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Analysis of the Influence of the Number of Electrolytic Cells and Changes in Current Set on the Electrolysis Process in the Chlorination Plant of XYZ Gas Power Plant

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Abstract: The Priok PLTGU Block 4 Chlorination Plant had experienced component damage, which is the electrolysis generator B, to be precise in the 4th order electrolysis cell. The results of this study indicate that the concentration of chlorine resulting from the operation of the 3 cell mode is not much different from the normal 4 cell operation, and is able to meet the min-imumswitch over to the electrolysis generator A which has a standby status. In this study the authors aim to create simulation conditions, and see the feasibility of performance if the electrolysis generator is still running using only 3 cells. The feasibility of the performance is assessed based on a comparison of the concentration of chlorine produced, then compared with the minimum requirement for the generating unit's water purification system, and calculating the available residual chlorine. The results of this study indicate that the concentration of chlorine resulting from the operation of the 3 cell mode is not much different from the normal 4 cell operation, and is able to meet the min-imum requirement of chlorine for the generator, as well as the residual which is classified as safe limits so that the 3 cell operating mode is classified as feasible to operate.

Keywords: Chlorine; Chlorination Plant; Electrolysis; Sodium Hypochlorite (NaOCl)

Citation:. Al Qorni, M. U., Hidayati, N., Ulfina, A. (2024). Analysis of the Influence of the Number of Electrolytic Cells and Changes in Current Set on the Electrolysis Process in the Chlorination Plant of XYZ Gas Power Plant. Recent in Engineering Science and Technology, 2(01), 32–41. Retrieved from https://www.mbi-journals.com/index.php/riestech/article/view/41

Academic Editor: Iwan Susanto

Received: 3 January 2024
Accepted: 18 January 2024
Published: 31 January 2024

1. Introduction

The Chlorination Plant in the Gas Power Plant (PLTGU) is an auxiliary equipment unit that functions to produce Sodium Hypochlorite (NaOCl). NaOCl is used to inhibit the pro-liferation of marine life and microorganisms that may adhere to the inner walls of heat exchanger tubes, potentially causing disruptions in the heat transfer process[1]. The working mechanism of this chlorination plant is through electrolysis, which involves breaking down seawater injected by a DC current on the inner side of the electrolytic generator.

The Chlorination Plant at PLTGU XYZ has 2 electrolytic generators, namely A and B, and each electrolytic generator has 4 electrolytic cells. However, the electrolytic generator has experienced leakage issues. Electrolytic generator B suffered damage to the 4th cell, re-sulting in abnormal current and voltage. Due to this incident, electrolysis generator B cannot be operated and must be diverted to electrolysis generator A. Based on this event, the author aims to provide a simulation scenario if the generator continues to operate using 3 operating cells and compare it with the normal condition of operating with 4 cells. Therefore, adjustments to the current and voltage settings are needed for the safety of the electrolysis generator components. When the injected voltage and current are the same as in normal conditions, there is a concern about overvoltage or overcurrent in these electrolysis cells [2]. The reduction in the number of cells causes the current and voltage to be reduced by 25% or 1/4 of normal conditions. In normal conditions, a voltage of 95-98V and a current of 4134 A are used. When the number of cells is reduced, the voltage is lowered to 73-75 V, and the current is 3102 A. Adjusting these set point values will impact the result-ing concentration[3].

Therefore, in this research, the author aims to simulate the occurrence of damage or anomalies in one of its cells, leading to the operation of 3 cells. The simulation is conducted by analyzing the feasibility of performance and operation of the chlorination plant. This study aims to determine the influence of the number of electrolytic cells and changes in the current injection set point in the electrolysis process in the Chlorination Plant at PLTGU XYZ.

2. Materials and Experiment Methods

The research methodology is a description of the stages carried out in conducting the research[4] for this research, beginning with data management. The collected data consists of specifications and nameplate data from the Chlorination Plant components, the chlorination plant manual book, single-line diagram of the Chlorination Plant, chlorination plant commissioning data, and set point alarm parameter data.

After data management, the data is used for calculations using predefined formulas. The calculation process is conducted meticulously to minimize errors. The calculation results will be presented in the form of tables and graphs comparing voltage, current, and chlorine concentration.

The main formula used is based on Faraday's law, which studies the fundamentals of electromagnetism. Faraday's law is related to the process of chemical changes that produce electric current, or vice versa[5]. Additionally, formulas for supporting theories are presented, such as the formula for calculating the required power, the substance requirements for clean water treatment systems[6], and residual substances[7]. The combination of Faraday's laws 1 and 2 is obtained as follows:

$W = (e \times i \times t)/F$ ……………………………………………(2.1)

And the method to find its concentration is:

concentration = (Mass of Chlorine added (grams))/(volume of solvent (Liters))

Data processing is carried out using Microsoft Excel for calculating the mass of the substance produced and the chlorine concentration obtained during the electrolysis process, both during the 4-cell operating mode and the simulation with the 3-cell operating mode. After obtaining the concentrations, they can be visually represented through graphs. The graphs created provide a comparison of voltage, current, and concentrations obtained.

After creating the graphs, the next step is to examine the alarm parameters for the 3-cell operation to determine whether the voltage used will result in overvoltage, whether the current is below standard operation, whether the concentration is below the minimum requirement for the power plant unit, or to observe the residuals from the 3-cell operation.

If it is considered safe, the study will then assess whether it aligns with the theories presented in previous research. If the results match the theories of previous research, the findings of this study, namely whether the operation using the 3-cell operating mode can be performed or not, will be presented, supported by supporting theories and data.

Once the calculation results are obtained, graphs are created, alarm set points are reviewed, and in accordance with previous research, the next step is to present supporting theories if the operation is carried out with the 3-cell simulation conditions. Supporting theories, in addition to being based on matching alarm set points, involve calculating chlorine dosage, determining the minimum requirements for the power plant unit, and comparing chlorine residual substances.

Considering the alarm set points and adjusting to the theories from previous research, the final step is to draw conclusions and provide recommendations for the study. These recommendations are made to ensure that future research will be more successful

The steps of the above research can be presented in the form of a flowchart, as illustrated in the diagram below.

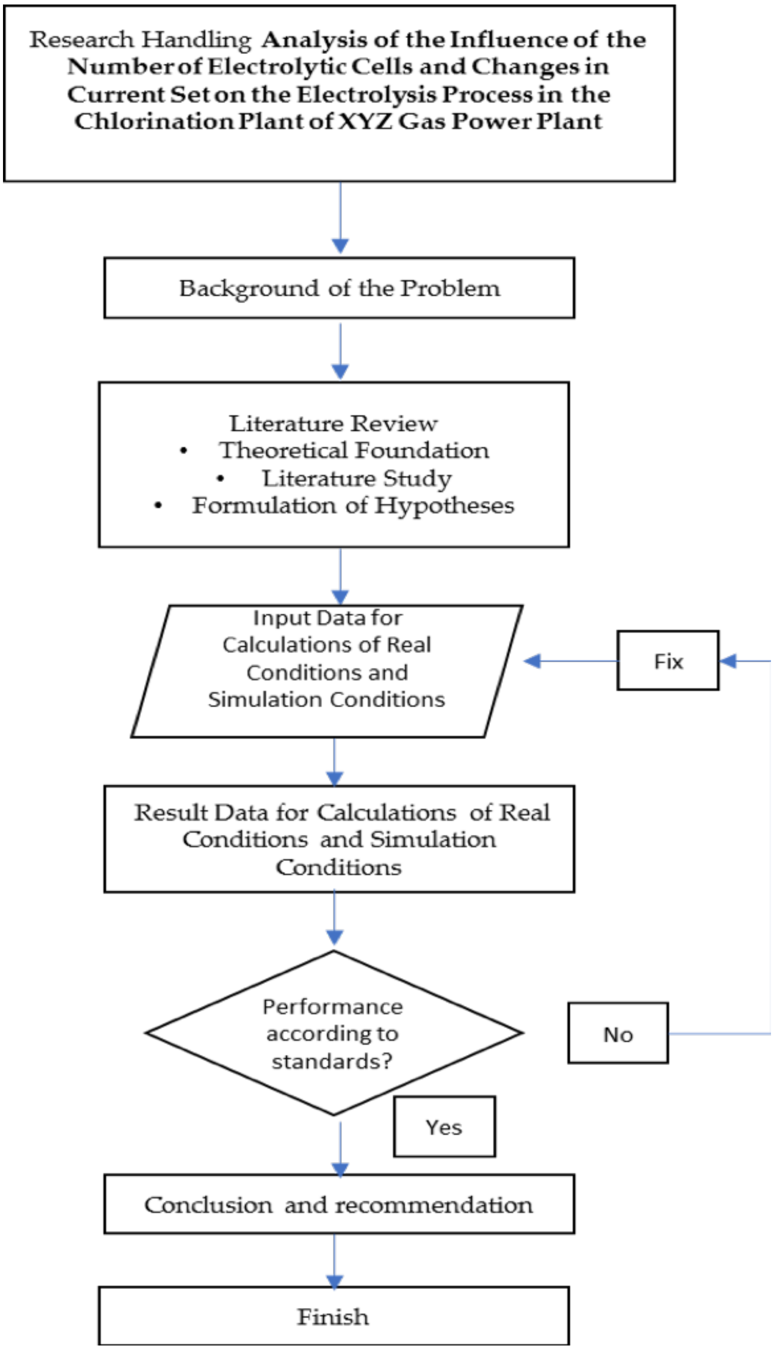

Figure 1. Research Flowchart

To find references or standards in assessing whether the 4-cell or 3-cell operating modes are suitable for operation, it is necessary to have formulas to determine minimum performance standards, the given dosage, and the available residual chlorine substance. The formula used to determine the dosage given is the chlorine requirement formula as follows:

$$\textbf{Dosage} = \frac{\textbf{Mass of substance added}}{\textbf{Water capacity treated with the substance}}$$

Then, for the minimum chlorine requirement for the power plant:

$$\textbf{Minimum Chlorine Requirement} = \textbf{Dosage} - \textbf{Detected residual substance}$$

And the formula to find the chlorine residual is as follows:

$$\textbf{Residual} = \textbf{Dosage} - \textbf{Minimum Requirement}.$$

3. Results and Discussion

Here is the average operating data taken based on the operating time, presented in two conditions: operating with the 4-cell mode and 3-cell mode:

Table 1. Average Operating Data for 4-Cell Operation

Average operating data for 4-cell operation from November 18 to 28 November 2022.									
Operating hour	Transformer Rectifier B Voltage	Transformer / Rectifier B Ampere	Voltage Electrolytic Gen. B No. 1	Voltage Electrolytic Gen. B No. 2	Voltage Electrolytic Gen. B No. 3	Voltage Electrolytic Gen. B No. 4	Flow Used (m3/h)	Mass Chlorine	Concentration
00.00	96,60	4135	24,18	24,09	23,97	24,40	1,60	5476	3423
03.00	96,26	4135	24,12	24,01	23,80	24,41	1,60	5476	3423
06.00	95,86	4134	24,05	23,89	23,73	24,32	1,60	5475	3422
09.00	96,04	4134	24,05	23,98	23,80	24,37	1,60	5475	3422
12.00	95,72	4134	24,08	23,98	23,77	24,35	1,60	5475	3422
14.00	96,46	4135	24,19	23,96	23,68	24,34	1,43	5476	3820
17.00	96,09	4136	24,13	23,68	23,95	24,37	1,53	5476	3571
20.00	97,00	4135	24,14	24,07	23,79	24,37	1,57	5474	3494
22.00	96,09	4042	24,09	23,97	23,78	24,40	1,70	5353	3149

Table 2. Average Operating Data for 3-Cell Operation

Average operating data for 3-cell operation from 15 to 25 October 2022.								
Operating hour,	Transformer Rectifier B Voltage	Transformer / Rectifier B Amper Ampere	Voltage Electrolytic Gen. B No.1	Voltage Electrolytic Gen. B No.2	Voltage Electrolytic Gen. B No.3	Flow used (m3/h)	Mass Chlorine	Concentratio(ppm)
00.00	73,48	3215	24,89	24,33	24,13	1,57	4258	2712
03.00	73,37	3101	24,53	23,92	23,79	1,52	4106	2701
06.00	73,72	3099	23,51	23,51	23,16	1,46	3650	2500
09.00	74,4	3102	24,63	23,97	2388	1,38	4106	2975
12.00	74,2	3101	24,65	23,95	23,91	1,54	4106	2666
14.00	73,86	3100	24,57	23,86	23,83	1,33	4108	3089
17.00	74,11	3100	24,3	23,88	23,88	1,54	4104	2665
20.00	74,31	3100	24,61	23,82	23,95	1,6	4105	2566
22.00	73,96	3103	24,71	23,98	23,96	1,4	4104	2931

Table *1* and **Table** *2* contain data for the operation of 4 cells and 3 cells, obtained from the average results per operating time over 11 days. The mass of chlorine produced is based on equation (2.1), and the chlorine concentration is obtained based on equation (2.2). The calculations are as follows:

When using the 4-cell operating mode, the data used is from electrolysis generator A. The calculations are as follows:

$$W = \frac{e\ x\ i\ x\ t}{F}$$
$$W = \frac{Cl\ x\ 4133\ x\ 3600}{F}$$
$$W = \frac{35.5\ x\ 4133\ A\ x\ 3600\ s}{96500\ C}$$
$$W = 5.473{,}54818\ gram$$
$$W = 5474\ gram$$

When using the 3-cell operating mode, the data used is from electrolysis generator B. The calculations are as follows:

W = (e x i xt)/F
W = (Cl x 3102 A x 3600 s)/F
W = (35.5 x 3102 x 3600 s)/(96500 C)
W = 4.108,14093 gram
W = 4.108 gram

Once the mass of chlorine in grams produced is known, the chlorine concentration obtained through electrolysis can be determined. Based on equation 2.2:

$$\text{concentration} = \frac{Mass\ of\ Chlorine\ added\ (grams)}{\text{Flow rate of water used for electrolysis (liters/hour}}$$

With the known mass and volume of water used for electrolysis, with a water volume of 1.6 m^3/h, the concentration can be calculated. Here is the calculation of the concentration obtained during electrolysis in normal 4-cell operating mode.

With the known mass and volume of water used for electrolysis, with a water volume of 1.6 m^3/h, the concentration can be calculated. Here is the calculation of the concentration obtained during electrolysis in normal 4-cell operating mode.

$$\textbf{concentration} = \frac{\textbf{Mass of chlorine added (grams)}}{\textbf{Flow rate of water used during electrolysis (liters/hour)}}$$

= (5.474 gram)/(1600 liter/h)
= 3,42096759 gr/l per hour
= 3.42096759 gr/l x 1000 mg = 3420.96759 mg/L per hour

Here is the concentration calculation obtained during electrolysis in the simulated 3-cell operating mode:

$$\text{concentration} = \frac{\text{Mass of chlorine added (grams)}}{\text{Flow rate of water used during electrolysis (liters/hour)}}$$

= (4108 gram)/(1600 liter)
= 2,56758808 g/L
= 2,56758808 g/L x 1000 mg = 2.567,58808 mg/L
concentration = 2568 mg/L

Based on the operational data of both operating modes, both in 4-cell and 3-cell configurations, the graphs obtained are presented as shown in the following graph images:

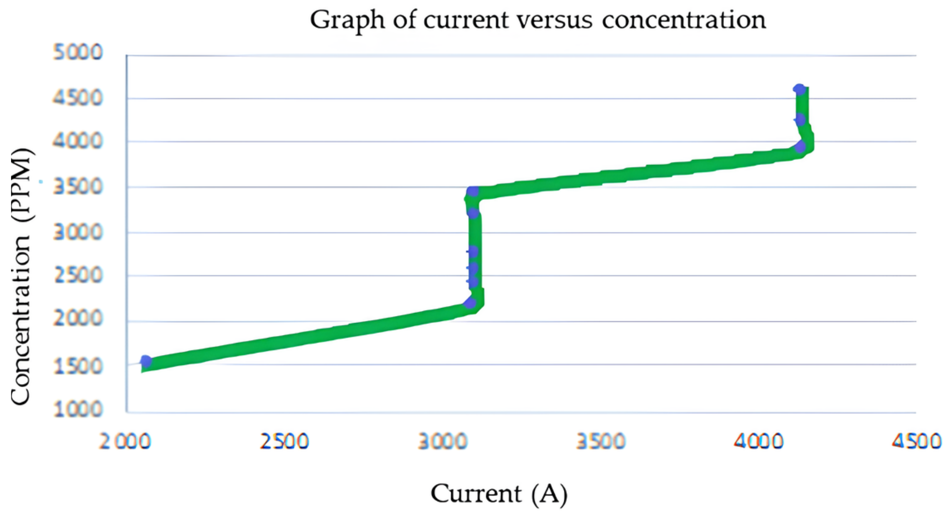

Figure 2. Graph of average current versus average concentration

In graph 3.1, it is obtained that the average current used in both modes is around 4134 Amperes for 4-cell operation and 3100 Amperes for 3-cell operation. Additionally, there is an anomaly or abnormality in the current, which is 2068 Amperes, due to a switch-over process on Saturday, October 17, 2022. This component exchange occurred a day before, and the current used in the electrolysis process had not been raised to the normal set point, which is around 3100 A for 3-cell operation or 4136 A for normal operation. Based on the trend or direction of the graph, the concentration strengthens as the current increases during the electrolysis process. Therefore, from the graph, it can be observed that the current influences the amount of concentration produced[8].

However, over time, it is known that the chlorine concentration produced varies each day depending on the situation and environmental conditions. As evidence, even though the current used is relatively stable, as explained in the operational data in tables 3.1 and 3.2, the chlorine concentration appears to depend on the amount of water flow used during the electrolysis process[9]. The following is a graph comparing the water flow rate and chlorine capacity produced.

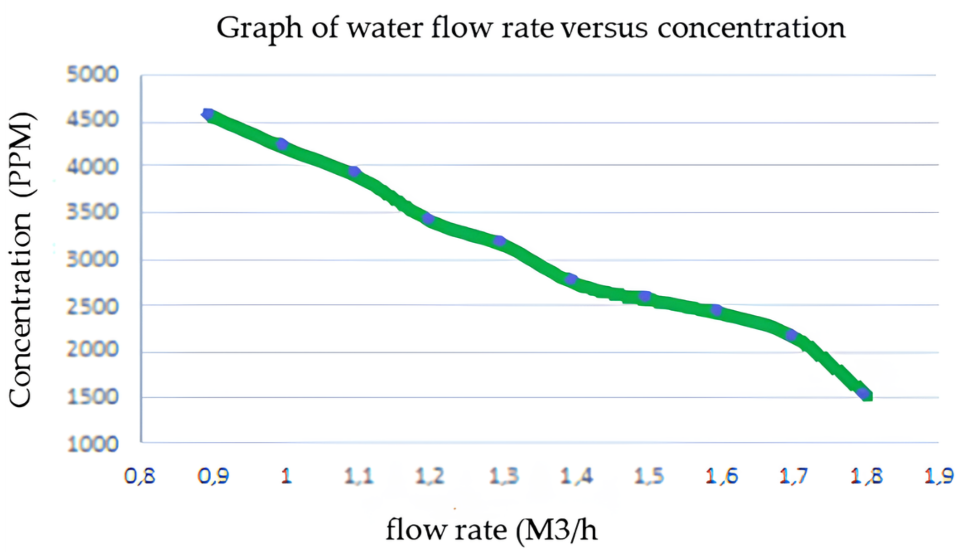

Figure 3. Graph comparing current and water flow rate used in electrolysis

Graph 3.2 is obtained based on relatively similar currents among each other, but differentiated based on the water flow rate used during the electrolysis process. By observing the graph, it is gathered that the amount of water flow used in electrolysis influences the strength of the concentration produced during electrolysis. This aligns with the theory that explains chlorine concentration, indicating that the strength or weakness of the concentration is influenced by the mass of chlorine added and the amount of water flow used in the electrolysis process[8]. From **Figure** *4* The average mass of chlorine obtained from the operation of the electrolysis generator in simulated 3-cell mode is 4065 grams, and the resulting concentration averages 2812 mg/L.

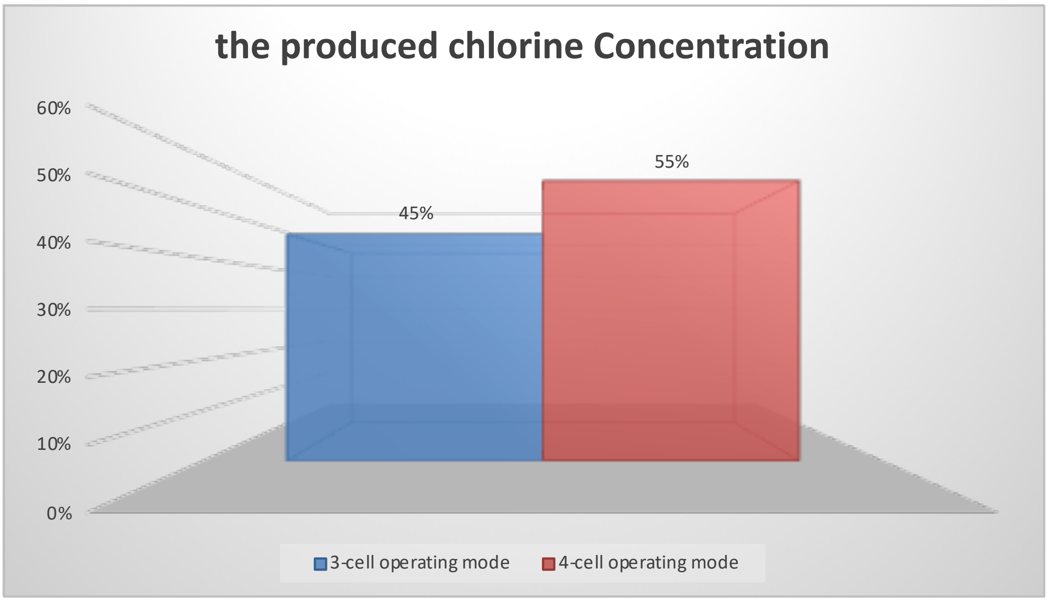

Figure 4. Percentage Comparison of Chlorine Concentrations

Table 3. Comparison of 4 Cell and 3 Cell

4 cell	*3 cell*
3476 mg/L	2812 mg/L
5465 gram	4065 gram

For comparison, the following are graphs and tables presenting the results of the comparison of chlorine concentrations produced between using the normal operating mode with 4 cells and the simulated operating mode with 3 cells. It can be observed that the concentration strength will differ between using the 4-cell operating mode and the 3-cell operating mode. However, the difference is not significant because both operating modes are still within the safe limits, as will be explained in the next section regarding the feasibility of operation based on chlorine dosage, minimum chlorine requirements for the power plant, and chlorine residuals at the power plant's output.

Chlorine Dosage Usage

The usage of chlorine dosage for the Closed Cooling Water (CCW) system of the power plant must be monitored to ensure it is within normal limits. Exceeding or falling below these reasonable limits could potentially impact chlorine residuals and production[10].

To determine the dosage used, the chlorine requirement formula is employed:

$$\boldsymbol{Dosage} = \frac{\textbf{Mass of chlorine added (grams)}}{\textbf{Water capacity treated with chlorine (liters)}}$$

Based on the formula, the dosage is the content of the substance per unit of solution capacity used. This addition is calculated based on grams, while capacity uses flow units (m^3 or liters). Therefore, based on this formula, it will result in a dosage that uses units of mg/L or commonly referred to as 1 PPM.

Given:

Water Flow: 35,000 m^3/hour

Mass of chlorine produced: 5474 grams (4 cells) / 4,108 grams (3 cells)

Residual chlorine (Normal operation): 0.1 PPM

Question: What is the chlorine dosage?

The formula or equation used is equation (2.3), and the equation is as follows:

$$\boldsymbol{Dosage} = \frac{\textbf{Mass of chlorine added}}{\textbf{Water capacity treated with chlorine}}$$

Here is the chlorine dosage given when using 4 cells:

$$Dosage = \frac{\text{Mass of chlorine added (grams)}}{\text{Water capacity treated with chlorine (liters)}}$$

$$Dosage = \frac{\text{Mass of chlorine added (grams)(5474 grams} \times \text{1000 mg)}}{\text{(35,000 m3/h} \times \text{1000 L)}}$$

$$Dosage = \text{ 0.1564 mg/L per hour}$$

Or, when converted with the theory that 1 mg/L = 1 PPM:

$$Dosage = \text{ 0.1564 PPM per hour}$$

When compared to operating with 3 cells:

$$Dosage = \frac{\text{4108 grams} \times \text{1000 mg}}{\text{35,000 m3/h} \times \text{1000 L}}$$

$$Dosage = \text{ 0.1174 mg/L per hour}$$

Or, when converted with the theory that 1 mg/L = 1 PPM:

$$Dosage = \text{ 0.1174 PPM per hour}$$

The minimum chlorine requirement for the power plant is the minimum dosage needed for a power plant's water purification system. Based on the operational data history, the average normal chlorine residual is 0.1 mg/L.

Using the formula or equation (2.4), the minimum chlorine requirement for the power plant can be found:

Minimum Chlorine Requirement:

$$Minimum\ chlorine\ requirement = Dosage - Detected\ chlorine\ residual$$

By substituting the dosage given during normal operation with 4 cells (0.1564 mg/L) and the normal chlorine residual (0.1 mg/L), we get:

$$Minimum\ chlorine\ requirement = Dosage - Normal\ chlorine\ residual$$
$$Minimum\ chlorine\ requirement = 0.1564 mg/L - 0.1 mg/L$$
$$Minimum\ chlorine\ requirement = 0.0564\text{mg/L}$$

Converting 1 mg/L to 1 PPM based on equation (2.14):
$Minimum\ chlorine\ requirement = 0.0564\text{PPM}$

From the calculation, the minimum chlorine requirement for the power plant during normal operation is 0.0563 mg/L or 0.0563 PPM. Given that the chlorine dosage is sufficient, with 4 cells providing 0.1564 mg/L and 3 cells providing 0.1174 mg/L, the chlorine requirement for the power plant is well covered. Therefore, both operating modes, with 4 cells and 3 cells, are suitable for operation.

Chlorine Residual:
$Residual\ chlorine = Dosage - Minimum\ requirement$

As known from operational data, the residual chlorine during normal operation with 4 cells is 0.1 PPM. Assuming the chlorine requirement for the power plant is 0.0563 mg/L, when using the 3-cell operating mode, the residual is calculated as follows:

$Residual\ chlorine = Dosage - Minimum\ requirement$
$Residual\ chlorine = 0.1174\text{mg/L} - 0.0563\text{mg/L}$
$Residual\ chlorine = 0.0611 mg/L$

Or, when converted (1 mg/L = 1 PPM):
Residual chlorine = 0.0611PPM
Residual chlorine=0.0611PPM

Based on the calculation, the residual chlorine during normal operation with 4 cells is 0.1 PPM, and during 3-cell operation, it is 0.0611 PPM. According to the water quality standard values in the appendix, the permissible limit for chlorine to be discharged directly into the sea/environment is 0.5 mg/L or 0.5 PPM. The detected residual chlorine is within acceptable limits according to environmental regulations. Therefore, the operation of the electrolysis generator in both normal 4-cell and simulated 3-cell modes is allowed.

4. Conclusions

1. Based on the calculation results and operational feasibility considerations for both the normal 4-cell operating mode and the simulated 3-cell operating mode discussed in the previous sections, it can be concluded that even there was a 25% reduction in chlorine production due to use of 3-cell operating mode, this condition is considered safe for operation. Because with the allowable safe limit for chlorine residue being 0.5 mg/L, the 4-cell operating mode has a residue of 0.1 mg/L, and the 3-cell operating mode has a residue of 0.0611 mg/L. Therefore, it can be concluded that both operating modes are appropriated to use.

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