Landfill Leachate Circulation on Old Waste Pretreatment Performance Prediction with Artificial Neural Networks

Mohssen Shoeybi, Arman Shafiei Kamel, and Jonathan L. Salvacion

***Abstract*—Performance of landfill fresh leachate pretreatment by circulation on primitive waste deposits predicted by artificial neural network (ANN) mathematical modeling. Landfill simulation reactor (LSR) for laboratory scale modeling was applied to prepare the old waste and evaluation of pretreatment performance. Concentration of BOD_5 and COD in leachate measured as organic compound indicators and NH_3 and NH_4 concentrations as nitrogen compounds. The results indicated that organic matters removal (64%) was higher compare to nitrogen compounds removal (42%). Optimized neural network was constructed with a mean absolute error (MSE) of 30.85 and 6-7-4 structure. The input of model was leachate characteristics and time, while the output was removal performance for organic and nitrogen compounds. The R value of 0.979 from regression analyses indicated there was very good agreement in the trends between forecasted and measured data.**

***Index Terms*—Laboratory scale, landfill simulation reactor, organic compound, nitrogen.**

I. Introduction

The mass of waste produced in the world has been growing considerably for many decades. Landfills have been used to contain wastes in order to isolate them from environment. Landfilling in worldwide still is the most common disposal option for solid waste. Landfill leachate form when soluble chemicals, from breakdown of biodegradable waste by micro organisms, combine with water that passes through landfill deposits. The landfill leachates contain complex compositions, such as high concentration of ammonia nitrogen and salt, the suspended solids, nitrogen and heavy metals.

Traditionally, the landfilling of solid wastes has been accomplished at the least possible cost. Initially, urban areas deposited their solid wastes on nearby low-value lands, creating a waste dump. As science and technology developed, the management of an ever increasing volume of waste became a very organized, specialized and complex activity. Modern waste management practices involve disposal of waste in specially sited and engineered sites known as sanitary landfills. Now days landfill leachate has to be controlled, recorded and treated in a way that it reduced to environmentally acceptable impacts afterwards otherwise there is a permanent risk of a leachate outflow into the underground and thus into the ground water [1-2-3]. A number of serious and highly publicized pollution incidents associated with incorrect waste management practices, led to public concern about lack of controls, inadequate legislation, environmental and human health impact. Government and health authorities are under increasing pressure from the public to provide evidence of potential adverse health effects produced by these activities [4-5]. With stricter regulations regarding ground and surface water contamination, landfills have to find new treatment alternatives [6-7].

Leachate recirculation and/or water addition through the waste layers in a landfill is considered to accelerate the biodegradation of the readily and moderately degradable organic fraction of waste [8]. Recirculation of leachate into the waste mass is the primary concept of a bioreactor landfill since this technique help enhancing waste decomposition and methane production rate through the application of moisture as it provides an aqueous environment that facilitates the provision of nutrients and microbes within the landfill cells. Furthermore, by recycling the leachate back into the landfill, the amount of leachate that must be treated by other means can be lessened. A typical landfill is divided into a series of sections called "cells". Landfill is filled so systematically, cell by cell, with specific fill plan and fills sequence so landfill operators are able to pinpoint where a specific load of waste was deposited days, weeks, or even months afterward. In this study we proposed, with aid of landfill fill plan, fill sequence and considering some details in landfill design and construction; more complicated systems for circulating the leachate of young cells on older cells might be used instead of simple recirculation systems to enhance the effect of leachate recirculation. However, testing these theories is difficult as the result of the heterogeneity of waste components, seasonality, costs and safety. This is where laboratory scale models represents a simplified way to represent the reality under study, and allows to simulate the variations suffered both its quality and quantity from the elements of the system.

Artificial neural networks (ANN) were developed as large parallel-distributed information processing systems that attempt to model the learning procedure of the human brain. ANNs are among the newest signal processing technologies nowadays and the field of work is very interdisciplinary. ANNs specialize in identifying non-linear relationships given large datasets and have a relatively simple mathematical architecture that makes them computationally efficient. They are usually used to model complex relationships between inputs and outputs or to find patterns in data. Their architecture consists of layers of nodes with weighted arcs connecting the nodes within the different layers. One specific ANN architecture is the multilayer perceptron (MLP) with feed-forward and one or more layers between the input and output nodes (hidden layers). Training of MLP might achieve by the back propagation (BP) algorithm, which generalized least mean square algorithm. Feed-forward back-propagation

Manuscript received March 21, 2012; revised May 7, 2012.
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neural networks consist of an input, a hidden and an output layer all containing nodes. The numbers of nodes in input and output layers correspond to the number of input and output variables of the model. The number of hidden nodes can be chosen freely; the optimum number depends on the complexity of the underlying problem and is to be determined empirically. Recently, numerous studies have reported the use of ANN models in environmental engineering applications for controlling and predicting of complex systems such as evaluation of water quality and air quality [9-10-11]. Due to its successful application in these fields, ANN model holds obvious potential to be applied to predict landfill leachate treatment process. However, few previous studies were reported in this regard.

In this study the proposed ANN model predicts the performance of circulation of fresh waste leachate on old deposits from pH, time, biological oxygen demand (BOD_5), chemical oxygen demand (COD), ammonia (NH_3-N) and ammonium (NH_4-N) concentration for performance of organic and nitrogen compounds removal. The overall goal of this paper is to demonstrate that use of recirculation of fresh waste leachate on old deposits will reducing the current high cost of off-site leachate disposal by reducing the organic and nitrogen compounds concentration with a simple procedure. Then to develop and determined a optimal architecture of computational model base on MLP-BP neural network to predict the performance process of this complex biological system.

II. Experimental and Method

A. Landfill Simulation Reactor (LSR)

Landfill simulation reactor (LSR) for laboratory scale modeling was applied to conduct the present study. All LSRs were constructed from a drum made of high density poly ethylene (HDPE) having a diameter of 500 mm and a total height of 1000 mm. In order to avoid the clogging of the water outlet and waste saturation by leachate, 30 cm thick of gravels were filled at the bottom of each landfill reactor. Also, top portion of waste covered with a thin layer of sand for homogen distribution of circulated leachate in LSR medium.

To provide the old waste an LSR filled with shredded waste and had run with simultaneous leachate circulation and water addition at room temperature in 130 days, until COD, BOD_5, total dissolved solids (TDS), conductivity, TKN, ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N) and sulphate (SO_4) concentrations showed more than 90% degradation [12].

To evaluate the pretreatment performance pair of set-ups, each composed of two LSRs in series, were set up. First set-up used as the reference while both reactors (A1 and B1) filled with fresh waste and leachate was circulated daily, first sampling point (Point A) defined at reactor A1 leachate outlet. In second set-up, that composed of an LSR with fresh waste and an LSR with old waste, daily the leachate from fresh waste LSR (A2) was passed through the another LSR filled with old waste (B2), also at the same time the leachate from LSR B2 was passed through LSR A2. Second sampling point (Point B) defined at reactor A2 leachate outlet and third sampling point (Point C) defined at leachate outlet of reactor B2. Furthermore, detailed procedure for the experiment was reported in [13].

B. Artificial Neural Network (ANN)

Artificial neural networks (ANNs) or shortly neural networks (NN) have an ability to capture non-linear information very efficiently. Neural networks are composed of simple elements operating in parallel. As in nature, the network function is determined largely by the connections between elements. Commonly NN are adjusted, or trained, so that a particular input leads to a specific target output. In the basic neural networks architecture, the network is adjusted, based on a comparison of the output and the target, until the network output matches the target. Typically many such input/target pairs are used to train a network. Back propagation (BP) algorithms use input vectors and corresponding target vectors to train an NN. The neural networks with a sigmoid and linear output layer are capable of approximating any function with a finite number of discontinuities. The standard BP algorithm is a gradient descent algorithm, in which the network weights are changed along the negative of the gradient of the performance function.

MLP was used, with a tan-sigmoid (tansig) transfer function at the hidden layer and a linear transfer function (purelin) at the output layer. Tansig is a hyperbolic tangent sigmoid transfer function calculating a layer's output from its net input. tansig(N) calculates its output according to Eq. (1). Purelin transfer functions calculate a layer's output from its net input. Mean Squared Error (MSE) is the average squared difference between outputs and targets (Eq. (2)). Regression R Values measure the correlation between outputs and targets (Eq. (3)). An R value of 1 means a close relationship and 0 a random relationship.

$$n = {}^{2}/_{(1 + exp(-2 * n))} - 1 \tag{1}$$

$$MSE = \frac{1}{X}\sum_{i=1}^{n}(Y_i - X_i)^2 \tag{2}$$

$$R = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sum_{i=1}^{n}(Y_i - X)^2 \sum_{i=1}^{n}(Y_i - Y)^2} \tag{3}$$

where X_i is removal efficiency from experiment, Y_i is predicted removal efficiency by ANN, $\overline{X}$ is mean of experiment data and $\overline{Y}$ is the mean of predicted outputs.

III. Results and Discussion

A. Leachate Pretreatment

BOD is amount of oxygen required for the biodegradation of organic compounds. Fig.1 demonstrates the variation of BOD_5 over time during degradation of waste in both set-up at each sampling points. It shows that the BOD_5 concentration at point A in set-up 1 increased from its initial value of 5,560 mg/L on day 3 to 73,120 mg/L on day 17. It was followed by decreasing phase and reached to 55,810mg/L on day 100. At point B in set-up 2, BOD_5 increased rapidly from 7,840mg/L to 87,000 mg/L on day 17. From this day degradation phase started and on day 100 it reached to 22,440 mg/L. The degradation phase that accrue at point B was the effect of LSR with old waste (B2) or in other way circulation of fresh leachate on old waste. On day 100 point A showed 24% degradation in BOD, however at the same time point B in set-up 2 showed 74% degradation.

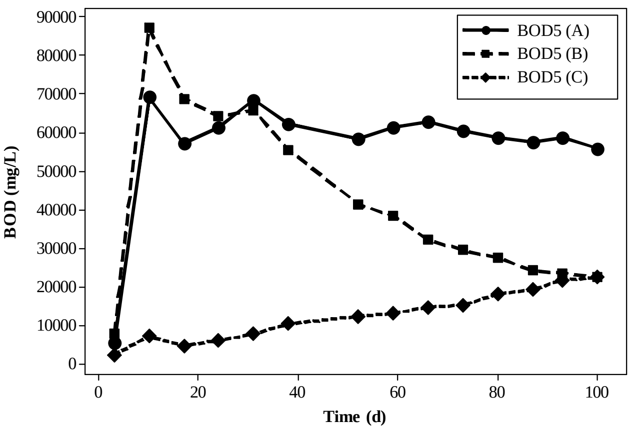

Fig. 1. BOD_5 concentrations in all sampling points

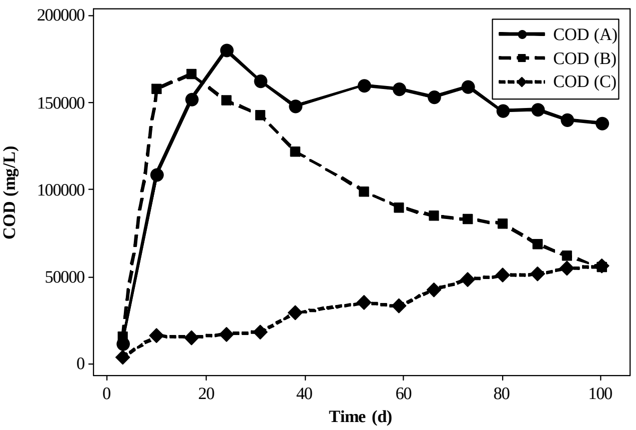

Fig. 2. COD concentrations in all sampling points

Fig. 2 shows COD data for effluent of three reactors. COD determine the amount of organic compounds in water and wastewater indirectly. As illustrated, the leachate COD concentration increased rapidly after experiment started in reactors with fresh waste (A1 and A2) in both systems, which increased to maximum values of 180,000 and 166,000 mg/L after 24 and 18 days, respectively. While point A in set-up 1 did not show significant degradation trend, COD concentration at point B in set-up 2 reached to 55,400 mg/L and showed 67% degradation on day 100. Results confirmed that set-up 2 was successful in significant organic matter removal from leachate. Enhanced anaerobic digestion due to better microbial activity in set-up 2 compare to set-up 1 and dilution were responsible for these phenomena.

At point A, COD increased from 12,100 mg/L on day 3 to maximum value of 180,000mg/L on day 27 but as it shows in Fig. 1, BOD reached its maximum value on day 17. In other way there is 10 days between BOD and COD extrema. This phenomenon was caused by soluble microbial product (SMP) which is in contributed to the COD value in the effluent. SMP are soluble cellular components that are released during biomass decay, they are inevitably produced because of microbial metabolism. The main components of SMP have been identified as protein, polysaccharides, humic acids, and nucleic acids [14]. SMPs are important because they are always former during biological treatment, and they constitute the majority of the effluent COD in many cases [15]. Various articles have proven that formation of SMP in anaerobic system indeed contributed to a certain percentage of COD in the effluent [16]-[17].

BOD_5/COD ratio describes the biodegradability level of materials by which organic matter containing leachate is readily broken down in the environment. It is known that BOD_5/COD ratio of leachate decreases with time in landfill, resulting in the stability of leachate. It decrease rapidly from 0.70 to 0.40 with the aging of the landfills. BOD_5/COD ratio for sampling points in both set-ups demonstrate in Fig. 3, all points are showing descending pattern in this ratio. All reactors show the same value (0.40) at the end of experiment, that means some portions of the waste are still in the acid phase, also it may indicate that the degree of solid waste stabilization did not reach to stable level yet. This might be because of some large molecule compounds like humic acid in leachate which takes longer time to break down by micro organisms.

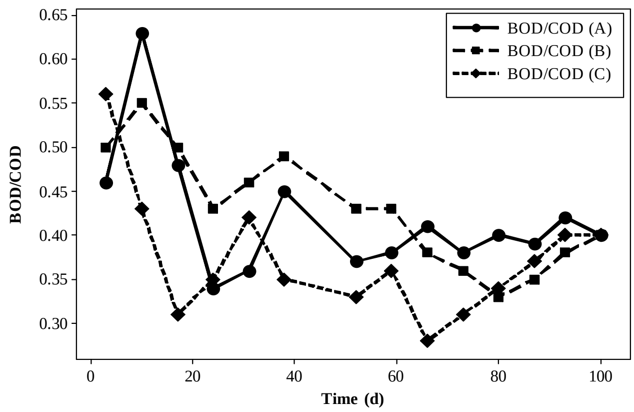

Fig. 3. COD concentrations in all sampling points

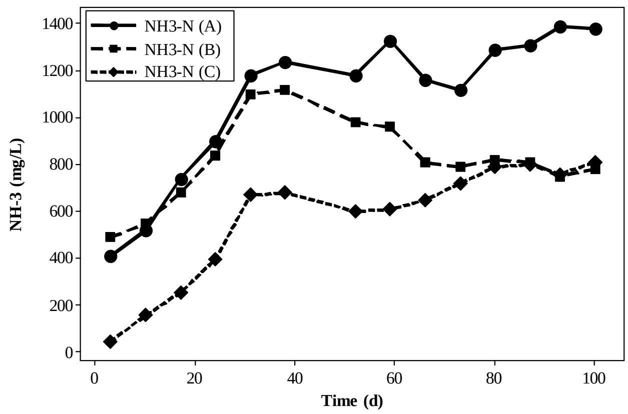

Fig. 4. NH_3-N concentrations in all sample points

Degradation processes of fresh waste due to microbial activity are responsible for nitrogen compound in leachate. Nitrogen removal efficiency was carried out by determination of ammonia and ammonium nitrogen concentrations in both set-ups. Ammonia and ammonium changes at different sampling points were shown in Fig. 4 and Fig. 5, respectively. As figures show ammonia and ammonium nitrogen were linked together directly. Ammonia concentration from 409 mg/L on day 3 reached 1,381 mg/L on day 100 in point A; but point B only increased to 780 mg/L from 490 mg/L at same period of time. Ammonium concentration from 434 mg/L on day3 reached 1,448 mg/L on day 60 at point A; but point B only raise to 837 mg/L from 538 mg/L at same period of time. Point B compare to point A shows 44% and 42% lower concentration in ammonia and ammonium, respectively. This shows applicability of this method on nitrogen removal. The ammonia and ammonium concentrations have remained elevated which is consistent with the absence of nitrifying bacteria for nitrification under anaerobic conditions so nitrogen removal was lower than organic matter removal. Reductions in nitrogen compounds concentration were due to adsorption onto the old waste surface and utilization of nitrogen compounds through assimilation of anaerobic microorganisms for cellular growth [7].

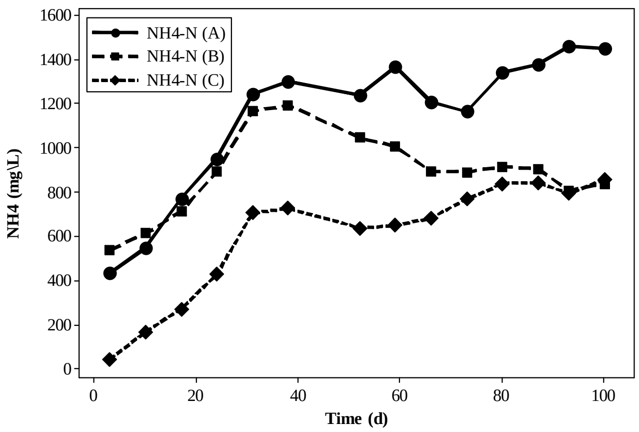

Fig. 5. NH_4-N concentrations in all sample points

B. Removal Efficiency

BOD_5, COD, NH_3-N and NH_4-N removal efficiency presented in Fig. 6. Pollutants removal efficiency were calculated by following Eq. (4).

$$Removal\ efficiency = {}^{C_{in} - C_{eff}}\!\Big/_{C_{in}} \times 100 \qquad (4)$$

where C_{in} is the concentration in the influent of the reactor and C_{eff} is the concentration in the effluent of the reactor.

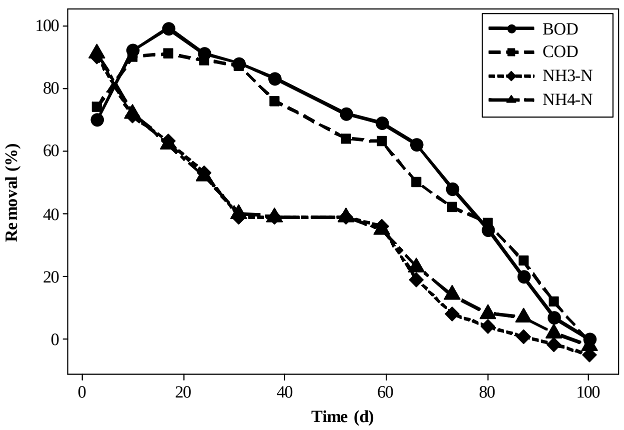

Fig. 6. Removal performance for BOD_5, COD, NH_3 and NH_4

Removal efficiency decreased by time and decreasing rate for nitrogen removal was higher than organic removal. At the beginning of the test organic removal efficiency increased due to rapid increasing in BOD_5 and COD concentrations and from day 20 it started to decrease up to the end of experiment. Since adsorption was the only reason for nitrogen removal on day 80 the system saturated and reached to equilibrium due to recirculation of leachate, after this day system was unable to reduce the nitrogen compound concentrations.

C. Neural Network Modeling

In this study a 3-layer MLP-BP neural network model, with the aid of neural network toolbox in Matlab, was developed base on data from sampling pints B and C [18]. Each point had 14 sets of data which means 28 sets of data used for development of this model. 80% of these data used for training the model, 10% for validating the model and the last 10% used for testing the model and evaluating the performance of model in prediction for method performance. To optimize the neuron number in hidden layer, between 2 to 10 neuron numbers with the increments of one were run ten times. Multi-training the ANN produces different output, therefore minimum MSE and maximum R chose among the ten runs. Thereafter, the MSE and regression R values were separately evaluated for the neuron numbers. With increasing neuron numbers, MSE decreased. However, as showed in Fig.7 increasing neuron numbers to more than 7 caused the mean squared error begins to increase. Therefore, the optimal neuron number for hidden layer was adopted as 7 with a MSE of 30.85. Thus as demonstrated in Fig. 8 and Fig 9, 6-7-4 optimized structure network was constructed with a tan-sigmoid transfer function at the hidden layer with monolayer structure, and a linear transfer function at the output layer with. The input layer of network included six parameters: BOD, COD, NH_3-N, NH_4-N, pH and Time. The output variable of the entire network were the removal efficiency for organic and nitrogen compounds individually in percentage (4 neurons). A regression analysis of the network response between the output and the corresponding target for optimized network presented in Fig. 10. The R value of 0.979 indicates there is very good agreement in the trends between forecasted and measured data.

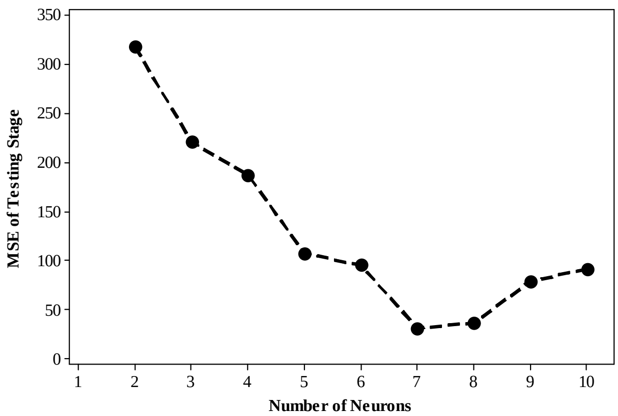

Fig. 7. Variation in MSE and nodes in hidden layer

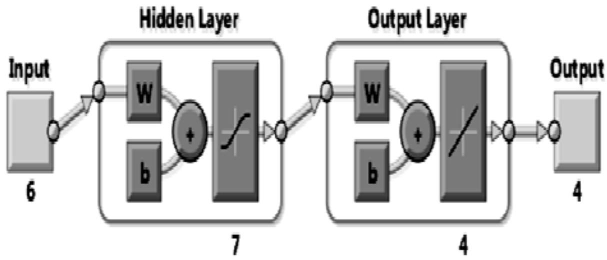

Fig. 8. Schematic of optimized neural network

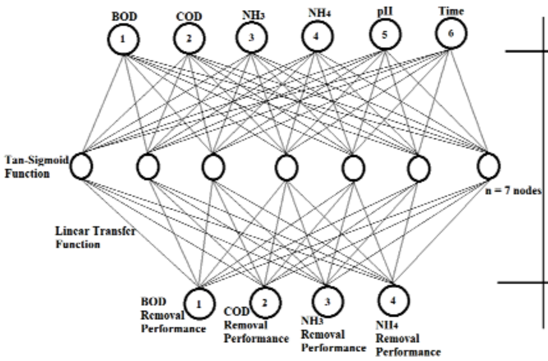

Fig. 9. Architecture of the optimized ANN model

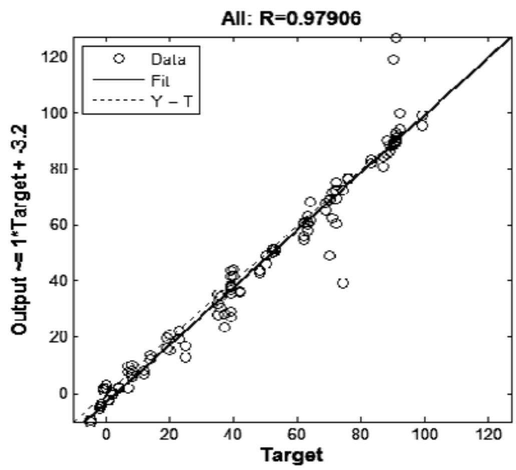

Fig. 10. Regression results for proposed ANN model

IV. Conclusions

The results indicate that fresh waste leachate by circulating on old waste deposits method has capability to use as a pretreatment in organic component and nitrogen removal. Also, organic component removal performance was higher than nitrogen removal because the only process that is responsible for nitrogen removal is adsorption onto the old waste surface. Furthermore optimized ANN model base on fitted models on experimental data by using regression analysis were determined. This model may be helpful in prediction of method performance in any time period.

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