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Research Article

Electrooxidation-based on-site disinfectant generation using IrO_2-RuO_2 coated titanium anodes: Investigation and development

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ABSTRACT

Disinfection is a critical process for preventing microbial contamination of water and surfaces, thereby protecting public health. Increasing hygiene needs and the need for a safe water supply necessitate effective and sustainable disinfectant generation. The study covers the examination and development of on-site disinfectant generation by electrooxidation method. With this process, disinfectants can be generated at the site of use in the required quantities. In addition, the fact that the generated disinfectant can be used without storage causes its disinfectant activity to be high, which makes disinfection more effective. An electro-oxidation reactor with 100 × 100 × 200 mm dimensions was designed, utilizing F-type titanium cathodes and IrO_2-RuO_2 coated F-type titanium anodes. The effects of experimental parameters, such as pH (5-8), flow rate (20-100 mL/min), current intensity (5-25 A), and NaCl concentration (1-5 M), were investigated. Based on the obtained data, the most efficient active chlorine generation occurred at pH 7. As the flow rate increased, residence time in the reactor decreased, leading to reduced energy consumption. Considering both energy efficiency and disinfectant generation, the optimum flow rate was determined as 40 mL/min. Current intensity up to 20 A increased disinfectant generation; however, the expected rise at 25 A was not observed. Thus, the optimum current intensity was selected as 20 A. Salt concentrations up to 3 M enhanced disinfectant generation, but higher concentrations did not yield further improvements. Under optimum conditions (pH 7, 40 mL/min flow rate, 20 A current intensity, 3 M salt concentration), 5450 mg/L of disinfectant was generated. Additional experiments to assess higher current intensities and saturated salt concentrations demonstrated 7750 ppm disinfectant generation at 50 A, placing this value among the highest reported in the literature. This study evaluates a broad range of parameters to determine optimal conditions, demonstrating that the disinfectant yield from this reactor is applicable for both laboratory-scale and field applications.

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INTRODUCTION

Disinfection is an important process used to eliminate harmful microorganisms and prevent their spread [1]. Considering the decreasing global water resources [2], disinfection is a vital process to ensure health and safety standards, especially in drinking water and wastewater treatment plants [3]. The disinfection process is used for surface cleaning in homes, public areas, the health sector, and various industries as well as drinking water and wastewater treatment plants [4,5]. Today, chlorine and chlorine compounds are the most widely used disinfectants in chemical disinfection applications [4,6]. The main reason for this situation is the high disinfectant efficiency of chlorine [7,8]. In addition, the easy availability of chlorine, its low cost, and its application with simple techniques are some of the reasons why it is frequently preferred [9,10].

Chlorine, especially in the form of hypochlorite, has been used for cleaning and disinfection for years [11]. Sodium hypochlorite (NaOCl) is known as a highly effective disinfectant in the elimination of harmful microorganisms [12,13]. Another advantage that makes NaOCl stand out is that it shows high effectiveness even at low doses. Even at a concentration of only a few ppm, it can inactivate most harmful microorganisms [14,15]. Another advantage of NaOCl is that it breaks down quickly and easily after application. In this case, the risk of environmental accumulation is eliminated. While providing effective disinfection, the negative effects on the environment and human health are also quite low [14,16].

Due to its high activity, NaOCl is widely used as a disinfectant in household cleaning, health institutions, various industrial facilities, and drinking water treatment plants [17,18]. However, some problems may arise in its storage and preservation. NaOCl in solid form is chemically unstable. It tends to deteriorate under atmospheric conditions [19]. NaOCl in liquid form is more stable than its solid form, but it must be stored at low temperatures. If it is not stored under appropriate conditions, it decomposes and causes the release of chlorine gas, which is harmful to human and environmental health [20]. To prevent these problems, the use of on-site disinfectant generation (OSDG) technologies in disinfectant generation offers a great advantage in terms of sustainability [21].

In classical disinfectant generation, disinfectant is transported from the centers where it is produced to the places where it will be used. The transportation distance is usually long distances. This situation both increases the carbon footprint and reduces the effectiveness of the disinfectant if it is not transported under appropriate conditions. In addition, failure to provide appropriate storage conditions in the places where it will be used causes the disinfectant to deteriorate and become an environmental risk [22]. OSDG offers a reliable and environmentally friendly alternative, especially in areas where hygiene is critical.

In OSDG, the electrooxidation process (EOP) is widely used [23]. EOP is a process that stands out with its short reaction time, versatility, environmental compatibility, low investment cost, high degree of automation potential, ease of operation, and safety [24, 25]. This method is an important process widely used in the removal of many organic and inorganic pollutants, as well as OSDG [26]. EOP is essentially a process based on the treatment of organic substances by direct and indirect oxidation using insoluble anode electrodes [26, 27]. The stability and catalytic activity of the anode electrode in EOP is a critical factor that determines the reactor's operating life and oxidation capacity [28, 29]. Therefore, it is very important to select the anode electrode appropriate to the experimental conditions in EOP studies. The anode types commonly used in EOP are platinum [30], graphite [31], stainless steel [32], dimensionally stable anodes (Ti/PtO_2 -IrO_2, Ti/RuO_2 -TiO_2, Ti/RuO_2 -IrO_2, and Ti/IrO_2 -Ti_2O_5) [33,34], boron-coated diamond [35], ruthenium [36], and titanium [37]. Boron-coated diamond, lead, graphite, and pure titanium anodes are anode electrodes with high catalytic activity [38].

Apart from the electrode type, the distance between the electrodes, flow rate, current density, electrolyte type and concentration, feed water pH value, temperature, and placement of the electrodes are important [39,40].

The basic working principle of EOP and OSDG is the generation of active chlorine compounds from salt water solution. Salt solutions that can be used in this process are $MgCl_2$, KCl , HCl and NaCl. The most commonly used electrolyte type among these is NaCl [41,42]. The reasons why NaCl is widely preferred can be listed as; low cost, easy availability, practical transportation and easy dissolution in water [43]. In addition, the formation of NaOCl, which is widely used as a strong oxidant and disinfectant, is another reason why NaCl is preferred. Chlorine and chlorinated disinfectants (NaOCl, OCl^-, HOCl) are obtained in the EOP and OSDG process where NaCl and pure water solution are used [23, 44]. In addition, this process allows the generation of disinfectants in the required amounts and concentrations and eliminates the need for storage [45, 46]. Therefore, it provides a more environmentally friendly and low-cost solution compared to traditional disinfection methods [47,48]. However, depending on the purpose and frequency of use, the electrodes to be used and the reactor design as well as the optimum conditions must be determined appropriately. Since the electrodes used wear out over time, the selection of long-lasting electrodes contributes to the process [49].

The mechanism of on-site disinfectant generation by electrooxidation occurs through the reactions given in equations 1-7 [50].

Reactions occurring at the anode;

$$2Cl^- \rightarrow Cl_{2(g)} + 2e^- \quad (1)$$

Reactions occurring at the cathode;

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2 \quad (2)$$

Reactions occurring in solution;

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^- \quad (3)$$

$$HOCl + OH^- \rightarrow H_2O + OCl^- \quad (4)$$

$$Na^+ + OH^- \rightarrow NaOH \quad (5)$$

$$Cl_2 + 2NaOH \rightarrow NaOCI + NaCl + H_2O \quad (6)$$

The final reaction is;

$$NaCl + H_2O \rightarrow NaOCl + H_2 \quad (7)$$

Although many studies exist on this subject, further research is needed to enhance the efficiency and controllability of the process. In this context, this study focuses on the research and development of the OSDG process via EO. An EO cell has been designed, and experimental parameters have been established for the operation of the process. The effects of initial pH, salt solution concentration, flow rate, and current intensity on the process have been examined. As a result of these examinations, the conditions for achieving optimum efficiency in the process have been determined.

MATERIALS AND METHODS

EOP and OSDG; 5 pieces of 80 x 180 mm F type titanium mesh cathodes and 5 pieces of 80 x 180 mm IrO_2-RuO_2 coated F type titanium mesh anodes have been provided. The main reason for preferring titanium coated anodes for EOP and OSDG process in the study is that these anode types have high catalytic activity and their resistance is suitable for salty environment conditions [51,52]. The reason for choosing mesh anodes is that they provide low energy loss and homogeneous current distribution [53]. Total surface area of the plates has been calculated as 2880 cm^2 . Surface area of the electrodes has an important role in terms of reaction efficiency and disinfectant generation capacity. Increasing surface area of the electrodes supports increasing reaction rate and disinfectant generation. However, increasing surface area increases energy consumption and initial investment cost. For these reasons, establishing a balance between efficiency and energy consumption is very important. After the electrodes have been supplied, the EO cell has been designed with dimensions of 100*100*200 mm and the distance between the electrodes has been fixed as 5 mm. The distance between the electrodes is a parameter that affects the interaction between the reactor efficiency, energy consumption and the electrode surface in the electron oxidation process. The reason for fixing the distance between the electrodes as 5 mm in the study is that it is a common value used to optimize these parameters [54,55]. After the electrodes have been placed in the reactor, steel screws and silicone gaskets have been used to close and seal the reactor. The durability and chemical resistance of the silicone gasket have been tested in our previous studies. However, it needs to be replaced at certain intervals for long-term use.

Solutions prepared with NaCl and pure water have been used for the experiments. There is an inlet and outlet system in the cell where NaCl solution is given at a constant concentration and flow rate. The disinfectant solution produced is taken from the outlet line. The inlet flow rate is provided in a constant and controlled manner by a peristaltic pump. The solution taken from the outlet line is collected in a graduated container. Possible deviations of the flow rate have been observed during a full cycle. As a result of the observations, no significant deviations have been generally detected in the outlet flow rates. A DC power supply (Chrom a 62024P-40-120) capable of producing 40 V-120 A power has been used in the experiments.

The analysis of disinfectants taken from the exit line has been carried out by Thermo It has been done with a scientific orion star portable pH/Ion meter. The device has been calibrated at certain intervals. The dilution method has been applied while analyzing the samples. In order to reduce the error rate of the measurements, three repetitive analyses have been made for each output sample. In general, similar results have been obtained, but a more reliable value has been obtained by averaging the results obtained. In experimental studies, the temperature and pH parameters of the feed water and the produced disinfectant have been measured with a WTW brand multi-parameter meter. This device has been calibrated at certain intervals and measurement security has been ensured.

Some experimental conditions have been repeated at regular intervals to increase reliability, and generally consistent results have been obtained.

The experimental setup where OSDG with EOP takes place is shown in Figure 1.

The experimental parameters studied in the experimental setup in Figure 1 are given in Table 1. With the help of the fixed variables specified in Table 1, the given parameters have been examined and the optimum experimental conditions have been determined.

The purpose of the study, previous studies, and the limitations of the equipment and materials used have been considered when determining the parameter ranges in this experimental study.

Equation 8 has been used to calculate the energy consumption in experimental studies [26].

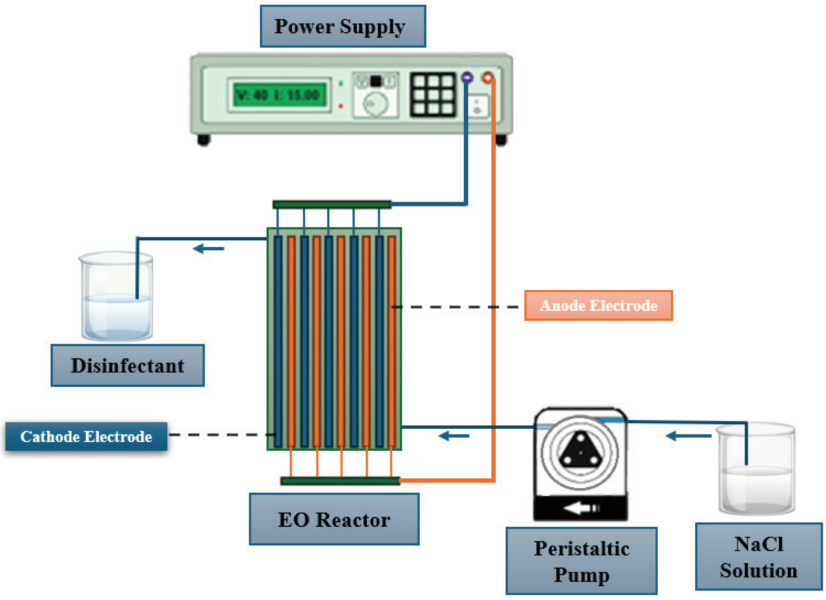

Figure 1. The experimental setup where OSDG with EOP.

Table 1. Parameters affecting the OSDG process in the EO cell

Parameters examined	Parameter range	Variables held constant
Initial pH value	5, 6, 7 and 8	10 A current intensity, 1 M feed water NaCI concentration, 50 ml/min flow rate
Flow rate, (ml/min)	20, 30, 40, 50 and 100	10 A current intensity, 1 M feed water NaCI concentration, Optimum pHi
Current intensity (A)	5, 10, 20, 25, 30, 40 and 50	Optimum pHi is 1 M feed water NaCl concentration
Feed water NaCl concentration, (M)	1, 2, 3, 4, 5 and saturation concentration	Optimum current intensity, Optimum pHi

$$E\ (kW\text{-}h/m^3) = (I*V*h)/v \quad (8)$$

Here, E represents energy consumption. (kW-h /m^3), I constant current intensity (A), V is the applied potential difference value (Volt), h is the retention time (h) depending on the flow rate, and v (m^3) is the electrochemical reactor volume.

The applied potential difference value has been read directly from the power supply. The value read during the experiment has been used in experimental calculations.

RESULTS AND DISCUSSION

The effects of initial pH value, salt concentration, flow rate, and current intensity on the EOP and OSDG process have been examined by considering the parameter ranges given in Table 1. The results obtained are available in the subheadings.

Effect of Initial pH Value on System Parameters

The effects of the initial pH value of the solution in the OSDG process have been examined with EOP. The initial pH value is a critical parameter affecting the chemical reactions and disinfectant formation in the OSDG process [56]. The optimum initial pH value must be determined to provide the desired effectiveness and efficiency in disinfectant generation.

The experiments have been conducted by maintaining a constant current intensity of 10 A and a sodium chloride (NaCl) concentration of 1 M, with the flow rate set at 50 mL/min. During the experiments, the ambient temperature has been measured as 19°C. The initial pH values of the feed solutions have been adjusted to 5, 6, 7, and 8. No external intervention has been made to the pH values throughout the experiments. The variations in pH observed in the outlet water are attributed to the reactions occurring within the EO cell.

The effluent pH values and energy consumption depending on the initial pH value are given in Figure 2.

When Figure 2 is examined, it is seen that the effluent pH values and energy consumption give similar results even though the initial pH values are different. Therefore, it is possible to say that the initial pH value has no effect on

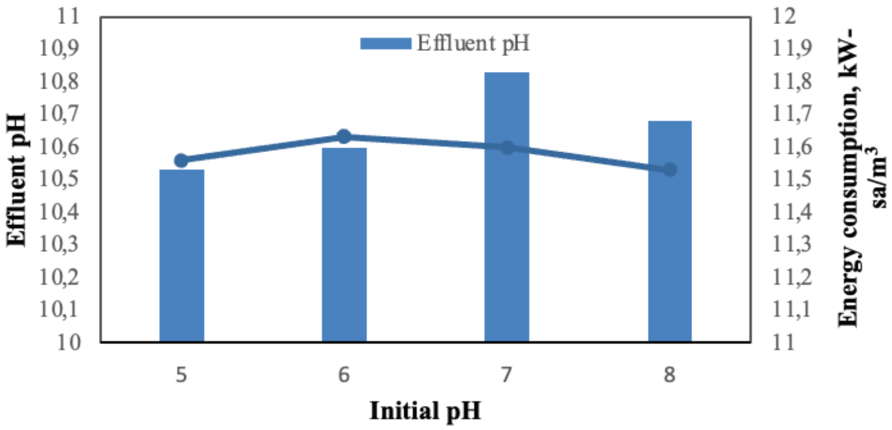

Figure 2. Effect of initial pH value on effluent pH and energy consumption.

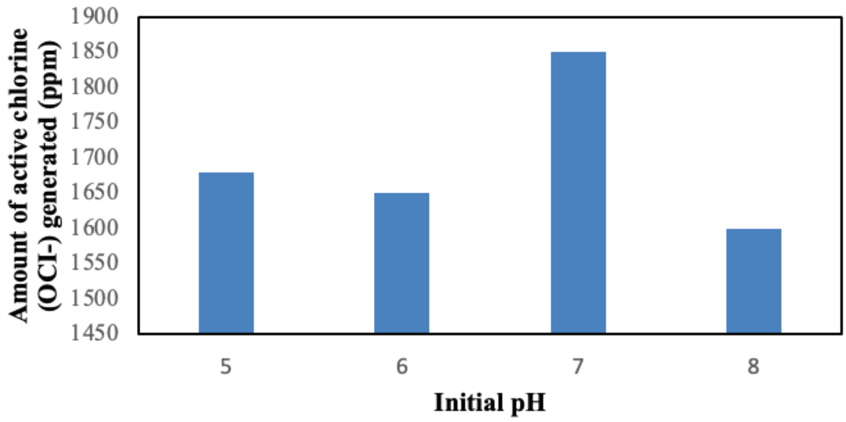

Figure 3. Effect of initial pH value on active chlorine (OCl^-) generation as NaOCl.

energy consumption and effluent pH values. In addition, it is seen that the output pH values are basic. The reason for this is that hypochlorite ions (OCl^-) consume hydrogen ions (H^+) while reacting with water. In addition, the OH^- ions released cause the pH to increase.

The effect of the initial pH value on disinfectant generation (NaOCl) is given in Figure 3.

When Figure 3 is examined, it is seen that when the initial pH value is 7, the generation of active chlorine (OCl^-) is higher than other initial pH values. This reveals the fact that the initial pH values affect disinfectant generation.

It is known that chlorine gas is released in OSDG with EOP. When the pH increases above 6.5, the hydrolysis reaction of chlorine accelerates. Therefore, at conditions above pH 6.5, a large part of the chlorine dissolves in the anode diffusion layer by hydrolysis [57]. In addition, the highest oxidation capacity of chlorine occurs at neutral pH levels [58,59]. This information explains the increased active chlorine efficiency when the initial pH value is 7.

Another important parameter affecting the efficiency of the OSDG carried out by EOP is the HOCI (hypochlorous acid) concentration. Around pH 5, the dominant active chlorine species in the medium is HOCI [60]. As pH increases, HOCI rapidly ionizes and this accelerates the reactions. Therefore, the highest active chlorine generation after pH 7 occurred at pH 5.

When the initial pH value increased above 7, a decrease in active chlorine efficiency has been observed. Similarly, Le et al. [61] reported in their study comparing pH 7 and pH 8 that the active chlorine efficiency at pH 8 has been almost half of the efficiency obtained at pH 7.

Effect of Flow Rate on System Parameters

The effect of the feed solution flow rate on the EOP, particularly in OSDG, is a complex issue influenced by several factors. Generally, the feed flow rate is a critical parameter affecting the efficiency of the EOP, energy consumption, and the quality of the disinfectant. Optimizing the flow rate is essential to ensure effective mass transfer, proper electrode reaction, and minimized energy usage,

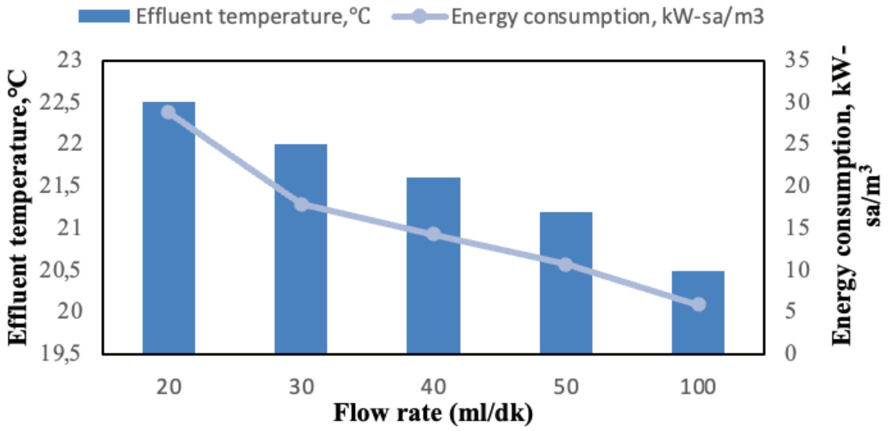

Figure 4. Effluent temperature values and energy consumption depending on flow values.

while also maintaining the desired properties of the end product.

The study has investigated five different flow rates: 20, 30, 40, 50, and 100 ml/min. Since the reactor volume is approximately 1200 ml, the holding times corresponding to each flow rate have been calculated as 60, 40, 30, 24, and 12 min, respectively.

While examining the effects of flow rate on the process, the salt solution concentration has been kept constant at 1 M, the initial pH value is 7, and the current intensity is 10 A. The ambient temperature has been determined at 19 °C. The effluent temperature values and energy consumption depending on the flow rate values are given in Figure 4.

When Figure 4 is examined, it can be observed that the effluent temperature and energy consumption decrease as the flow rate increases. This phenomenon is primarily attributed to the reduction in residence time within the reactor. A shorter residence time results in lower energy consumption, as less electrical energy is converted into thermal energy. Moreover, a reduced residence time decreases the resistance within the system, thereby diminishing the overall heat generation. Consequently, the temperature increase in the solution is less pronounced.

The effect of flow rate changes on disinfectant generation is given in Figure 5.

The increase in flow rate in the EO cell has shortened the residence time in the reactor, making it challenging to achieve reactions with the desired efficiency. In experiments, when the flow rate has been set to 20 ml/min, approximately 2160 mg/L of active chlorine has been produced for a solution with an initial pH of 7 after subjecting a 1 M concentration solution to an electrochemical reaction for 60 minutes. Increasing the flow rate to 100 ml/min under the same conditions has reduced the residence time in the reactor to 12 minutes, resulting in a decrease in active chlorine generation to 1400 mg/L. Similarly, Hsu (2003) has determined that higher flow rates decrease active chlorine concentration in the effluent [62].

The active chlorine concentration measured at 40 ml/min in the study has reached 2080 ppm, which is close to the value at 20 ml/min. To optimize time and energy,

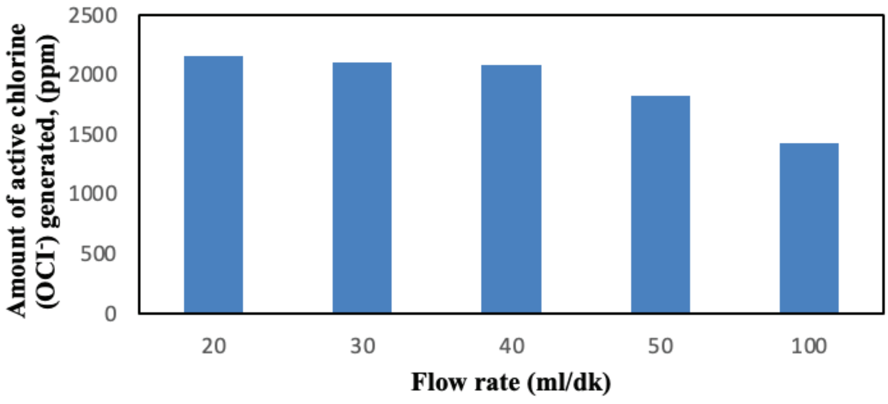

Figure 5. Effect of flow rate changes on active chlorine (OCl^-) generation as NaOCl.

subsequent trials have been conducted at flow rates of 40, 50, and 100 ml/min.

Effect of Current Intensity on System Parameters

In OSDG with EOP, current intensity plays a critical role in initiating and directing redox reactions between electrodes. Thus, it is essential to investigate the effects of current intensity on disinfectant generation.

In this part of the study, the effect of current intensity on system parameters has been investigated. Current intensities have been set at 5, 10, 15, 20, and 25 A, while flow rates have been maintained at 40, 50, and 100 ml/min. The initial pH has been adjusted to 7, and the ambient temperature has been measured at 18°C. Table 2 has shown the effluent temperature and energy consumption values for the different current intensities.

When Table 2 is examined, it can be seen that the temperature values and energy consumption have increased with the rising current intensity. The primary reason for this is that higher current intensities have increased the system resistance. Under a constant electrical conductivity, an increase in current intensity results in the generation of higher potential difference values. The rise in potential difference values, in turn, has led to an increase in energy consumption.

Figure 6 presents the active chlorine (OCl^-) concentrations produced at varying current intensities and flow rates.

When Figure 6 is examined, it can be observed that increasing current intensity has significantly enhanced disinfectant generation at the evaluated flow rates. A review of the literature indicates that efficiency increases as the applied amperage intensity to inlet waters with the same initial pH and flow rate rises[63]. The results obtained at 20 A and 25 A values appear to be quite close to each other. Specifically, when disinfectant generation is analyzed at 40 ml/min for 20 A and 25 A, the concentrations

Table 2. Effluent temperature and energy consumption values according to changing current intensities

Effluent temperature values corresponding to changing current intensities (°C)			
	40 ml/min	**50 ml/min**	**100 ml/min**
5 A	19.8	18.7	19.3
10 A	22.3	21.2	20.5
15 A	23.7	22.2	21.9
20 A	26.2	24.5	22.3
25 A	28.1	24.9	22.9
Energy consumption values for varying current intensities (kW-h/m³)			
	40 ml/min	**50 ml/min**	**100 ml/min**
5 A	6.48	5.27	2.64
10 A	14.29	10.74	5.89
15 A	23.81	19.50	9.75
20 A	34.33	27.27	14.13
25 A	46.25	35.58	18.50

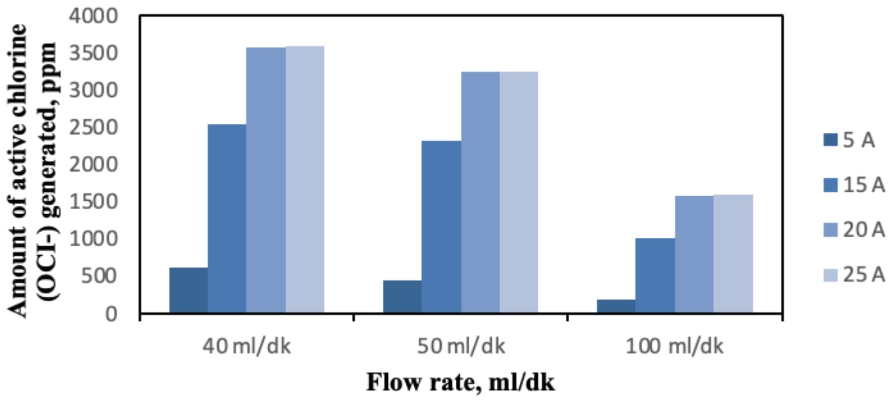

Figure 6. Effect of current intensity and flow rate changes on active chlorine (OCl^-) generation as NaOCl.

are found to be 3576 ppm and 3580 ppm, respectively. At a flow rate of 50 ml/min, the disinfectant generation values at 20 A and 25 A are 3244 ppm and 3240 ppm, respectively. Similarly, at 100 ml/min, the generation values at 20 A and 25 A are recorded as 1580 ppm and 1590 ppm, respectively. Therefore, since the results at 20 A and 25 A with a 1 M salt concentration are similar, it appears more advantageous to select a current intensity of 20 A in terms of energy savings.

Effect of Salt Concentration on System Parameters

In the OSDG with EOP, salt concentration is an important parameter affecting product efficiency and reaction speed. High salt concentrations increase disinfectant generation efficiency by accelerating electrochemical reactions. Optimal salt level reduces by-products and NaCl consumption, improving product quality and reducing costs.

To investigate the effects of salt concentration on disinfectant generation, experiments have been conducted using 1, 2, 3, 4, and 5 M NaCl, with an initial pH value set at 7, flow rates of 40, 50, and 100 ml/min, and a constant current intensity of 20 A. The ambient temperature has been measured in the range of 17.0-17.3 °C. Table 3 presents the effluent temperature and energy consumption values at different salt concentrations.

When Table 3 is examined, the change in effluent water temperature with the increase in salt concentration is observed. Higher salt concentrations have increased the electrical conductivity of the solution while decreasing the electrical resistance in the system, thereby limiting the conversion of electrical energy into thermal energy. As a result, the temperature rise in the electrochemical reactor has been mitigated with increasing salt concentrations. Additionally, the increase in salt concentration has led to a partial decrease in energy consumption. Even at the lowest salt concentration, high electrical conductivity has been achieved, resulting in similar potential difference values within the system. This situation has prevented a significant change in energy consumption.

Table 3. Effluent temperature and energy consumption values at different salt concentrations

Effluent temperature values at different salt concentrations (°C)			
	40 ml/min	**50 ml/min**	**100 ml/min**
1M	26.2	24.5	22.3
2M	25.4	23.6	21.5
3M	22.1	21.5	20.1
4M	21.7	19.4	18.1
5M	21.2	18.8	17.6
Energy consumption values at different salt concentrations (kW- h /m^3)			
	40 ml/min	**50 ml/min**	**100 ml/min**
1M	33.25	27.33	13.67
2M	32.92	26.93	13.59
3M	32.75	26.73	13.55
4M	32.33	26.65	13.53
5M	31.87	26.59	13.51

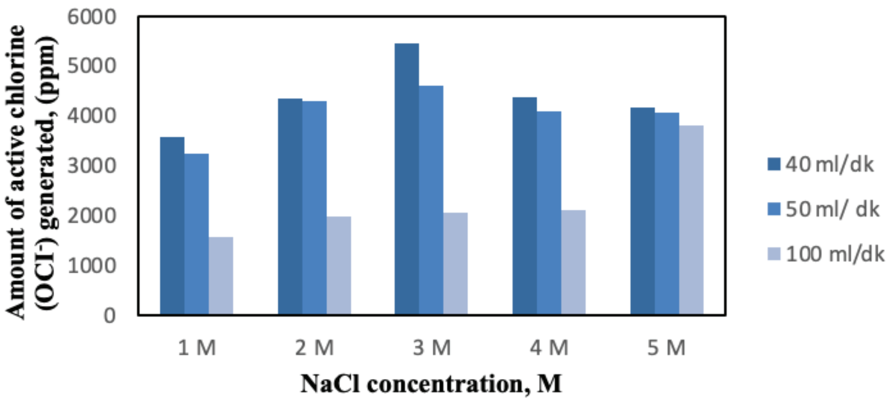

Figure 7. Effect of salt concentration and flow rate variations on active chlorine (OCl^-) generation as NaOCl.

Figure 7 shows the active chlorine (OCl^-) concentrations corresponding to different salt concentrations and flow rates.

When Figure 7 is examined, the increase in salt concentration from 1 M to 3 M has led to an increase in disinfectant concentration at all flow rates. However, the rise in salt concentration from 3 M to 5 M has resulted in a relative decrease in active chlorine formation. The highest active chlorine yield of 5450 ppm has been achieved at a 3 M salt concentration and a flow rate of 40 mL/min. In the experiments conducted with a 5 M solution, the effect of the flow rate diminished, resulting in similar active chlorine concentrations across all three flow rates. This situation has positively impacted the generation of relatively more active chlorine at higher flow rates.

Effect of Saturation Salt Concentration and High Current Intensities on Disinfectant Generation

Examining the effects of salt concentrations reaching saturation levels and high current intensities on disinfectant generation is critically important for determining optimum operating conditions and understanding the relationships between energy consumption and efficiency. In the conducted studies, it has been observed that increasing salt concentration positively affects the generation of relatively more active chlorine at high flow rates. Therefore, this stage of the study has been carried out at a flow rate of 100 ml/min, with an initial pH value of 7 and a saturated salt concentration of 5.8 M NaCl. Current intensities have been set at 30, 35, 40, and 50 A, while the ambient temperature has been measured at 19 °C. Figure 8 presents the effluent temperature values and energy consumption at different current intensities.

The increase in current intensity caused an increase in energy consumption and effluent temperature values.

Figure 9 presents the concentrations of active chlorine (OCl^-) generated at different current intensities.

Figure 9 illustrates that increasing current intensity has led to an increase in active chlorine generation. At a current intensity of 50 A, the active chlorine concentration has reached up to 7750 ppm, which is among the highest values reported in the literature for OSDG with EOP [44,64].

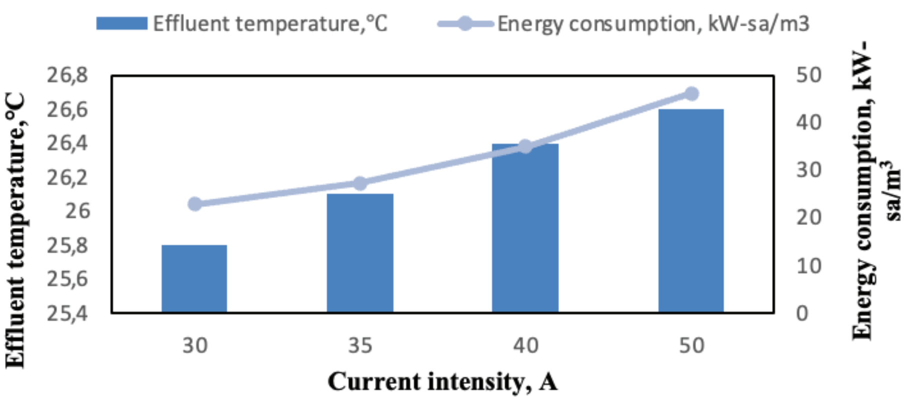

Figure 8. Effluent temperature values and energy consumption at different current intensities.

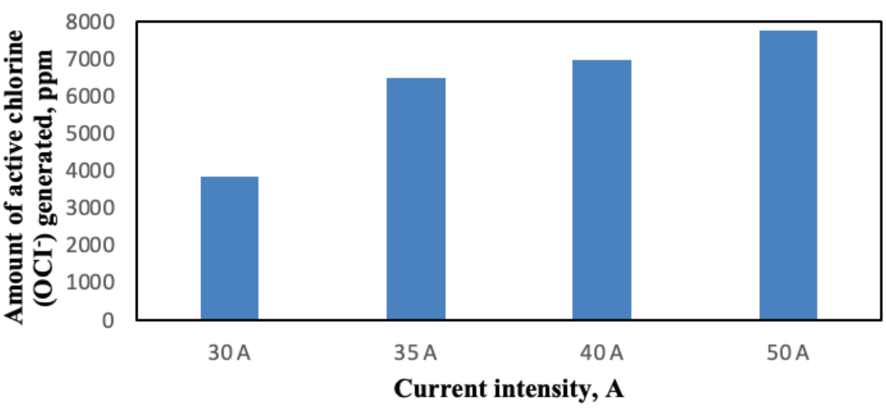

Figure 9. Active chlorine (OCl^-) generation as NaOCl concentrations formed at different current intensities.

CONCLUSION

In this study, on-site disinfectant generation using the electro-oxidation method was investigated. An electro-oxidation reactor was designed with 5 F-type titanium cathodes (80 × 180 mm) and 5 IrO_2-RuO_2 coated F-type titanium anodes (80 × 180 mm). The EO cell was constructed with dimensions of 100 × 100 × 200 mm, and the distance between the electrodes was fixed at 5 mm. The effects of experimental parameters such as pH, flow rate, current intensity, and NaCl concentration on disinfectant production were examined. The active chlorine generated as a disinfectant was in the form of OCl^- (sodium hypochlorite, NaOCl). The conclusions obtained from the study are as follows.

- ✓ The pH values were set between 5-8 and the system was operated without intervention. It was shown that the initial pH values had minimal effect on the effluent pH values. The system tended to a basic environment during the reaction. Active chlorine generation was found to be most efficient at pH 7.
- ✓ In the study, current intensities between 5 and 25 A were examined and it was observed that increasing current intensity increased disinfectant production. However, it was determined that the effect of increasing current intensity up to 20 A on disinfectant production was seen more clearly, but the expected increase was not seen at 25 A. Therefore, the optimum current intensity was determined as 20 A in order to ensure energy efficiency.
- ✓ The flow rates were set between 20 and 100 mL/min and it was observed that the energy consumption decreased as the residence time in the reactor decreased with increasing flow rates. However, the increase in flow rates caused a decrease in the amount of disinfectant produced. Considering both high disinfectant production and low energy consumption, a flow rate of 40 mL/min was determined as optimum.
- ✓ Salt concentration was examined between 1 and 5 M and it was concluded that increasing salt concentration increased disinfectant production. However, it was observed that increasing salt concentration up to 3 M increased disinfectant production visibly, and this increase was not as expected at higher salt concentrations. Therefore, 3 M salt concentration was determined as the optimum salt concentration.
- ✓ Optimum conditions were determined as 3 M salt concentration, 20 A current intensity, pH 7, and 40 mL/min flow rate. Under these conditions, 5450 mg/L disinfectant production was obtained. Under the determined optimum conditions, 32.75 kW-h/m^3 energy consumption occurred.
- ✓ Since it was determined that increasing the current intensity and salt concentration positively affected the disinfectant production, another study was conducted to determine the maximum production capacity of the system. Experiments were conducted at saturated salt concentration, pH 7, 100 mL/min flow rate, and 30, 35, 40, and 50 A current intensities. Since a current intensity above 50 A would negatively affect the system, no current intensity above this intensity was studied. 7750 ppm disinfectant production was achieved at a current intensity of 50 A and this value was recorded as a very high production amount according to the literature.
- ✓ The disinfectant amounts obtained are above the values determined for microbial applications in most areas. Therefore, it is possible to use a reactor of the same size in laboratory and field applications. It is possible to revise and use the process appropriately according to the required disinfectant concentrations and amounts.
- ✓ This process prevents disinfectants from being transported from generation areas to long distances where they will be used. In addition, being in a form that can be used after generation eliminates the need for storage. This eliminates possible risks to human and environmental health during transportation and storage. This enhances the sustainability of the process.

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ABBREVIATIONS

EO	Electrooxidation
EOP	Electrooxidation process
OSDG	On-site disinfectant generation
NaOCI	Sodium hypochlorite
OCl^-	Hypochlorite

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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