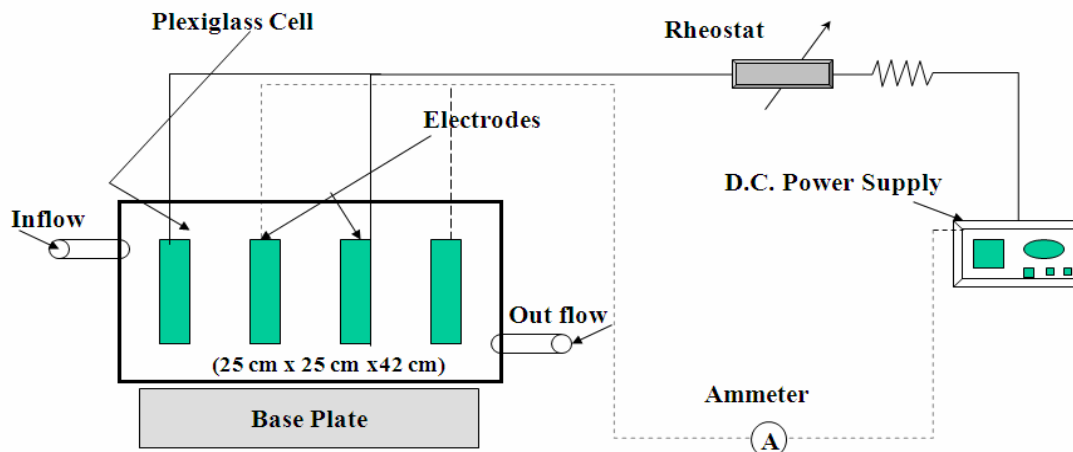


Fig. 7: Schematic of continuous flow electrochemical set-up.

This coating liquid was 'painted' onto the dried titanium surface, and then the electrode was baked in an oven at 420 °C for 15 min. This 'painting-and-baking' operation was repeated for about 15 times till the coating liquid was used up. In the final baking operation, the oven temperature was set to 450 °C and the baking time was prolonged to 1 h to complete the dissolution of RuCl_3 and $\text{Ti}(\text{OC}_4\text{H}_9)_4$, and harden the $\text{RuO}_2\text{-TiO}_2$ layer [22].

Conclusions

In the present study an electrochemical process was investigated to determine optimum conditions for the production of sodium hypochlorite disinfectant on site. Critical operating parameters were investigated and the following were concluded:

1. Titanium + DSA electrode showed excellent stability in comparison to other electrode materials and production of sodium hypochlorite reached to an optimum of about 7500 ppm.
2. Power consumption is directly related to the applied current density. However, current density of 9.8 A/dm^2 found to be a reasonable value for an efficient production of sodium hypochlorite because after this value power consumption is increasing sharply with insignificant improvement in process efficiency.
3. An anode to cathode surface area of unity was found to be an optimum value for an efficient production of sodium hypochlorite.
4. An inter-electrode spacing of 8 cm was found to be optimum for the production of sodium hypochlorite disinfectant.

Overall, it was concluded that the production of sodium hypochlorite on site using an electrochemical

process is a feasible and promising option for the power industry using seawater as cooling and/or process water. However, operating parameters need to be optimized to achieve maximum available process efficiency.

Acknowledgement

Author acknowledges the support and facilities provided by Karachi Institute of Power Engineering (KINPOE) to carry out this study.

References

1. T. S. Rao, A. J. Kora, P. Chandramohan, B. S. Panigrahi, and S. V. Narasimhan, *Biofouling: The Journal of Bioadhesion and Biofilm Research*, **25**, 591 (1999).
2. A. Verween, F. Hendrickx, M. Vincx, and S. Degraer, *The Journal of Bioadhesion and Biofilm Research*, **23**, 35 (2007).
3. Q. Zhao, C. Wang, Y. Liu, and S. Wang, *International Journal of Adhesion and Adhesives*, **27**, 91 (2007).
4. L. Akesso, M. E. Pettitt, J. A. Callow, M. E. Callow, J. Stallard, D. Teer, C. Liu, S. Wang, Q. Zhao, F. D. D'Souza, P. R. Willemsen, G. T. Donnelly, C. Donik, A. Kocijan, M. Jenko, L. A. Jones, and P. C. Guinaldo, *Biofouling*, **25**, 67 (2009).
5. G. Kiely, *Environmental Engineering*, McGraw Hill International, Boston, MA, p.148 (2007).
6. A. Latif, S. Noor, Q. M. Sharif and M. Najeebullah, *Journal of the Chemical Society of Pakistan*, **32**, 115 (2010).
7. S. Baig, R. Farooq, A. H. Malik and N. B. Uzbek, *Journal of the Chemical Society of Pakistan*, **31**, 857 (2009).

8. M. Afsar, M. S. Thesis, *Design of a cell to produce sodium hypochlorite from sea water/RO rejected water*, Karachi Institute of Power Engineering, Karachi, Pakistan (2005).
9. D. V. Sickle, M. A. Wenck, A. Belflower, D. Drociuk, J. Ferdinands, F. Holguin, E. Svendsen, L. Bretous, S. Jankelevich, J. J. Gibson, P. Garbe, and R. L. Moolenaar, *American Journal of Emergency Medicine*, **27**,7 (2009).
10. G. Gordon, L. C. Adam, and B. P. Bubnis, *Journal of American Water Works Association (AWWA)*, **89**, 149 (1997).
11. M. E. Pulido, PhD Dissertation, *Evaluation of an electro-disinfection technology as an alternative to chlorination of municipal wastewater effluents*, Depart. Eng. and Appl. Sci., University of New Orleans, USA, 2005.
12. Metcalf and Eddy Inc. *Wastewater Engineering: Treatment, and Reuse*. McGraw-Hill Inc., New York (2003).
13. P. Eginton, J. Holah, D. Allison, P. Handley, and P. Gilbert, *Letters in Applied Microbiology*, **27**, 105 (1998).
14. J. Behrsing, S. Winkler, P. Franz, and R. Premier, *Postharvest Biology and Technology*, **19**, 192 (2000).
15. W. R. Weissinger, W. Chantarapanont, and L. R. Beuchat, *International Journal of Food Microbiology*, **62**, 131 (2000).
16. B. Joseph, S. K. Otta, I. Karunasagar, and I. Karunasagar, *International Journal of Food Microbiology*, **64**, 372 (2001).
17. S. H. Flint, H. van den Elzen, J. D. Brooks, and P. J. Bremer, *International Dairy Journal*, **9**, 436 (1999).
18. A. Kraft, M. Stadelmann, M. Blaschke, D. Kreysig, B. Sandt, and F. Schröde, *Journal of Applied Electrochemistry*, **29**, 868 (1999).
19. G. Logsdon, V. Thurman, and J. Stoecker, *Journal of the American Water Works Association (AWWA)*, **77**, 66 (1985).
20. O. S. Savluk, *Khimiya i Tekhnologiya Vody*, **4**, 82 (1982).
21. W. Montiel, and B. Welte, *J. Français Hydrol.*, **21**(1), 40 (1990).
22. G. F. Qin, Z. Y. Li, X. D. Chen, and A. B. Russell, *Journal of Food Engineering*, **54**, 118 (2002).
23. C. Nistor, J. Emneús, L. Gorton, *Analytica Chimica Acta*, **387**, 309 (1999).
24. R. Ramesh Babu, N. S. Bhadrinarayana, K. M. Meera Sheriffa Begum, and N. Anantharaman, *Journal of the University of Chemical Technology and Metallurgy*, **42**, 206 (2007).
25. D. W. Kirka, and A. E. Ledas, *International Journal of Hydrogen Energy*, **7**, 932 (1982).
26. P. M. Robertson, W. Gnehm, and L. Ponto, *Journal of Applied Electrochemistry*, **13**, 315 (1983).
27. K. Rajeshwar, and J. Inanez, *Environmental Electrochemistry: Fundamentals and Applications in Pollution Abatement*, Academic Press, San Diego (1997).
28. *Standard Methods, Standard methods for the examination of water and wastewater*. 21st Ed. APHA, AWWA and WPCF, Washington, D.C.(2000).