Operational Performance of an Electrolytic Reactor in Configurating a Greywater Treatment System for Sewage/Wastewater Reuse

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Abstract: It is getting difficult to secure various kinds of usable water due to the worsening quality of water resources. Along with other regions, in Busan various measurements are considered to resolve the problems with increasing water consumption and limited water resources. In this point of view, a greywater treatment system (GTS) will be developed in this study as an alternative to reuse sewage/wastewater and its applicability will be confirmed to meet the demand. The GTS basically consists of an electrolytic cell which has shown highly effective in organic matter oxidation and nitrification, and its performance is investigated by assessing the treatment method and the water quality in both influent and effluent. A candidate system of electrolysis apparatus, which is the first reactor in the GTS, was selected and operated in batch and continuous types with real dye wastewater. The highest removal rates of BOD and COD were obtained with current density of 1.0 A/dm$^2$ and 10 % of electrolyte level. Also the removal rates of T-N and T-P were found to be moderate and could be improved with recycle ratios of between 20 and 50.

Keywords: water resources, greywater treatment system (GTS), sewage/wastewater reuse, electrysis

Introduction

It is known that due to its geographical setting Busan has problems with water shortage and its pollution. As improved convenience in lifestyle, however, demands a well-bing city with nature-friendly environment, purification of municipal watercourses has been a growing interest. Although reservoirs, drinking water, ground water as well as small/middle size dams have been used to secure water resources, they are not effective to be used together with other kinds of usable water such as industrial water and domestic water. In this study greywater treatment facilities and the operating technologies are developed to reuse water, which will supply the water shortage. Also the excess chemical costs for industrial wastewater treatment will be reduced, resulting in less operating costs for industry and preventing reasons for their secondary environmental pollution. Currently industry still has problems with odor production and COD and BOD levels in the wastewater treatment processing, and consequently with pH adjustment to treat various kinds of industrial wastewater at once.

For industrial wastewater treatment, physical, chemical and biological treatment methods have been introduced and shown good results. As sewage/wastewater treatments are done to meet current discharge standards, more strict standards are required to reuse the discharged water [1-4].

In this study, as an alternative to reuse sewage/wastewater produced in Busan, a greywater treatment system will be developed and its applicability will be confirmed to meet the demand. Firstly the greywater treatment system (GTS) consists of an electrolytic cell which has shown highly effective in organic matter oxidation and nitrification [4,5], and its performance is investigated by assessing the treatment method and the water quality in both influent and effluent. Also a candidate system of electrolysis reactors, which is the first reactor in the GTS, will be selected. A possibility to combine a carbon adsorber with a membrane separator will be inves-
tigated, showing the treated water quality, efficiency of electrolysis reactors and optimum operating conditions.

Material and method

Experimental Setup

The electrolysis apparatus used in this study is shown in Figure 1. The direct oxidation reactor (DOR) was made of acryl with size of $140 \times 210 \times 250$ and reduced in its effective volume to 5 L or 3 L from 7.4 L in total when required. The influent flowed downwardly between the pole plates by a peristaltic pump and its flow rate was adjusted according to each reaction time. An aeration device was installed to get the effluent from the pole plates well-mixed. Also the inflow water to the indirect oxidation reactor (IOR) was internally recycled to the DOR by using an internal recycle pump. The required current density was supplied via D. C. power (30 Voltage, 30 Amper) with constant current.

Dimensionally stable anodes (DSA) on which $\text{IrO}_2$ is electrodeposited with Ti, were used and cathodes were made of stainless steel [6]. Both anode and cathode were net types with thickness of 0.15 cm, area of 117 $\text{cm}^2$ ($13 \times 9 \text{ cm}$) and effective area of 40 $\text{cm}^2$.

Methodology

Optimum conditions were obtained to determine the operating variables of electrolysis by varying current density, reaction time, electrode interval, current density dosage, current efficiency [6]. Each experiment was firstly done in batch type whose optimum conditions were used later for continuous experiments.

Firstly for the batch experiments, optimum conditions in the treatment efficiency and economic points of view were obtained to understand the change of current characteristics with electrode intervals of 2, 6, and 10 mm and 5 electrodes (3 anodes and 2 cathodes) in total. Also the treatment efficiency was determined by regulating a galvanometer with current density of 0.25 to 1.0 A/dm$^2$ and residence time of 10 to 150 min. With residence time of 120 min and current density of 1.0 A/dm$^2$L, the current efficiency and the removal rate of organic matters and nutrients with electrolyte dosage were validated by changing NaCl of 30000 ppm from 0 to 30 % of the total amount of treating water.

For continuous experiments, at given optimum conditions that are current density of 1.0 A/dm$^2$L and electrolyte concentration of 10 %, the treatment stability was confirmed by changing internal recycle ratios of 0, 20, 50 and 100 % and taking samples for each ratio at every hour for the period of 24 h.

For the purpose of practical application to dye wastewater from the J dye industrial complex, batch experiments were done with electrolyte concentration of 10 %, electrode interval of 6 mm and current density of 0.5 A/dm$^2$L.

Quality of Raw Water

Synthetic wastewater and dye wastewater from the J dye industrial complex were used in this study to investigate the performance of electrolysis and their characteristics are shown in Tables 1 and 2, respectively.

The water quality before and after electrolysis was analysed according to Korean environmental pollution process techniques for each component analysis.

For COD$_{\text{Mn}}$, a large amount of free available chlorine remains in the effluent of electrolysis of wastewater with plenty of chlorine [7-9], being expected to affect the measurement accuracy. According to the environmental pollution process techniques, as it is recommended to use the COD$_{\text{Mn}}$ alkali method if free available chlorine level exceeds 2000 ppm [10], our COD$_{\text{Mn}}$ measurements were done accordingly with pretreatment below (i.e. adding sulfuric acid). Also, CODcr is expected to be the same case. wada and coworkers [11] have observed by adding NaOCl that the value of CODcr is decreased considerably when the level of free available chlorine ex-
ceeds 2000 ppm. They have concluded that the effect of free available chlorine up to 8000 ppm on CODcr measurement can be negligible by adding sulfuric acid with heat treatment for a short time.

Results and discussion

Characteristics of Current with Electrode Intervals

The relationship between voltage and current is determined to study the effect of changes in electrode interval, arrangement and electrolyte concentration and is shown in Figure 2. As the interval of pole plates gets smaller and the electrolyte concentration increases, the voltage is found to decrease.

It may be desirable to shorten the electrode interval and to increase the electrolyte concentration to reduce the operating costs of the electrolysis treatment system [12-15]. However, the consequence will increase the treatment capacity and chemical dosage for electrolyte, corroding the pole plates and shortening the replacement cycle of pole plates. Thus in this regard the electrolysis treatment system can be optimized with 10% electrolyte and electrode interval of 6 mm.

Figure 2. Variation of Voltage according to Current and electrolyte (electrode gap: a: 2 mm b: 5 mm c: 10 mm).

Removal Characteristics with Current Density Change

Removal Characteristics of Organic Matters and Current Efficiency

Figure 3 shows the removal characteristics of organic matters against current density. In general, as the current density increases, the removal rate increases up to about 90% of CODMn (at 1.0 A/dm²L). The effluent concentration was 18 mg/L, which is below the water quality criteria for discharge. Also the contact time to get the same COD removal rate is found to decrease with an increase in current density.

Current efficiency is plotted with current density in Figure 4. For electro-chemical oxidation methods to treat organic matters from wastewater, it is of very importance to calculate the current efficiency. As it is a criterion to select a proper treatment method and dominates the operating costs, the power consumption per the organic matter weight is a key factor in estimating the total operating costs for wastewater treatment.

The current efficiency is used to calculate the efficiency of electro-chemical oxidation processes for the removal of organic matters [15-17]. This is determined during the electro-chemical oxidation with the COD method [15]. That is, from the CODs before and after electrolysis, it is given in Eq. (1):

$$CE \ (\text{Current \ Efficiency}) = \frac{\left[COD_i - COD_f\right] \times V}{I \times t \times 2 \times M} \times 100$$

where CODi and CODf are COD concentrations (mg/L)
before and after electrolysis, respectively. $V$ is the volume (L) of solution, $I$ is the amount of current (A) applied for electrolysis, it is electrolysis time (sec), $F$ is Faraday constant (96500 coulomb/mole) and $M$ is the molecular weight (mg/L) of oxygen (O).

As can be seen in Figure 4, the current efficiency was kept highest at 0.5 A/dm$^2$L. However, as the COD removal rate in Figure 3 is higher at 1.0 A/dm$^2$L than at 0.5 A/dm$^2$L, it is desirable to keep the current density at 1.0 A/dm$^2$L to balance both current efficiency and removal rate.

**Removal Characteristics of Nitrogen**

Figure 5 shows the removal characteristics of total nitrogen (T-N) with respect to current density change. The T-N concentration in the influent was about 20 mg/L on average, which was then diluted to about 14 mg/L by adding electrolyte. With 10 % electrolyte, electrode interval of 6 mm and current density of 1.0 A/dm$^2$L, the T-N concentration in the effluent was about 2 mg/L, resulting in its removal efficiency to be about 86 %. The small amount of T-N detected may be associated with oxidation of nitrate and chloramine to combined residual chlorine due to direct/indirect oxidation of removed ammonia, some of which were considered to be converted to nitrogen gas [18]. However the effluent T-N concentration is lower than the discharge water quality criter-

**Removal Characteristics of Phosphorous**

The removal characteristics of phosphorous against current density are shown in Figure 6. At optimum conditions (i.e. 10 % electrolyte, electrode interval of 6 mm and current density of 1.0 A/dm$^2$L), the total phosphorous (T-P) was removed more than about 95 %, again indicating its effectiveness in removal nutrients. In addition, like to the case of T-N removal, the increase in current density shortens the time for which the high removal rate is achieved.

**Removal Characteristics with Change in Electrolyte Concentration**

**Removal Characteristics of Organic Matters and Current Efficiency**

Figures 7 and 8 show the COD removal rate and current efficiency in terms of electrolyte concentration, indicating that NaOCl and HOCl produced from electrolyte (NaCl) enhance the indirect oxidation during elect-
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Figure 8. Variation of COD\textsubscript{Mn} current efficiency according to electrolyte and contact time (electrode gap: 6 mm, current density: 1.0 A/dm\textsuperscript{2}L).

Figure 9. Variation of T-N removal according to electrolyte and contact time (electrode gap: 6 mm, current density: 1.0 A/dm\textsuperscript{2}L).

rolysis. As the electrolyte dosage increases, along with the direct oxidation on both electrodes the COD removal rate was improved.

As a result, the longer the residence time, the higher the removal rate. As the electrolyte dosage increases, the COD removal rate increases gradually. However, no difference was found in the removal rate between 10 and 20 % electrolyte. Current efficiency also exhibits more than 75 % for over 10 % electrolyte dosage.

Removal Characteristics of Nitrogen

The removal rate of total nitrogen (T-N) against electrolyte concentration is shown in Figure 9. It is seen that at a given residence time, the T-N removal rate is independent of electrolyte concentration. As residence time and electrolyte dosage increase, the removal rate increases gradually. The T-N removal rate was found to be about 86.7 % at optimum conditions (i.e. electrode interval of 6 mm and current density of 1.0 A/dm\textsuperscript{2}L) and the effluent T-N concentration was about 2 mg/L, which is lower than the discharge water quality criterion, proving that the electrolysis treatment system is effective in removal of organic matters as well as T-N.

Figure 10. Variation of T-P removal according to electrolyte and contact time (electrode gap: 6 mm, current density: 1.0 A/dm\textsuperscript{2}L).

Figure 11. Variation of COD\textsubscript{Mn} removal according to recycle ratio and operating time (electrode gap: 6 mm, current density: 1.0 A/dm\textsuperscript{2}L, electrolyte: 10 %).

Figure 12. Variation of T-N removal according to recycle ratio and operating time (electrode gap: 6 mm, current density: 1.0 A/dm\textsuperscript{2}L, electrolyte: 10 %).

Removal Characteristics of Phosphorous

The removal rate of total phosphorous increases with residence time and electrolyte dosage as shown in Figure 10. An increase in electrolyte concentration shortens the time to reach high removal rates.

Removal Characteristics with Change in Recycle Ratio in Continuous Reaction

Figures 11, 12, and 13 show the removal characteristics
of organic matters and nutrients with respect to internal recycle ratio for 24 h continuous reaction. As can be seen, the removal rates of organic matters and nutrients are stable with about 10% difference between with and without internal recycle. Also, comparing with 100% recycle ratio, the removal rate was higher for the case of 20% recycle ratio, indicating that there is an optimum recycle ratio. As a result, the recycle ratio should be adjusted to the wastewater characteristics dealt with to operate the electrolysis treatment system most economically.

**Characteristics of Electrolysis Treatment of Dye Wastewater**

With optimum conditions (i.e. 10% electrolyte concentration, current interval of 6 mm, current density of 1.0 A/dm²L, and residence time of 1 h) determined with synthetic wastewater, batch experiments were done for dye wastewater. The dye wastewater used is taken from the B dye company and has complex components with very high colority.

The results of electrolysis treatment of the dye wastewater are shown in Figures 14, 15, and 16. For raw wastewater, the COD$_{Cr}$ starts to decrease after 30 min of reaction whereas the COD$_{Mn}$ removal is not noticeable. However, for the effluent, the COD removal appears after 10 min of reaction. And 2 h later the COD$_{Cr}$ decreases to 10 ppm and COD$_{Mn}$ to 4 ppm. As a result, the COD removal rate of the effluent is satisfactory while the case of raw wastewater requires a long stabilization time, indicating that the dye wastewater contains a fair amount of non-degradable matters which deteriorate their conversion to degradable ones.

**Conclusion**

1) For electrolysis treatment systems, increases in treatment capacity and chemical dosage for electrolyte and quick corrosion of pole plates are expected. Also the replacement cycle for pole plates can be shortened. Thus the optimum conditions for electrolysis treatment systems are found to be 10% electrolyte concentration and electrode interval of 6 mm.

2) The removal rate increases gradually with increases in electrolyte dosage, current density and residence time.

3) It is proven that electrolysis treatment systems are effective in removing organic matters and nutrients.

4) For 24 h continuous operation, stable removal rates
were obtained with optimum conditions above and enhanced by introducing internal recycle.
5) From the results of electrolysis treatment for real dye wastewater, the optimum operating conditions obtained in this study are more effective for the effluent rather than the raw wastewater.

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References