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Prediction of Landfill Leachate Treatment using Artificial Neural Network Model

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***Abstract*—Based on the experimental results of landfill leachate treatment using AC/H_2O_2 method, a GA-BP artificial neural network (ANN) model was developed in this study to predict the treatment efficiency. Five experimental factors were selected as the input parameters while COD_{Cr} was selected as the output parameter of the ANN model. The maximum model prediction error was found as 8.99%. The relative importance of each factor on COD_{Cr} removal during AC/H_2O_2 treatment process was then studied based on the developed model, and it was found that landfill leachate PH was the most important factor affecting the treatment process, with influence order of leachate pH > H_2O_2 dosage (30% concentration) > reaction time > AC to H_2O_2 ratio > temperature. The optimal operating condition of AC/H_2O_2 treatment of landfill leachate was further obtained using the developed ANN model as leachate pH of 3, H_2O_2 dosage of 5 ml/L, AC to H_2O_2 ratio of 0.5, reaction time of 120 min, and temperature of 20 ^oC.**

Keywords- landfill leachate; GA-BP; artificial neural network (ANN); COD_{Cr}

I. INTRODUCTION

Landfill leachate is a wastewater containing high concentration of organic and inorganic components, which come from biological and chemical reactions of waste in the landfill. Some of these organic pollutants are carcinogenic and mutagenic, and are included in the list of priority pollutants of the environment [1]. Thus, effective treatment of such wastewater is of great importance to reduce its adverse impacts. In recent years, various methods have been developed and applied to treat landfill leachate, such as anaerobic and aerobic biological processes, coagulation-flocculation, as well as chemical and electrochemical oxidation [2-6]. Among these methods, chemical oxidation process has been proved to be one of the most efficient processes for the treatment of landfill leachate. Such process is to break down the structure of organic compounds by using certain oxidant such as hydrogen peroxide (i.e. H_2O_2). In terms of color removal of landfill leachate, active carbon (AC) has shown good performance. Thus, the combination of active carbon and hydrogen peroxide (H_2O_2) has become an effective method for landfill leachate treatment [7]. Generally, wastewater treatment process is affected by a number of factors, and modeling tools have been recognized as effective means of understanding such process. However, few models have been reported in the past years to predict the AC/H_2O_2 treatment process of wastewater.

Artificial neural network (ANN) model is a mathematical structure with the ability to represent the complex nonlinear and dynamic processes that relate inputs and outputs of any system. On the premise of modeling system convergence, the neural network weights can be changed through continuous self-training by inputting new training data, leading to dynamic model adjustment. ANN models have been applied to many fields during the past decades, including the field of environmental engineering, such as evaluation of water quality [8, 9] and air quality [10]. Due to its successful application in these fields, ANN model holds obvious potential to be applied to predict landfill leachate treatment process using AC/H_2O_2 [11]. However, few previous studies were reported in this regard.

The objective of this study is then to develop a GA (genetic algorithm) –BP (back propagation) artificial neural network (ANN) model to predict and optimize the AC/H_2O_2 process of landfill leachate treatment. A series of laboratory experiments on landfill leachate treatment using AC/H_2O_2 were conducted. The impacts of five experimental factors on the treatment efficiency were examined, including pH of leachate, dosage of 30% H_2O_2, mass ratio of AC to H_2O_2, reaction time, and temperature. The experimental results were then used for constructing an ANN model, while the five experimental factors were selected as model input parameters and COD_{Cr} removal as model output. The developed ANN model was then used for investigating the optimal condition of AC/H_2O_2 treatment of landfill leachate.

II. EXPERIMENTAL

Landfill leachate was collected from a garbage landfill site in Changping District, Beijing, China. The leachate was in dark brown color with almost no rancid odor, and had a COD_{Cr} of 2290~2545 mg/L. The leachate was treated in laboratory using AC/H_2O_2 method, while H_2O_2 was in concentration of 30%. Five experimental variables were investigated, including pH of leachate, dosage of H_2O_2, mass ratio of AC to H_2O_2, reaction time, and temperature. Each factor was examined within a range of values and the laboratory experiments were conducted with the values of experimental variables being combined randomly. As a result, 28 sets of experiments were implemented for ANN model training. For each set of experiments, 100 ml leachate sample was placed into a 250-ml conical flask, and the pH of leachate was adjusted by adding 0.1 mol/L NaOH or 0.1 mol/L H_2SO_4, followed by adding H_2O_2 and AC. The flask was then put in an oscillator for reaction for a certain period of time. Afterwards, the pH of the sample solution was adjusted to 11 to terminate the reaction. The COD_{Cr} of leachate before and after AC/H_2O_2 treatment were determined using quick sealed catalyzed digestion method [12]. The results (i.e. COD_{Cr} removal) from these 28 sets of experiments are listed in Table I.

TABLE I. 28 SETS OF EXPERIMENTS FOR ANN TRAINING

Test No.	30% H_2O_2 dosage (ml/L)	Mass Ratio of AC to H_2O_2	pH	Reaction time (min)	Temper-ature (^oC)	COD_{Cr} Removal (%)
1	0.8	0.125	8	60	20	1.34
2	5	0.1	12	120	20	33.48
3	2	0.5	3	120	20	10.00
4	3	0.5	10	30	20	17.29
5	4	0.5	3	120	20	23.33
6	0.5	0.167	3	90	20	18.69
7	1	0.1	3	60	40	18.3
8	1	0.167	10	120	25	4.67
9	5	0.125	6	90	25	10.28
10	5	0.5	2	120	20	33.33
11	3	0.1	8	150	25	8.88
12	7	0.5	3	120	20	22.32
13	1	0.125	12	30	50	15.89
14	0.5	0.1	6	30	30	8.48
15	3	0.5	3	120	20	13.33
16	1	0.5	8	90	30	18.22
17	6	0.5	3	120	20	30.00
18	0.8	0.167	12	150	30	4.21
19	1	0.5	3	120	20	9.33
20	5	0.25	10	60	30	13.55
21	5	0.5	3	150	50	27.57
22	3	0.25	12	90	40	9.35
23	0.5	0.125	10	150	40	2.8
24	0.8	0.5	6	120	40	6.54
25	0.8	0.25	3	30	25	22.43
26	3	0.167	6	60	50	17.29
27	5	0.5	3	120	20	36.67
28	0.5	0.25	8	120	50	7.01

III. GA-BP NEURAL NETWORK MODEL

A. *Structure of GA-BP Neural Network Model*

In this study, a 3-layer GA-BP neural network model was developed. The input layer of network included five parameters: pH of leachate, dosage of 30% H_2O_2, mass ratio of AC to H_2O_2, reaction time and temperature. The hidden layer was adopted as monolayer structure and included 16 neurons. The output variable of the entire network was the removal of COD_{Cr}. Thus a 5-16-1 structure network was constructed. The transfer functions of GA-BP neural network were chosen as tansig (), tansig (), and purelin (), while the training function was chosen as traingdm () [13].

B. *GA-BP Neutral Network Model Training*

In GA-BP neural network model, the population was chosen as 50, the generation was chosen as 200, the probability of crossover (P_c) was chosen as 0.7, and the probability of mutation was (P_m) = 0.1. The results from 28 sets of experiments on landfill leachate treatment using AC/H_2O_2 (Table I) were used as samples for GA-BP neural network model training.

IV. RESULTS AND DISCUSSIONS

A. *GA-BP Neural Network Model Prediction*

TABLE II. RESULTS OF GA-BP NEURAL NETWORK MOEL PREDICTION

Test No.	**H_2O_2 dosage (ml/L)**	**Ratio of AC to H_2O_2**	**pH**	**Reaction time (min)**	**Temper-ature (℃)**	**COD_{Cr} Removal(%)**		
						Measured	***GA-BP predicted***	***Error (%)***
1	3	0.125	3	120	30	28.04	29.37	4.47
2	1	0.25	6	150	20	4.02	4.27	6.22
3	0.5	0.5	12	60	25	12.95	13.77	6.33
4	0.8	0.1	10	90	50	4.67	4.25	8.99
5	5	0.167	8	30	40	15.89	15.1	4.97

Another five sets of experiments were conducted to examine the prediction accuracy of the developed GA-BP artificial neural network model. The combination of the values of experimental variables is presented in Table II. The measured and predicted COD_{Cr} removals for each combination of variables are also listed. It can be found that the prediction error using the developed ANN model was within 10%, with maximum error of 8.99%. Thus, the ANN model prediction accuracy is acceptable for the purpose of this study. In general, neural network model training requires large amounts of sample data, and the more the amount of data was, the more accurate the model was after training. In this study, the number of training sample data was small, and this is the main reason of model prediction error.

B. *Identification of Principal Factor of Treatment Process*

The relative importance (RI) of all input factors can be calculated by the following equations [14, 15].

$$Q_{ih} = \frac{|W_{ih}|}{\sum_{i=1}^{n}|W_{ih}|} \qquad (1)$$

$$RI(\%)_i = \frac{\sum_{h=1}^{nh} Q_{ih}}{\sum_{h=1}^{nh}\sum_{i=1}^{ni} Q_{ih}} \times 100 \qquad (2)$$

where W_{ih} is weight between input layer and hidden layer and nh and ni are numbers of neural units in input layer and hidden layer, respectively.

The relative importance of each factor on COD_{Cr} removal was then calculated, and was ranked as pH of leachate (i.e. 16.734) > H_2O_2 dosage (i.e. 15.997) > reaction time (i.e. 12.953) > ratio of AC to H_2O_2 (i.e. 11.658) > temperature (i.e. 4.117). Thus, pH of leachate was found as the most important factor, and should be carefully regulated during the leachate treatment process using AC/ H_2O_2.

C. *Investigation of the Influence of Factors*

The influence of each of the five selected factors on COD_{Cr} removal was further examined using the developed GA-BP ANN model, by changing the value of the investigated input parameter, while the values of the other four input parameters remained fixed.

1) Influence of Leachate PH: When H_2O_2 dosage was 5 ml/L, the ratio of AC to H_2O_2 was 0.5, reaction time was 120 min, and temperature was 20 °C, the influence of leachate pH on COD_{Cr} removal was analyzed using the devloped model, and the results were shown in Fig. 1.

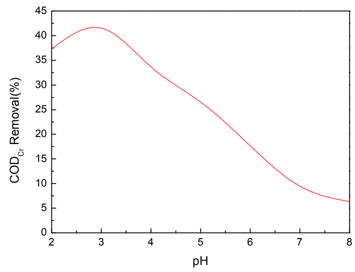

Figure 1. Influence of leachate pH on COD_{Cr} removal

As shown in Fig. 1, under acidic conditions, the landfill leachate treatment efficiency using AC/H_2O_2 method was obvious. The COD_{Cr} removal increased slightly with landfill leachate pH when pH was less than 3, and a maximal COD_{Cr} removal was obtained when leachate pH was 3. However, when landfill leachate pH was greater than 3, COD_{Cr} removal decreased sharply with the increase of PH. Under neutral and alkaline conditions, landfill leachate treatment efficiency using AC/H_2O_2 process was seriously restricted (COD_{Cr} removal < 10%).

2) Influence of H_2O_2 Dosage: When leachate pH was 3, the ratio of AC to H_2O_2 was 0.5, reaction time was 120 min, and temperature was 20 °C, the influence of H_2O_2 dosage on COD_{Cr} removal was investigated using the developed ANN model, with results shown in Fig. 2.

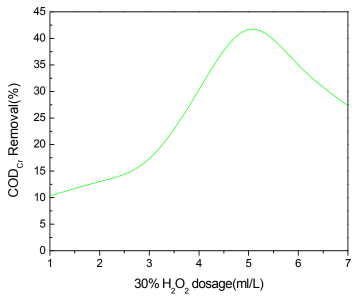

Figure 2. Influence of 30% H_2O_2 dosage on COD_{Cr} removal

It is observed from the modeling results that H_2O_2 dosage had significant effect on COD_{Cr} removal of landfill leachate. The COD_{Cr} removal first increased with H_2O_2 dosage, but decreased when H_2O_2 dosage was higher than 5 ml/L. A maximal COD_{Cr} removal was reached when H_2O_2 dosage was 5 ml/L.

3) Influence of mass ratio of AC to H_2O_2: When leachate pH was 3, H_2O_2 dosage was 5 ml/L, reaction time was 120 min, and temperature was 20 °C, the influence of mass ratio of AC to H_2O_2 on COD_{Cr} removal was examined using the developed model (Fig. 3).

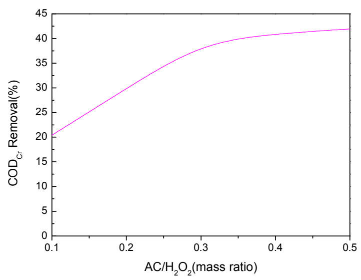

Figure 3. Influence of mass ratio of AC to H_2O_2 on COD_{Cr} removal

As shown in Fig. 3, COD_{Cr} removal increased gradually when the ratio of AC to H_2O_2 increased from 0.1 to 0.4. When the ratio of AC to H_2O_2 was above 0.5, COD_{Cr} removal curve almost leveled off.

4) Influence of Temperature: When leachate pH was 3, H_2O_2 dosage was 5 ml/L, mass ratio of AC to H_2O_2 was 0.5, and reaction time was 120 min, the influence of temperature on COD_{Cr} removal was investigated. As shown in Fig. 4, COD_{Cr} removal almost had no changes when the temperature of solution varied from 20 to 50 °C, indicating that temperature had minimal impacts on COD_{Cr} removal when using AC/H_2O_2 method.

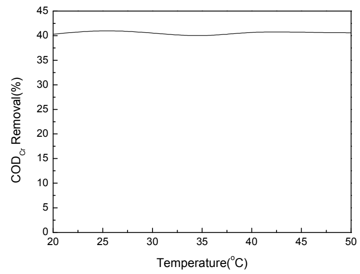

Figure 4. Influence of temperature on CODCr removal

5) Influence of Reaction Time: When leachate pH was 3, H_2O_2 dosage was 5 ml/L, mass ratio of AC to H_2O_2 was 0.5, and temperature was 20 °C, the influence of reaction time on COD_{Cr} removal was analyzed (Fig. 5).

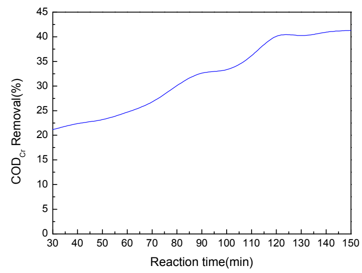

Figure 5. Influence of reaction time on COD_{Cr} removal

As shown in Fig. 5, reaction time had significant impact on the treatment of landfill leachate using AC/H_2O_2 process. When reaction time was increased from 30 min to 120 min, COD_{Cr} removal was increased gradually. COD_{Cr} removal curve almost leveled off after 120 min of treatment. This indicates that COD_{Cr} removal increased evidently with reaction time in the beginning of AC/H_2O_2 treatment, but had no significant rise after 120 min of reaction.

D. Optimal Condition of AC/H_2O_2 Treatment

Based on the above analysis, the optimal operating condition of AC/H_2O_2 treatment for landfill treatment was obtained as leachate pH of 3, 30% H_2O_2 dosage of 5 ml/L, AC to H_2O_2 ratio of 0.5, reaction time of 120 min, and temperature of 20 ^{o}C. Under the optimal operating condition, the predicted COD_{Cr} removal using BP-GA neural network model was 41.85%. Experiment was also conducted under the optimal condition, and COD_{Cr} removal was observed as 43.44%. Thus, the relative error between predicted and measured COD_{Cr} removal was 3.66%. Consequently, the developed GA-BP artificial neural network model in this study had reasonable prediction accuracy for modeling the AC/H_2O_2 treatment process. It could provide sound information for designing an optimal landfill leachate treatment system.

V. CONCLUSION

Landfill leachate is a poisonous and harmful wastewater with high concentration of organics, which needs to be treated effectively. In this study, the AC/ H_2O_2 process was selected to treat landfill leachate. The impacts of five experimental factors, including leachate pH, dosage of 30% H_2O_2, AC to H_2O_2 ratio, reaction time and temperature, were investigated through laboratory experiments. A three-layer GA-BP neural network model was developed by using the five selected factors as inputs and COD_{Cr} removal as output. After training the network using the experimental data, the error of model prediction was found acceptable, with maximum error of 8.99%. The relative importance of each of the five factors was then calculated using the developed model, and leachate pH was found as the most important factor, with the impact order of leachate pH > H_2O_2 dosage > reaction time > AC to H_2O_2 ratio > temperature. The developed ANN model was further used to examine the detailed impact of each factor on COD_{Cr} removal, and it was found that the optimal operating condition of AC/H_2O_2 treatment process was leachate pH of 3, H_2O_2 dosage of 5 ml/L, AC to H_2O_2 ratio of 0.5, reaction time of 120 min, and temperature of 20 °C.

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