Effects of electric voltage and sodium chloride level on electrolysis of swine wastewater

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A B S T R A C T

The effects of electric voltage and NaCl concentration on the removal of pollutants in swine wastewater were investigated to determine the optimum operation conditions for a designed electrolysis process. An up-flow electrolytic reactor was fabricated from Plexiglas, and one titanium anode coated with iridium oxide (IrO_2) and two stainless steel cathodes were installed in it. The anode surface area was $80\,cm^2/L$ and the hydraulic retention time (HRT) was 6 h. The results indicated that the pollutant removal was highly proportional to the electric voltage and removal could be enhanced by adding NaCl. The removal efficiencies of NH_4-N, soluble nitrogen (NH_4-N plus NO_x-N), soluble total organic carbon (STOC), and color were proportional to the NaCl level up to 0.05% NaCl level, beyond which no further enhancement in removal was observed. However, such a tendency was not observed in the case of PO_4-P removal. The obtained results indicate that 7 V and 0.05% (8.56 mM) NaCl level would be the optimum conditions for the designed electrolysis process. Under these conditions, the average removal efficiencies of NH_4-N, soluble nitrogen, PO_4-P, STOC, and color were 99%, 94%, 59%, 64%, and 93%, respectively.

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1. Introduction

Swine wastewater contains a large amount of nitrogen, phosphorus, and suspended and dissolved solids that cause water pollution. These contaminants lead to eutrophication of surface water bodies and cause severe environmental problems [1] affecting both aquatic life and human health. Therefore, it is essential to remove these pollutants from swine wastewater before discharging it into soil or any water body. Several studies have already investigated the removal of pollutants from wastewater [2–5].

Wastewater treatment by electrolysis is a modern treatment process that removes pollutants through electrooxidation and electrocoagulation (EC). The key process in electrolysis is the interchange of atoms and ions by the removal or addition of electrons from an external circuit. Electrocoagulation occurs during electrolysis. The anode is involved in rapid adsorption of soluble organic compounds and trapping of colloidal particles that can be easily separated from an aqueous medium by H_2 flotation. Mollah et al. [6] reported that a gelatinous suspension was produced in an aqueous medium because of oxidation, which can remove pollutants from wastewater by either complexation or electrostatic attraction, followed by coagulation. This process has an advantage in that it can even remove very small

colloidal particles because the applied electric field sets them in rapid motion and thereby facilitates their coagulation. Also, electrooxidation occurs during electrolysis because of the oxidative action of hydroxyl and hypochlorite ions. Hydroxyl ions can successfully remove toxic organic chemicals in wastewater because the hydroxyl radical is more powerful as compared to conventional oxidants such as chlorine, chlorine dioxide, and potassium permanganate [7]. The oxidation efficiency of hydroxyl ions depends on their interaction with the materials present in a water stream. In a solution, NaCl supplies a sufficient number of chloride ions (Cl^-) that generate chlorine at the anode and immediately react with water to form hypochlorite (HOCl), which then reacts with ammonia during electrolysis to produce N_2 gas. Chen [8] reported that NaCl could significantly reduce the adverse effect of other anions such as HCO_3^- and SO_4^{2-} in addition to providing chloride ions in the electrolytic media. Further, the electrolysis efficiency depends on several factors such as electric current density, pH, ionic concentration, and electrode material, especially the anode material [9,10]. The anode material plays an important role in deciding the operating cost and the removal efficiency. Kim et al. [11] reported that a titanium anode coated with IrO_2 successfully oxidized organic pollutants in aqueous media. An IrO_2 coating imparts dimensional stability to a Ti anode and makes it corrosion-resistant; for example, a lifetime of more than 10,000 h has been demonstrated under severe operating conditions [12]. Mussy et al. [13] reported that a IrO_2-coated Ti anode exhibits long-term catalytic stability during electrolysis.

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1) influent bucket
2) influent loading pump
3) coarse screen
4) effluent storage bucket

5) D.C. power supply
6) electrolytic reactor (H:120 cm, Ø 8 cm)
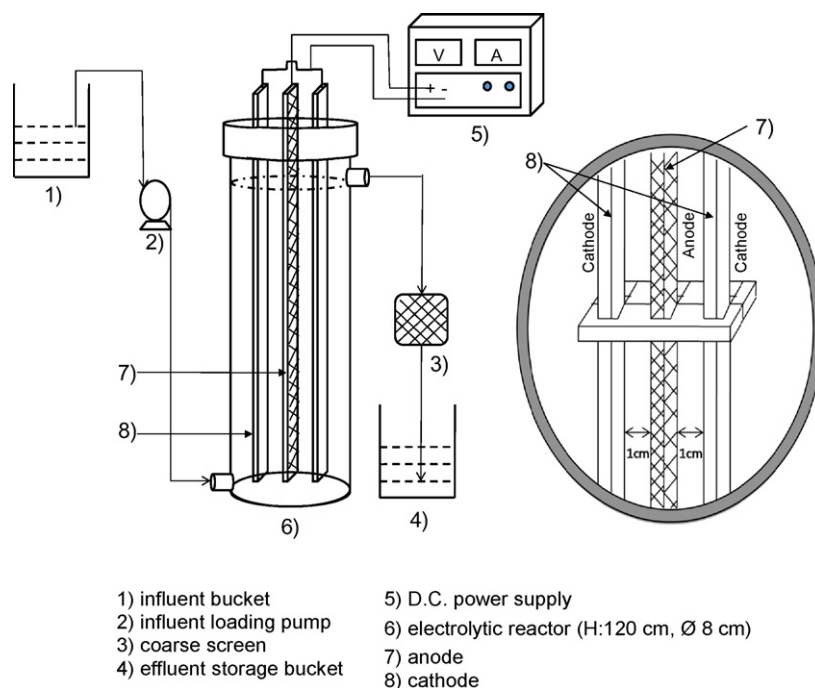7) anode
8) cathode

Fig. 1. Schematic of the electrolytic process.

In recent times, electrolysis has been effectively applied to treat various types of wastewater such as poultry wastewater [14], cattle slaughterhouse wastewater [15], poultry slaughterhouse wastewater [16], tannery wastewater [17], textile wastewater [18], laundry wastewater [19], and restaurant wastewater [20]. However, most of these researches have focused on organic matter removal from wastewater using aluminum or iron as the anode. The combined removal of nitrogen (N), organic matter, phosphorus (P), and color from high-strength animal wastewater such as swine wastewater has rarely been conducted. Thus, the ideal operational parameters required for achieving enhanced pollutant removal from animal wastewater, such as optimal NaCl concentration and electric voltage or current density, have not been established yet.

Therefore, in this study, we designed an up-flow electrolytic reactor with an IrO_2-coated Ti anode and examined the effects of electric voltage and NaCl concentration on the performance of the electrolytic process in the treatment of swine wastewater.

2. Materials and methods

2.1. System configuration and process operation

The electrolytic reactor was made of Plexiglas; it had eight spigots that were separated from each other by a distance of 15 cm in order to maintain the reaction volume and facilitate effluent decanting. The height, diameter, and working volume of the reactor were 120 cm, 8 cm, and 6.0 L, respectively. One Ti plate (thickness: 1 mm) and two stainless steel plates (thickness: 1.2 mm) were used as the anode and the cathodes, respectively. The anode was coated with IrO_2 to make it dimensionally stable. Two cathodes were arranged parallel to each other on either side of the anode plate by means of an acrylic band; they were positioned at a distance of 1.0 cm from each other in order to obtain an efficient electric field. The electrolytic reaction is normally inversely proportional to the distance between the electrodes. However, a very small separation between the electrodes can result in the coagulation of solids and the adsorption of colloidal materials on the electrodes, thereby interfering with the water flow in the electrolytic reac-

tor. In contrast, a very large separation between the electrodes will definitely inhibit the electrolytic reaction. Therefore, it is important to maintain an appropriate distance between the electrodes for effective electrolysis. In several researches [6,10,11,16–22], the gap between the electrodes was maintained at approximately 10 mm or in the range of 5–15 mm. In this study as well, the distance between the electrodes was fixed as 10 mm. The anode surface area appropriate for installing the anode along with two cathodes in the designed electrolytic reactor, as shown in Fig. 1, was 480 cm^2 (80 cm^2/L, 120 cm × 4 cm). The apex of the reactor was sealed along with the electrodes by means of acrylic and silicone gel. The electrodes were connected to a digital DC power supply (DC 12 V 30 A, Model: WER 312) that regulated the electricity. Influent wastewater was loaded into the reactor through the lowermost spigot by using a pump, and the effluent decanted from the reactor was stored in a bucket after passing it through a filter. The filter was made of Plexiglas (10 cm × 10 cm × 15 cm), and textile fabrics (3 cm × 4 cm) were packed into the filter system. A schematic diagram of the electrolytic process is shown in Fig. 1. The electrolysis process was operated in a continuous up-flow mode and the hydraulic retention time (HRT) was 6 h. In a preliminary batch test, which was conducted at conditions of high voltage (7 V) and high NaCl levels (0.2%), the amount of N removal began to dramatically decrease after 5 h; the color removal at 5 and 6 h was approximately 70% and 90%, respectively, indicating that 6 h might be required for obtaining a high N and color removal. Therefore, 6 h was considered as HRT and the changes in the performance of the electrolytic process at various NaCl and voltage levels were studied to ultimately determine the optimal NaCl and voltage levels required to achieve a high removal of pollutants.

2.2. Experimental design

Two different experiments were conducted to study the effects of electric voltage and NaCl concentration on electrolysis. In order to determine the optimal NaCl and electric voltage levels for the designed electrolytic reactor, the electrolysis was studied by gradually reducing the NaCl and voltage level. First, in

Table 1
Experimental design.

Exp. I	Salt level % (mM)			0.2 (34.2)	
	Voltage	3	5	7	9
Exp. II	Salt level % (mM)	0 (0.00)	0.025 (4.28)	0.05 (8.56)	0.1 (17.10)
	Voltage			7	

experiment I, the effect of the voltage level on the electrolytic process and pollutant removal was tested by reducing the voltage ($9 \rightarrow 7 \rightarrow 5 \rightarrow 3$ V) but maintaining a high constant NaCl level (0.2%, 34.2 mM); an ideal voltage level for the treatment of high-strength swine wastewater was selected on the basis of the obtained results. Then, in experiment II, the effect of the NaCl level on the electrolytic process was tested by gradually decreasing the NaCl levels ($0.1\% \rightarrow 0.05\% \rightarrow 0.025\% \rightarrow 0\%$) but maintaining a constant voltage (7 V); an optimal NaCl level was determined on the basis of the obtained results. The detailed layout of the experimental design is specified in Table 1. Further, the leachate discharged from a slurry composting and biofiltration system for swine manure treatment was used as an influent, and pure NaCl was mixed well with the influent wastewater before loading into the influent bucket.

2.3. Sampling and analysis

Samples were collected every three days from the influent and effluent storage buckets, and the latter was emptied after sampling. The influent and effluent samples were preserved at $4\,°$C until analysis, and the chemical contents were measured within one week. The parameters studied were soluble total organic carbon (STOC), ammonium nitrogen (NH_4-N), nitrite and nitrate nitrogen (NO_x-N), orthophosphate (PO_4-P), and color. Samples were centrifuged at 3000 rpm for 5 min in order to separate the solids, and the supernatant was used for analysis. The STOC was analyzed using a Shimadzu total organic carbon analyzer (Model TOC-500). NH_4-N, NO_x-N, and PO_4-P were analyzed using an auto analyzer (Quick Chem 8000, LACHAT). Color was analyzed using a spectrophotometer (Model OPTIZEN 2120). All analyses were performed in accordance with standard methods [23].

The data obtained in this study were analyzed by using a spreadsheet application (Microsoft Office Excel, 2007) for the calculation of descriptive statistics.

2.4. Feed swine wastewater

Leachate from a slurry composting and biofiltration (SCB) system, which was used in a local farm for swine manure treatment, was used as an influent during this study; the characteristics of the influent are shown in Table 2. Sawdust was used as a filter media in the SCB system (W 8 m $\times L$ 40 m $\times H$ 1.5 m), and 15 m^3 slurry was filtrated daily by spreading it on the system and rotating the upper layer with a rotary-type agitator. The leachate was stored in 25-L containers at $4\,°$C until it was required.

Table 2
Influent characteristics used in this study.

	Means	Min	Max	SD[a]
NH_4-N	849	637	1163	188
NO_x-N	13.8	0.3	33.0	15.1
Soluble N	863	667	1164	177
PO_4-P	180	74	311	91
STOC	1378	868	1984	406
Color (unit)	3392	963	4100	989

[a] Indicates standard deviation, $n = 102$.

3. Results and discussion

3.1. Effects of electric voltage

The efficiencies of pollutant removal at different electric voltages are listed in Table 3. The results revealed that the NH_4-N removal was a function of the electric voltage. The removal of NH_4-N at 3 V was rather low (15%). However, the removal increased to approximately 46% at 5 V. Significantly, the removal increased to 99% at 7 V. When 9 V was applied, the Plexiglas reactor started to bend due to high temperature, and therefore, the electrolysis performance could not be measured at this voltage. The observed average current at 3, 5, and 7 V was 2 (4.17), 11 (22.9), and 29 A (60.4 mA/cm^2), respectively. The results suggest that the electric voltage influenced the chemical reaction rate during electrolysis. In fact, Mollah et al. [6] reported that the current density is the most important parameter for controlling the reaction rate within an electrochemical reactor. In the present study, the removal of NH_4-N might be due to the conversion of NH_4-N into N_2 gas during electrolysis. Further, Li and Liu [9] reported that approximately 88% of the total removed ammonium nitrogen was removed as N_2 gas. The overall reaction occurring in an aqueous solution between hypochlorite and ammonia during electrolysis can be expressed as follows:

$$2NH_4^+ + 3HOCl \rightarrow N_2 + 3H_2O + 5H^+ + 3Cl^-$$
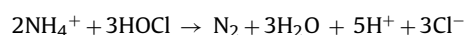
NO_x-N in the effluent was clearly proportional to the voltage applied, its amounts being 1.6, 2.3, and 20 mg/L at 3, 5, and 7 V, respectively. These increases in NO_x-N should be due to the electrooxidation of NH_4^+ to NO_3^- via the following reaction:

$$HOCl + 1/4NH_4^+ \rightarrow 1/4NO_3^- + 1/4H_2O + 3/2H^+ + Cl^-$$
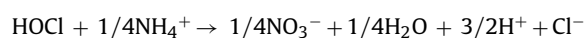
The removal efficiency of soluble nitrogen (NH_4-N plus NO_x-N) was maximum at 7 V, its values being 14%, 46%, and 97% at 3, 5, and 7 V, respectively. The obtained data suggest that the conversion of NH_4-N and NO_x-N into N_2 gas was very active at 7 V. Otherwise, NO_x-N would have accumulated during the electrooxidation, resulting in less removal of soluble nitrogen. In fact, it is known that ammonium nitrogen is converted into NO_2-N and NO_3-N and then finally emitted from the aqueous solution as N_2 gas during the electrooxidation reactions in a reactor, and it has been reported that a small amount of NO_x-N existed in the effluent after electrolysis of an ammonium solution [5].

In the present study, the average removal efficiencies of PO_4-P and STOC were also proportional to the electric voltage. The removal of PO_4-P was 3%, 21%, and 82% and that of STOC was 5%, 24%, and 57%, at 3, 5, and 7 V, respectively. This removal of OP and STOC should be attributable to electrooxidation, electrocoagulation, and electroflotation during the electrolysis.

Color removal was very low (1%) at 3 V. Further, with an increase in the electric voltage, the color removal was considerably enhanced, being approximately 67% and 92% at 5 and 7 V, respectively. On the basis of these results, it might be stated that the color removal in the electrolytic reactor was proportional to the electric voltage. Such increases in color and COD removal with electric current density have also been reported by Daneshvar et al. [21], Wang et al. [19], and Yetilmezsoy et al. [14]. During electrolysis, chlorine forms at the anode by the reaction occurring in the aqueous solu-

Table 3
Performance at different electric voltage.

Parameters (mg/L)	Voltage	Influent				Effluent				Removal (%)
		Means	Min	Max	SD[a]	Means	Min	Max	SD[a]	
NH$_4$-N	3	1023	981	1151	63	870	775	1062	93	15
	5	1125	1087	1163	31	603	532	714	67	46
	7	1021	963	1077	38	9	0	39	15	99
NO$_x$-N	3	0.6	0.4	0.8	0.1	2.0	0.4	4.3	1.6	–
	5	0.3	0.3	0.4	0.0	3.0	2.5	3.6	0.4	–
	7	0.3	0.2	0.3	0.0	20.0	19.0	22.5	1.1	–
Soluble N	3	1024	981	1152	63	872	777	1062	99	14
	5	1125	1088	1164	31	606	535	717	67	46
	7	1021	964	1035	38	29	20	62	16	97
PO$_4$-P	3	82	74	92	6	80	73	86	5	3
	5	84	80	90	3	66	64	71	3	21
	7	83	78	87	4	15	11	16	2	82
STOC	3	1915	1799	1981	17	1819	1614	1889	121	5
	5	1812	1714	1942	87	1305	1367	1409	15	24
	7	1713	1625	1984	135	728	704	740	13	57
Color (unit)	3	3541	3504	3606	37	3506	3434	3600	54	1
	5	3528	3447	3604	58	1171	1095	1230	51	67
	7	3371	3299	3490	69	282	261	310	17	92

[a] Indicates standard deviation, $n = 14$ for each operation.

tion and it is then converted to hypochlorous acid and hypochlorite via the following reactions:

$$2Cl^- \rightarrow Cl_2 + 2e^-, \quad Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-,$$

$$HOCl \rightarrow H^+ + OCl^-$$
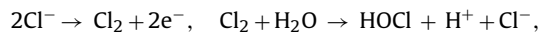
Color degradation by the oxidative action of hypochlorous acid has been described by Lide [24] and Costa and Olivi [17]. Chlorine, hypochlorous acid, and the hypochlorite ion, which are collectively referred to as active chlorine, are powerful oxidizing agents that can degrade and electrooxidize many biologically recalcitrant contaminants.

The obtained results indicated that the removal efficiencies of pollutants were highly proportional to the electric voltage. During the experiment, a comparatively high-density bubble was generated at high voltage, and this might also have resulted in a large flux and high removal of pollutants through electrocoagulation and electroflotation. Chen [8] reported that the electric density determines the production rate of coagulants and bubbles. Moreover, it was found that electrooxidation spontaneously occurred at a high electric voltage and enhanced the production of N$_2$ gas. Photographs of the final effluents obtained at 3, 5, and 7 V are shown in Fig. 2 for reference.

Table 4
Performance at different NaCl levels.

Parameters (mg/L)	Salt level %	Influent				Effluent				Removal (%)
		Means	Min	Max	SD[a]	Means	Min	Max	SD[a]	
NH$_4$-N	0.000	712	670	820	55	471	289	605	120	33
	0.025	752	704	870	56	210	149	246	31	72
	0.050	671	637	715	31	10	0.4	8.3	16	99
	0.100	665	640	702	23	0	0	1	0	100
NO$_x$-N	0.000	1.2	1.0	1.7	0.2	24.5	17.9	29.8	4.4	–
	0.025	32.4	31.6	33.0	0.5	31.5	29.7	32.3	0.8	–
	0.050	30.4	29.8	40.0	0.4	31.8	30.0	32.4	0.8	–
	0.100	28.8	26.5	30.4	1.7	30.4	28.7	31.8	1.2	–
Soluble N	0.000	713	671	822	57	495	314	622	117	31
	0.025	785	737	902	55	241	182	276	31	69
	0.050	701	673	745	31	42	31	41	16	94
	0.100	694	666	733	24	31	29	32	1	95
PO$_4$-P	0.000	179	173	189	6	143	134	146	7	20
	0.025	244	227	257	10	153	141	165	10	37
	0.050	300	283	311	9	122	114	132	5	59
	0.100	269	217	311	32	120	112	125	5	55
STOC	0.000	940	868	1033	71	617	522	697	58	36
	0.025	1208	1153	1321	63	644	579	701	47	47
	0.050	1016	1000	1030	12	366	337	384	19	64
	0.100	1019	922	1132	88	448	416	494	31	56
Color (unit)	0.000	4075	4039	4093	20	1810	1704	2086	191	56
	0.025	4068	3993	4100	39	919	726	1123	139	77
	0.050	3657	3640	3677	58	252	121	388	107	93
	0.100	3803	3698	3890	75	148	103	231	50	96

[a] Indicates standard deviation, $n = 15$ for each operation.

Table 5

Comparison of the performance and conditions with other findings.

	Reference numbers														
	[5]	[14]	[15]	[16]	[17]	[18]	[19]	[20]	[6]	[10]	[11]	[21]	[25]	[22]	Authors Work
Wastewater (WW) type	Ammonia solution	Poultry manure WW	Cattle slaughterhouse WW	Poultry slaughter-house WW	Tannery WW	Textile WW	Laundry WW	Restaurant WW	Organic dye WW	Municipal WW	PVA WW	Dye solution	Power plant WW	Treated WW	Swine WW
Electrolytic reactor vol. (mL)	20	800	300	250	145	250	1000	300	2000	1000	1710	250	400	850	6000
Electrode type															
Anode	RuO_2	Al	Al	Al	$Ti/Ir_{0.1}Sn_{0.9}O_2$	Fe	Al	Al/Fe	TiO_2/ITO	Ti/IrO_2	Ti/RuO_2	Fe	Ti/RuO_2	Al	Ti/IrO_2
Cathode	Ti	Al	Al	Al	Stainless	Fe	Al	Al/Fe	TiO_2/ITO	Stainless	Stainless	Steel	Stainless	Al	Stainless
Electrode area (cm^2/L)	400	60	238	320	97	312	72	187	13	65.4	67	100	25	1765	80
Stirring (RPM)	–	200	100	200	–	200	200	–	–	–	–	–	–	150	–
Current density (mA/cm^2) or voltage (V)	80	15	25	150	20	8–10	5 V	3–8	10 V	15.4	1.34	6–8	120	1.00	60.4 7 V
Reaction pH	12	5	7.8	2–3	4.3–6	<6	5–9	6–9	NI[a]	7 or low	NI[a]	5.5–8.5	5.5–10	7.0	7–8
HRT (min)	90	30	60	25	300	30	40	60	120	180	300	5	60	25	300
Conductivity (μS/cm)	NI[a]	NI[a]	3200	1990	7000	1000–4000	229–334	443–2850	NI[a]	1420–1500	NI[a]	8000	378–501	NI[a]	NT[b]
Electrolyte type/concentration (mM)	Cl^- ion/171.1	NaCl/8.56	Na_2SO_4/50	NaCl	NaCl/50	NaCl	NaCl/4.28	NaCl	TiO_2 solution	Cl^- ion/5.13	Cl^- ion/17.1	NaCl	NaCl/119.7	NaCl/5	NaCl/8.56
Distance between electrodes (mm)	NI[a]	62	NI[a]	11	6	11	10	6	11	10	20	15	NI[a]	5	10
Removal (%)/influent conc. (mg/L)	-NH_4-N: 85/14000	-COD: 90/4120 -Color: 92/3390	-COD: 94/4200	-COD: 93/27500	-TOC: 45/932 -Phenol: 100/NI[a]	-COD: 77/3422	-COD: 62/2270	-COD: 90/292–3390 -Oil: 94/1970	-BB26: 98/10	-NH_4-N: 95/32	-PVA: 70/410 -COD: 27/NI[a]	-COD: BB3–75, BR46–99/20–200	-NH_4-N: 100/492–936	-PO_4-P: 100/50	-NH_4-N: 99/671–1021 -SN[c]: 94/701–1021 -PO_4-P: 59/300 -STOC: 64/1016 -Color: 93/3657 unit
Operation mode	Batch	Batch	Batch	Batch	CF[d]	Batch	Batch	CF[d]	Batch	Batch	CF[d]	Batch	CF[d]	Batch	CF[d]

[a] Not indicated (NI).

[b] Not tested (NT).

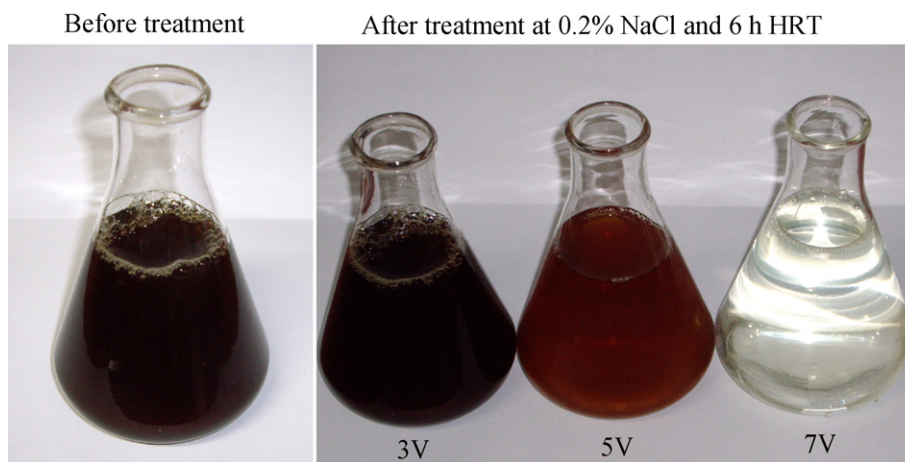[c] Soluble nitrogen (SN).

[d] Continuous flow (CF).

Fig. 2. Effect of voltages on color removal.

3.2. Effects of NaCl level

The effects of NaCl levels on electrolysis, which were examined at 7 V in experiment II, are shown in Table 4. NH_4-N removal was enhanced with the addition of external NaCl, the removal being 33%, 72%, 99%, and 100% at 0% (0), 0.025% (4.28), 0.05% (8.56), and 0.1% (17.1 mM) NaCl levels, respectively. Li and Liu [9] reported that the ammonium oxidation rate increased with the initial Cl^- concentration; this is in good agreement with the results of the present experiment. In addition, Vanlangendonck et al. [25] reported that ammonia can be efficiently removed with an appropriate chloride concentration. In the present study, as the NO_x-N concentration increased during electrolysis, the removal efficiency of soluble nitrogen was somewhat lower than that of NH_4-N, its values being 31%, 69%, 94%, and 95% at 0%, 0.025%, 0.05%, and 0.1% NaCl levels, respectively. The removal efficiencies of color at 0%, 0.025%, 0.05%, and 0.1% NaCl levels were 56%, 77%, 93%, and 96%, and those of PO_4-P were 20%, 37%, 59%, and 55%, respectively. Further, the STOC removal efficiencies were 36%, 47%, 64%, and 56% at 0%, 0.025%, 0.05%, and 0.1% NaCl levels, respectively.

The results revealed that the removal of NH_4-N, soluble nitrogen, STOC, and color, except PO_4-P, was clearly proportional to the NaCl level up to 0.05%, beyond which no further improvement in the removal was observed. Wang et al. [19] reported that the addition of NaCl to wastewater served as a useful technique to enhance the performance of electrocoagulation, but a high NaCl level deteriorated the performance. Irdemez et al. [22] also reported that NaCl was the best electrolyte among four different types of chemicals, namely, NaCl, $NaNO_3$, Na_2SO_4, and $CaCl_2$. The obtained results and process conditions of our study were compared with other findings from literature; these comparisons are summarized in Table 5.

4. Conclusions

In this research, the effects of the electric voltage and the NaCl level on the electrolysis of swine wastewater were studied with a newly designed up-flow electrolytic reactor that was operated under conditions of 80-cm^2/L anode area and 6-h HRT. We obtained the following results in this study.

1. The removal efficiencies of pollutants from swine wastewater were proportional to the electric voltage. At 0.2% NaCl level, the removal efficiencies of NH_4-N were 15%, 46%, and 99% and those of soluble nitrogen were 14%, 46%, and 97%, at 3, 5, and 7 V, respectively.

2. The removal efficiencies of STOC, PO_4-P, and color were also proportional to the electric voltage, and their respective removal efficiencies at 7 V were, on average, 82%, 57%, and 92%. The maximum influence of electric voltage was on color removal, with 1%, 67%, and 92% removal at 3, 5, and 7 V, respectively.

3. The pollutant removal was affected by the NaCl level. The removal efficiencies of NH_4-N, soluble nitrogen, STOC, and color were proportionally enhanced up to 0.05% NaCl level, beyond which no further improvement could be obtained; however, such a tendency was not observed in the case of PO_4-P removal.

4. Considering the overall removal efficiency of pollutants, it might be stated that approximately 0.05% NaCl and 7 V would be optimum conditions for the tested electrolytic process. Under these conditions, the average removal efficiencies of NH_4-N, soluble nitrogen, PO_4-P, STOC, and color were 99%, 94%, 59%, 64%, and 93%, respectively.

5. The electrolysis time for highly variable swine wastewater should be optimized in the near future; this optimization will be possible by the development of strategies for real-time control or monitoring of electrolytic processes.

Acknowledgements

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