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Application of Taguchi Optimization on the Cassava Starch Wastewater Electrocoagulation using Batch Recycle Method

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Abstract. Tapioca waste water is very difficult to treat; hence many tapioca factories could not treat it well. One of method which able to overcome this problem is electrodeposition.This process has high performance when it conducted using batch recycle process and use aluminum bipolar electrode. However, the optimum operation conditions are having a significant effect in the tapioca wastewater treatment using bath recycle process. In this research, The Taguchi method was successfully applied to know the optimum condition and the interaction between parameters in electrocoagulation process. The results show that current density, conductivity, electrode distance, and pH have a significant effect on the turbidity removal of cassava starch waste water.

INTRODUCTION

Cassava starch was used in many industries such as the food industry, pharmaceuticals, textiles, paper, and adhesives. The major problem in the cassava starch industry is the waste water which causes serious environment problem. To produce 1 ton of tapioca starch, it will produce 4000-6000 liter of waste water which it contains total suspended solid 1500 – 5000 ppm, biological oxygen demand (BOD) of 3000 - 7500 mg/L, turbidity reach 1400 NTU and chemical oxygen demand (COD) of 7000 – 30000 mg/L [1]. There are many method to treat this tapioca waste water such as the biological treatment (using the microbes) [2], adsorption [3], sedimentation [4], membrane filtration [5], the processing of waste into biogas [1, 6], as well as the method of coagulation-flocculation [7, 8]. However, the adsorption and membrane filtration methods require regeneration of the adsorbent material as well as a filter. In addition, microbes and sedimentation have several weaknesses such as require certain chemicals that have high economic value and it raises new problems for the environment [9]. In addition, the adsorption and membrane filtration methods require regeneration of the adsorbent material as well as a filter. Therefore, electrocoagulation has a bright prospect to solve this problem. This process has many benefits for both the economy and the environment such as use simple equipment, and able to produces stable and slightly sediment (sludge), and also can remove the odor and color of the waste water [10, 11].

In this study, the electrocoagulation using batch recycle process was chosen to ensure the waste water was treated well. To increase the performance of electrocoagulation process, an aluminum bipolar electrode was chosen to treat a wastewater of cassava starch industry. The selected electrode material is aluminum because it is more robust, economical and rustproof hence more stable when it operated for a long time. In addition, the aluminum produces effective cations (Al^{3+}) as a coagulant. The design of experiment of Taguchi was applied not only to choose the optimum operating conditions but it able to analyze all parameters simultaneously [12]. Taguchi method also will reduce the time and cost required because it needs a few numbers of experiments which this less than another design experiment. The purpose of this work is to get a high percentage of turbidity removal by studied and optimized the parameters such as current, conductivity, electrode distance, and pH.

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EXPERIMENTAL PROCEDURE

Experimental set up of electrocoagulation using batch recycle methods is shown in Figure 1. The design of experiment (DOE) of Taguchi which use four parameters was chosen in this work. Three parameters were considered: the current density, the conductivity, the electrode distance and the pH of waste water. The level of that parameter was arranged using Taguchi orthogonal array as shown in Table 1. The volume tapioca waste water is 2.5 Liter which is placed in the waste water tank. In this tank, the pH of waste water is adjusted using 0.1 M of NaOH and 0.1 M of H_2SO_4 to increase and decrease the pH, respectively. Mean while the conductivity of waste water was adjusted using 0.1 M of NaCl. The waste water from the waste water tank is pumped to the bottom of electrocoagulation cell. This electrocoagulation cell has dimension of 6 cm x 7.5cm x 16 cm and it able to treat 0.5 liters of waste water. This electrocoagulation cell has five bipolar aluminium electrode with dimensions of 14 cm x 4.4 cm x 0.05 cm, which these electrodes were connected to DC power supply as shown in Figure 1. The electrodes distance were adjusted inside the electrocoagulation cell. The following reactions for aluminum (Al) occurred in the electrocoagulation process [13]. At an anode:

$$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e^- \quad (1)$$

At a cathode:

$$6H^+_{(aq)} + 6e^- \rightarrow 3H_{2(g)} \quad (2)$$

General reaction for hydrolysis of waste water:

$$Al^{3+}_{(aq)} + H_2O_{(l)} \rightarrow Al(OH)_{2(aq)} + H^+_{(aq)} \quad (3)$$

Hydrolysis reaction in the waste water will form $Al(OH)_3$, this will create the complex compound of multimeric hydroxo. This compound has positive charge in the waste water, hence it will absorb the pollutants and then coagulate the pollutants [10]. These hydrolysis reactions are mention as follow:

$$2Al^{3+}_{(aq)} + 6H_2O_{(l)} \rightarrow 2Al(OH)_3 + 6H^+_{(aq)} \quad (4)$$

$$NAl(OH)_3 \rightarrow 2Al(OH)_{3n} \quad (5)$$

The waste water from electrocoagulation cell flowed to a settling tank which has capacity 1 liter. The pollutants were coagulated in this setting time. The waste water form this tank was recycled to waste water tank. The turbidity of waste water was measured after 90 minutes of time operation for each. The percentage of turbidity removal (%NTU) was calculated using following equation:

$$\%\ NTU = \frac{(NTU(0) - NTU(p))}{NTU(0)} \times 100\% \quad (6)$$

Where $NTU_{(0)}$ is the turbidity value of waste water and $NTU_{(p)}$ is the turbidity value of electrocoagulation product.

RESULT AND DISCUSSION

The results of the experiment were listed in Table 1. Percentages of turbidity removal for each experiment were calculated using Equation 2. These results were used in the Taguchi analysis of the signal to noise (S/N) ratio of larger the better is chosen in order to get high accuracy in predicting the optimum condition. This type of S/N ratio is calculated using equation as follows:

$$S/N\ ratio\ [dB] = -10 \log \left[\frac{1}{n} \sum_i \frac{1}{Y_i^2} \right] \quad (7)$$

where Yi is the value of the percentage of turbidity removal and n is a number of levels [12].

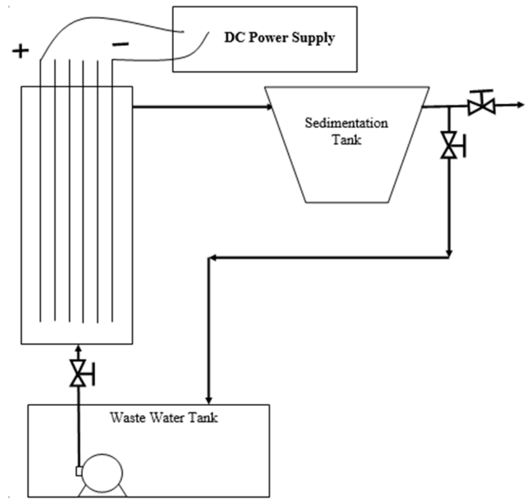

FIGURE 1. Experimental set up of electrocoagulation using batch recycle process

TABLE 1. The design of experiment of Taguchi

Run	Experiment design					Experiment result (Turbidity)		
	Electric current (A)	Conductivity (μS/cm)	Electrode distance (cm)	pH	Operation Time (Hr)	Initial NTU	Product NTU	NTU (%)
1	0.1	1000	0.6	4.0	1.5	520	430	17.31
2	0.1	1500	0.9	5.5	2.0	930	650	30.11
3	0.1	2000	1.2	7.0	2.5	400	280	30.00
4	0.1	2500	1.5	8.5	3.0	780	280	64.10
5	0.2	1000	0.9	7.0	3.0	460	60	86.96
6	0.2	1500	0.6	8.5	2.5	420	120	71.43
7	0.2	2000	1.5	4.0	2.0	890	320	64.04
8	0.2	2500	1.2	5.5	1.5	1600	750	53.13
9	0.3	1000	1.2	8.5	2.0	490	130	73.47
10	0.3	1500	1.5	7.0	1.5	460	80	82.61
11	0.3	2000	0.6	5.5	3.0	560	160	71.43
12	0.3	2500	0.9	4.0	2.5	1530	320	79.08
13	0.4	1000	1.5	5.5	2.5	1090	350	67.89
14	0.4	1500	1.2	4.0	3.0	1080	270	75.00
15	0.4	2000	0.9	8.5	1.5	440	20	95.45
16	0.4	2500	0.6	7.0	2.0	960	220	77.08

The Electric Current On The Percentage of Turbidity Removal

Electric current has a significant effect towards the percentage of turbidity removal as shown in Fig. 2. The figure shows the larger S/N response of the electric resistant of waste water is at the higher electric current at level 4. The increasing an electricity current at the electrode will increase the current density or the electricity current divided by the active area of the electrode. The increment of current density causes the increase of mass transport in the electrochemical process, hence the electrocoagulation process more effective and faster. However, the increasing the current density over the limiting current density will lead to high operating costs and cause side reactions which reduce the performance of electrocoagulation process. The maximum mass transport is held at the limiting current of electrochemical process. The optimum current is near the limiting current of the electrochemical process, however knowing the exact value of limiting current is very difficult. Therefore, knowing the optimum current value of electrocoagulation wastewater using the design of experiment of Taguchi is very important in order to get the best performance of electrocoagulation.

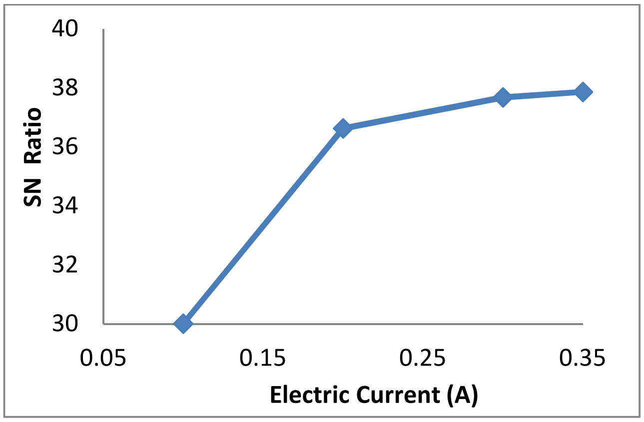

FIGURE 2. Means of S/N ratios of Electric Current in the Electrocoagulation Process

The Electric Conductivity of Waste Water Influence on The Percentage of Turbidity Removal

In order to know the effect of electric conductivity in the tapioca waste water electrocoagulation, the conductivity was varied from 1000 µS/cm to 2500 µS/cm using NaCl. The effect of the electric conductivity of waste water towards the percentage of turbidity removal is shown in Fig. 3. The figure shows the larger S/N response of the electric resistant of waste water is at the electric conductivity of 2500 µS/cm. This result indicates that the best percentage of turbidity removal is at the electric conductivity of 2500 µS/cm. The addition of these inorganic salts increase the conductivity in electrocoagulation cell was increased [14]. The increment of conductivity causes the increase of current density in the electrocoagulation cell. As the enhance of current density, the mass transport in the electrochemical process is increasing, hence this electrochemical process becomes more effective and faster. However, the excess NaCl in the waste water is caused the increase of high operating costs and also is initiated the side reactions which reduce the percentage of turbidity removal. Therefore, knowing this optimum conductivity value of wastewater is very important in order to get the best performance of electrocoagulation.

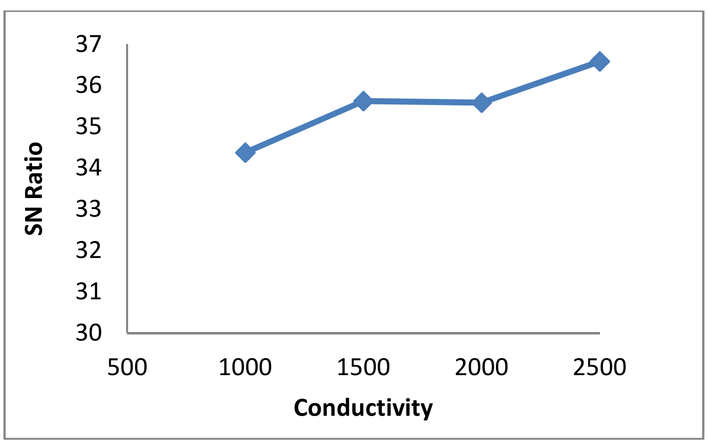

FIGURE 3. Means of S/N ratios of Electric Conductivity of Waste Water

The Electrode Distance Influence on the Percentage of Turbidity Removal

Electrocoagulation cell have five aluminium electrodes with dimensions 140 x 44 x 0.5 mm. The first and the last electrode in are connected with DC power supply. Meanwhile, the second, third and fourth electrodes are not connected with wire to DC power supply hence it has two poles which known as the bipolar electrodes as shown in Fig. 4 [15]. In order to know the effect of electrode distance toward the percentage of turbidity removal, the electrode distance was varied from 0.6, 0.9, 1.2 and 1.5 cm. Means of S/N ratios of the percentage of pollutant removal towards the electrode distance is shown in Fig. 3c. The figure shows that the larger S/N ratios of the electrode distance are at a distance of 1.5 cm (level 4). This result means that the optimum distance is at this level which has an optimum gap to passage the colloidal particles and an optimum space for the formation of hydrogen gas hence it not doesn't disturb with the coagulation process. The most effective coagulation occurs when the colloidal particles passing through the two side poles different electrodes with has a small hydrogen gas disturbance [14]. The coagulation of the colloidal particles is disturbed by gas bubbles which are formed if the electrode distance is too close. However, if the electrode distance is too far, it will reduce an electrical conductivity hence the electrical current in the electrocoagulation process is decreased which causes the electrocoagulation process become slower.

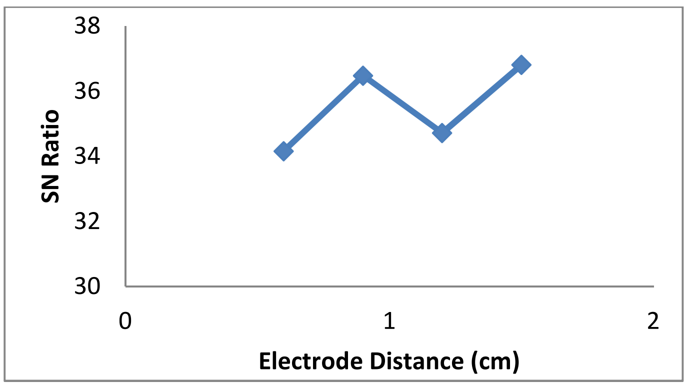

FIGURE 4. Means of S/N ratios of Electrode distance

The Waste Water pH Influence on the Percentage of Turbidity Removal

In this work, the pH of the waste water was varied from pH of 4 to 8.5 using NaOH and H_2SO_4 solution. The fresh tapioca waste water has pH of 5-6, mean while it pH is decreased after 24 hours to pH of 4 – 4.5. The effect of waste water pH towards the percentage of turbidity removal is shown in Fig. 5. The figure shows that the optimum of turbidity removal is at 8.5 of waste water pH.

The increasing of turbidity removal at the base condition is caused by increasing of Na^+ from NaOH. Ion of Na+ was acting as the pollutant coagulant. The pollutant colloid particle in tapioca waste water has a negative charge of electrostatic. At the higher base condition, destabilization of the outer electron cloud of colloid particles conducted by the positive ions in waste water. The interaction between negative of the colloid particle with the positive ion which is caused the neutral charge at the colloid particle surface. This neutral charge will increase the attraction force between the colloid particles, hence the colloid particle coagulated and become bigger flocks [15].

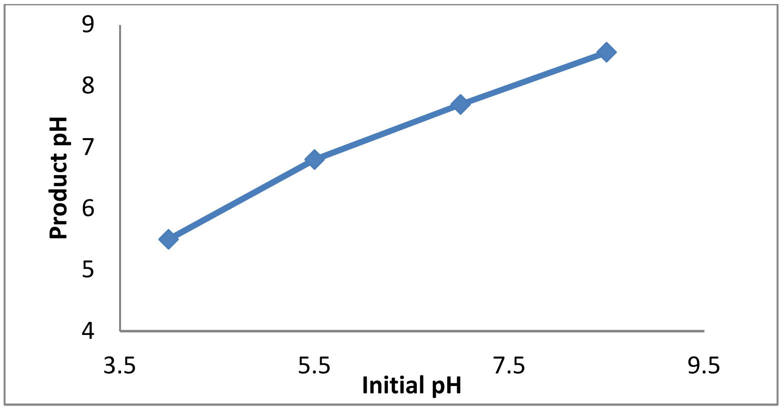

FIGURE 5. Effect of Influent pH towards Effluent pH

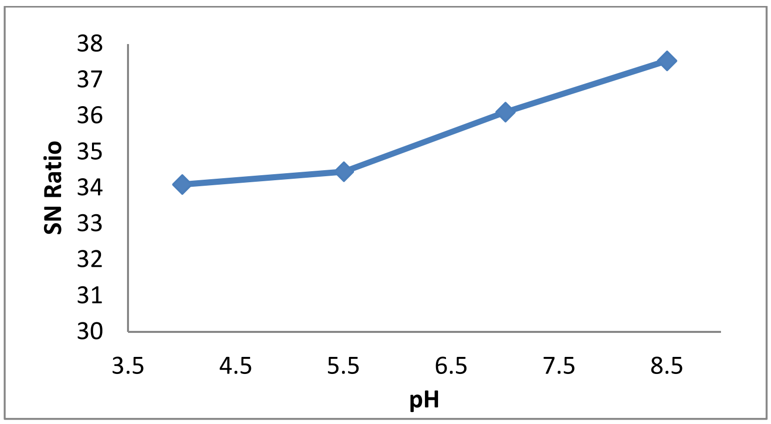

FIGURE 6. Means of S/N ratios of pH

At the pH influent between 4 until 8.5, the pH effluent was increased as shown in Fig. 5. The reaction during the electrocoagulation process at the acid and base conditions as shown below [14]:

$$2Al + 6H^{+} \longrightarrow 2Al^{3+} + 3H_2 \quad \text{(Acidic condition)} \tag{8}$$

$$2Al + 6H_2O + 2OH^{-} \longrightarrow 2Al(OH)_4^{-} + 3H_2 \quad \text{(Base condition)} \tag{9}$$

Hence, the electrocoagulation will lead to increase the waste water and also coagulate the colloid particles as shown in Fig. 6. At the acidic condition, reaction 8 occurs hence will decrease the ion H+. This reaction will increase the pH. Meanwhile at the base condition, the OH^{-} will be reduced and produce $2Al(OH)_4^{-}$, hence the pH will increase as shown in reaction (9).

The Time Operation Influence on the Percentage of Turbidity Removal

In order to know the effect of the time operation towards the percentage of turbidity removal, the time operation was varied from 1.5 to 3 hours as shown in Fig. 3e. The figure shows that the highest value of the SN ratio is at level 4 (3 hours), this confirms that at the 3 hours is the optimum of time operation. At the optimum time of the coagulant (Al^{3+}) produced in the electrocoagulation process is adequate to coagulate the pollutant in the tapioca waste water. However, if the operational time is increased until reach the excess of coagulant production, the product become more turbid because the charge reversal and restabilization colloid will happen in the electrocoagulation process [16]. More ever, the excess of time operation will create the excess of hydrogen bubbles at cathode electrode, which will damage the coagulation particles bonding.

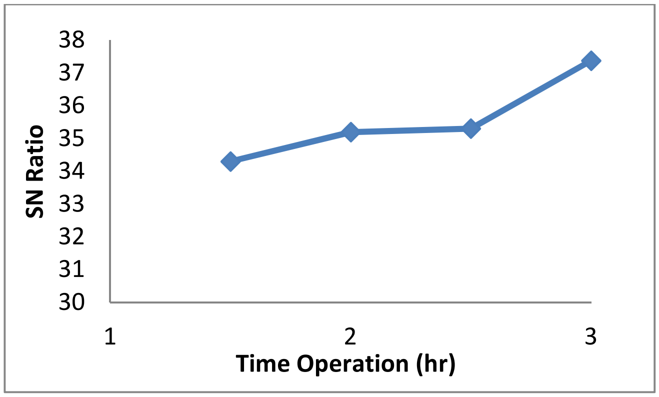

FIGURE 7. Means of S/N ratios of Time operation

TABLE 2. Response table for Means analysis

Level	Data Means				
	Electric Current	**Conductivity**	**Electrode Distance**	**pH**	**Operation Time (Hr)**
1	37.06	61.41	59.85	57.23	62.12
2	68.89	64.79	71.27	55.64	61.72
3	75.01	65.23	57.90	69.70	60.47
4	79.40	68.94	71.34	77.80	76.05
DELTA	42.34	7.53	11.49	20.57	13.93
RANK	1	5	4	2	3

The data of the responses for means analysis of the percentage of the turbidity removal for each parameter are listed in Table 2. The rank of parameters influence towards the percentage of turbidity removal are based on the delta value. This delta value is the difference between the biggest of means value to the smallest of means value. From this table, the electric current has the biggest delta value which means that this parameter is the most affecting parameter to the percentage of turbidity removal. This is followed by pH, time operation, electrode distance, and the conductivity of waste water, respectively.

CONCLUSION

The cassava starch wastewater has been processed using the batch recycle of electrocoagulation method. Larger the better of the analysis method of Taguchi was used in this work in order to know the effect of these parameters, as well as the optimum conditions of the batch, recycle of electrocoagulation process. The optimal conditions obtained were at the electric current of 0.35 A, pH of 8.5, time operation of 3 hours, electrode distance of 1.5 cm and the electric conductivity of 2500 µS/cm. Taguchi analysis results also showed that the electric current, pH, time operation, electrode distance, and the conductivity of waste water were on the first, second, third, fourth and fifth rank which were affecting on the percentage of the turbidity removal, respectively.

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