Amanda Fernandes Pereira da Silva
(Organizadora)

ENGENHARIAS: Pesquisa, desenvolvimento e inovação 2

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Amanda Fernandes Pereira da Silva
(Organizadora)

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Nesse sentido, esta coleção “Engenharias: Pesquisa, desenvolvimento e inovação 2” traz capítulos ligados à teoria e prática em um caráter multidisciplinar, tendo um viés humano e técnico. Apresenta temas relacionados as áreas de engenharias, dando um viés onde se faz necessária a melhoria contínua em processos, projetos e na gestão geral no setor fabril.

De abordagem objetiva, a obra se mostra de grande relevância para graduandos, alunos de pós-graduação, docentes e profissionais, apresentando temáticas e metodologias diversificadas, em situações reais.

Boa leitura!

Amanda Fernandes Pereira da Silva

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NONLINEAR MODEL OF COD AND OBD/COD AT THE CAXIAS DO SUL LANDFILL USING NEURAL NETWORKS

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ABSTRACT: Monitoring was carried out in order to collect data representing the physical, chemical and biological processes that take place in a landfill, in this case the landfill of Caxias Do Sul in Brazil, which are responsible for the degradation of the organic components of the solid waste mass in the landfill. The measurements indicate the state of decomposition of the landfilled mass and the transformations occurring in it. A non-linear model is presented to analyse the biodegradability of organic matter in order to demonstrate anaerobic microbial activity and biological activity as a function of time. A neural network capable of predicting COD and BOD/DQO values was proposed. The optimised network structure consisted of a 5-3-1 multilayer perceptron, and 5-6-1 with logistic sigmoidal transfer function in the hidden layer and linear activation in the output layer, trained with the Levenberg-Marquardt algorithm.

KEYWORDS: Landfill, Non-linear model, Neural network, anaerobic digestión, biodegradability indexes

INTRODUCTION

Population growth and rampant consumption have contributed to the increased production of urban solid waste, hence the importance of managing this waste to control environmental pollution. Heterogeneous solid waste can cause environmental impacts, especially if its disposal is not environmentally sound [1].

According to the Brazilian National Policy on Solid Waste (PNRS)[2], Environmentally appropriate final destination is the destination of waste that includes reuse, recycling, composting, recovery and energy use or other destinations permitted by the competent bodies of the Sisnama, the SNVS and Suasa, including final disposal, observing specific operating standards in order to avoid damage or risks to public health and safety and minimize adverse environmental impacts. Environmentally adequate final disposal is the orderly distribution of waste in landfills, observing specific operating standards in order to avoid damage or risk to public health and safety and minimize adverse environmental impacts [3].

The area called "Vazadouro de São Giácomo", Figure 1, owned by the City Hall of Caxias do Sul, RS, Brazil, located in the outskirts of the city on the banks of the Tega River, received in a disorderly way, for a period of two years from 1988 to 1990, the solid urban waste generated in the municipality causing environmental degradation of an area of approximately 1.4 hectares [4].

Caxias do Sul has a population of approximately 360 thousand inhabitants, produces approximately 300 tons of domestic waste daily collected by 230 Urban Cleaning workers and selective and organic waste is collected through the door-to-door system [5]. This area was impacted by the uncontrolled disposal of solid waste: domestic (50%); industrial (25%); commercial (20%) and health services (15%) totalling 64,000m3 in the period between 1988 and 1990.

The disposal of waste in landfill cells was implemented according to Brazilian standards for sanitary landfills,NBR 8418/1984 [6] and ABNT 8419/1992 [7], and the remediation system at São Giácomo is operating with an operating license from the state environmental agency undação Estadual de Proteção Ambiental (FEPAM) and is monitored monthly (Table 1 and Figure 1 and Figure 2).

Cells	General Date
C1/C2	From 1989 to 1992 (cells without waterproofing, resulting from the remediation of the existing dump).
C3	Started in 1992 (cells without waterproofing).
C4	Start 1992 to 1994. 1st enlargement – 1995. 2st enlargement – 1996
C5	Started in 1995 and finish 1997.
C6(on C4 and C5)	Started in 1997 and 1st enlargement – 1998.
C7(on C6 and C5)	Started in may 1999.
C8	Started in may 2000.
C9	Started in march 2001.
C10	Started in jully 2002.

Table 1. General information on the cells of the São Giácomo landfill site.

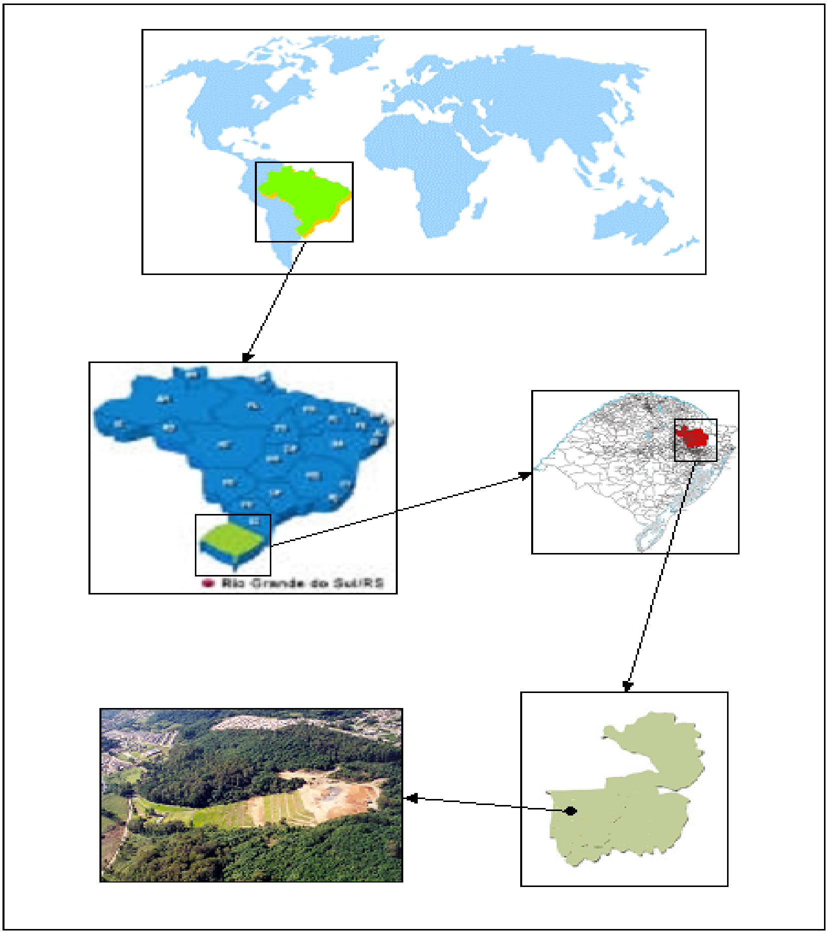

Figure 1. Location of the Sao Giacomo landfill in the municipality of Caxias do Sul

Figure 2. Partial view of the São Giácomo - Caxias do Sul landfill.

The amount of waste disposed of at the landfill is estimated by sampling that began in September 1999, with an average of the discharges for each type of waste (Table 2). From 2004 to 2006, about 128 thousand tons of waste were disposed of in December, the disposal at the landfill ended in March 2006 [8].

Year	Daily average (ton/day)	Monthly average (ton/month)	Annual average (ton/year)
1998	243.73	6336.98	76043.76
1999	280.73	7289.62	87475.44
2000	273.24	7104,24	85250.88
2001	291.81	7587.06	91044.72
2002*	294.74	7663.24	91958.88

* Values as at September 2002

Table 2. Loads of waste deposited in São Giácomo's landfill

The disposal of solid waste in San Giacomo in a controlled manner allowed suitable conditions for the development of the process of anaerobic digestion of the organic fraction present in the waste and the development of microbial activity within the cells of the landfill, associated with environmental factors, promote the percolation of quantities of leachate and its subsequent treatment, according to Standard Methods [9] (*Standard Methods*,.d.). Slurry is a dark liquid generated by the degradation of waste organic matter and is the result of the enzymatic action of microorganisms in the system and the resulting products of biodegradation [10].

The chemical composition of leachate varies depending on the age of the landfill and the events that occurred prior to sampling. The parameters used to classify leachate from different landfills are usually 5-day chemical oxygen demand (BOD5), chemical oxygen demand (COD), the BOD_5/COD ratio, alkalinity and pH [11,12].

The parameters that measure the biodegradability of organic matter are: COD and BOD while pH adjusts the microbial growth rate Emcon Associates [13] composition of slurry indicates whether anaerobic digestion is occurring, when there is a high degree of stabilization, mineralization of waste, unfolding of matter consecutively.

The biodegradability of leachate varies with time and can be determined by the variation of the BOD_5 /COD ratio. In young landfills, the BOD5/COD ratio is around 0.5 or higher, indexes between 0.4 and 0.6 are indicators of good biodegradability. In older landfills, this ratio usually varies between 0.05 and 0.2 [14]. The leachates with biodegradability indexes (BOD5 /DQO) higher than 0.4 are effectively treated by biological processes; however, for leachates from old dumpsites these treatments are not sufficient [15].

- Hydrogenic potential (pH): according to Emcon Associates [13], pH is a critical environmental parameter that affects the balance between the various populations of microorganisms, as well as the level of microbial activity. According to Alves [16], the pH has an effect on the biological activity of methanogenic bacteria, during the initial acid phase, its value may drop below 6.0 when CO_2 is released and with the formation of ammonia (NH_3), with increased production of CH_4 and pH near 7.0 occurring its stabilization between 7.2 and 8.5.

- Chemical oxygen demand (COD): it is a measure of the equivalent, in O2, of the portion of organic matter in the sample susceptible to oxidation by a strong chemical oxidant and is used to measure the content of organic matter in the landfill. According to Gandolla, Acaia & Fischer (1995) [17] the content of organic matter, expressed in terms of COD and BOD, is initially very high and then decreases due to biological degradation and leaching processes.

A considerable fraction of initial BOD is made up of volatile fatty acids, the concentration of which is a good indicator of the stage of anaerobic degradation. The BOD/COD ratio indicates the percentage of organic matter that is biodegradable, which decreases as the landfill progresses. Initially, this ratio is 0.5 to 0.8, dropping to 0.07 to 0.08 after several years. According Robinson & Maris (1979) [18], the BOD/ COD ratio assumes values higher than 0.4 during the acid phase and lower and equal to 0.4 during the methanogenic phase. Document Display [19] sows that the BOD/COD ratio decreases from 0.47-0.07 in a period of 23 years. Compared with the results of sanitary Landfill Leachates and Their Treatment decrease is 0.8-0.05 in 17 years. According to Hamada (1997) [21], the biodegradability of slurry varies with time and can be determined by the BOD/D COD ratio. Initially, it is around 0.5 or higher, and between 0.4 and 0.6 are the best biodegradability indicators. It describes that for old landfills, the same BOD/ COD ratio would be between 0.05 and 0.2.

Alkalinity becomes very important in the preservation of aquatic environments because it is directly related to the degree of decomposition of organic matter and the consequent release of CO2. When these values are above those indicated, it characterizes a high decomposition process that directly interferes with the dissolved oxygen in the environment, thus causing an imbalance in the environment and the various forms of life present therein [22]

METODOLOGIA

The slurry samples used in the present work come from the São Giacomo landfill and were characterized as to pH, alkalinity, COD and BOD; the analyses followed the standards contained in Standard Methods [23].

The landfill leachate used for the coagulation, flocculation and decantation tests had been previously treated by three facultative lagoons. After leaving the facultative lagoons, the leachate passes through a continuous flocculator at a flow rate of 3 m^3 /h of leachate and 15 L/h of $Al_2 (SO_4)_3$. The operation takes place in three independent lines (each operating with 3 m^3/h of leachate). The coagulant $Al_2(SO_4)_3.18H_2O$ with a concentration of 50% m/m and specific mass of 1.329 kg/m^3 obtaining a concentration of 270 mg Al^{+3}/L, dosage that is added directly to the flocculator. The mixer responsible for the agitation of the flocculator operates at a rotation of 4 rpm and is composed of two blades with dimensions 50 cm wide by 30 cm high. The flocculators operate with 1000 L of useful volume. After treatment in the flocculator the effluent passes to a 35 m^3 decanter. After the process, the pH of the leachate was adjusted with NaOH and the effluent was characterised. After the process, the pH of the leachate was adjusted with NaOH and the effluent was characterized. The analyses and methods performed were DBO_5 ($mgO_2.L^{-1}$) Standard Methods 22nd- Method 5210 B [24] and Standard Methods 22nd- Method 5220 B [25].

The determination of COD was performed according to standard methodology described in [25]. The procedure basically consists of digesting the sample in a closed tube followed by colorimetric determination at 600 nm. Calibration curves were prepared between 50 and 900 mg L^{-1}, using potassium biftalate standards. The methodology was validated using potassium biftalate 300 mg L^{-1}[26].

The BOD corresponds to the amount of oxygen required for the metabolization of biodegradable matter by living organisms or their enzymes, under the test conditions. The determinations were carried out according to the procedures described in Standard Methods for Biochemical Oxygen Demand (BOD) [24]. The simplified procedure can be understood through the following steps: a) determination of the COD of the slurry. The pH of the sample was corrected to 7.1-7.3 with H_2SO_4 or NaOH 0.1 mol L^{-1} solution; b) the initial BOD present in the samples was determined; d) similar samples were incubated (conditioned in BOD bottles for 5 days at 20 ± 1ºC and protected from light and c) the final BOD contained in the samples was determined. The difference in oxygen consumption over this period, discounting the control, is the measurement of BOD over 5 days (BOD_5) expressed as the mass of oxygen consumed per litre of sample.

The pH of the samples was determined by direct reading in Quimis potentiometers, both calibrated with pH 4.0 and 7.0 buffers (Figure 3).

Figure 3. pH meter image

The determination of the total alkalinity (mg of $CaCO_3$) was performed from the titration with sulfuric acid (H_2SO_4 0.093 mol/L) of 50.0 mL of the water sample with the use of methyl red indicator, which guarantees that the colour turn over occurs in a slightly acid solution. From the volume of titrant used, the total alkalinity of the sample was calculated, considering it to be the number of moles of H^+ required to titrate the volume of sample. The hydroxyl (OH^-), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions are mainly responsible for alkalinity.

Artificial neural networks can be used to estimate or predict biological oxygen demand (BOD) or COD [27]. In a landfill it is necessary to have COD monitoring systems or to have a way to estimate them through the application of algorithms by using software tools. In Azadi et al., 2016 [28] two expert systems were developed through the application of neural networks and principal component analysis to predict chemical oxygen demand (COD) in leachate produced in a laboratory-scale landfill. A discussion of principal component analysis (PCA) is presented in (Grisa et al., (2010) [29], describing the variables that are most correlated with COD (a parameter that measures biodegradability) and those that are most correlated with ammonia nitrogen, which is indicative of biological activity.

An artificial neural network model is used to predict BOD and COD removal in horizontal subsurface flow constructed wetlands [30], using principal component analysis for the selection of input parameters to the neural network.

Matlab R2019B was used to perform the programming of the multilayer perceptron neural network in the modelling and simulation stages. The number of neurons in the input and output layers was matched to the number of predictor and response variables, respectively [31]. The ANN was optimised for a 5-3-1 structure, employing the logistic sigmoidal transfer function (logsig) in the hidden layer and linear activation (purelin) in the output layer. Figure 4 shows the neural network architecture used for the COD modelling process.

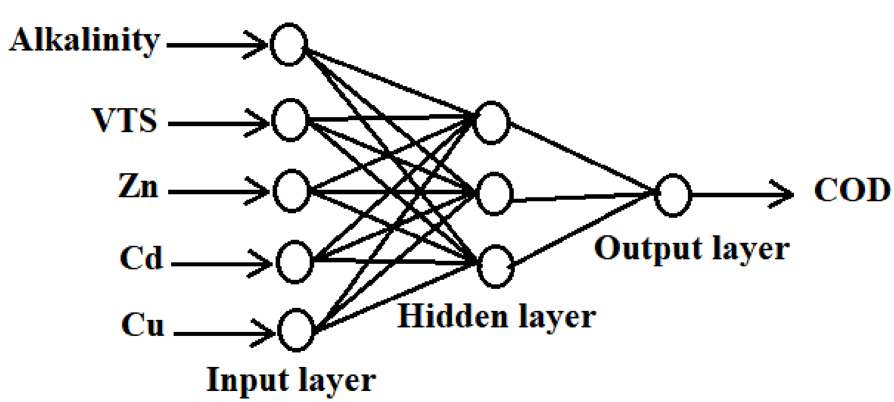

Figure 4. Neural network architecture

The data splitting (training-validation) was performed randomly, the training algorithm used was the Levenberg Marquardt algorithm and the performance used was the least squared error - MSE. In the training process of the ANN, the input vectors were normalised within the range 0 and 1, using the Equation 1, with the purpose of improving the efficiency of the algorithm and decreasing the convergence time.

x2(:,i)=(x(:,i)-min(x(:,i)))/(max(x(:,i))-min(x(:,i))) [1]

Equation 1 was programmed in a for loop with i being each of the inputs from the PCA algorithm in the data matrix.

For the output, the relation y2 = log(1+y) was used; in order to improve the distribution of the data for this variable. 1 is added to avoid log (0), when y=0. Here the variable y corresponds to the COD value. The mean square error was used as the control function, according to Equation 2, associated with the Levenberg-Marquardt learning algorithm.

sqrt(mean((yval-yvalTrue).^2)) [2]

0% of the data was used for training, 30% for validation.

The input data were normalised, initially selecting for the neural network training the input data reported in an Excel file corresponding to: pH, alkalinity, total solids (TS), total volatile solids (TVS), total nitrogen (N), ammonia nitrogen ($N-NH_3$), Fe, Mn, Zn, Cd, Cu and as output of the network the COD value. Subsequently, taking into account the principal component analysis (PCA) discussed in Grisa et al., (2010) [29], a neural network was designed using as inputs the variables most correlated with the COD value: alkalinity, total volatile solids (TVS), Zn, Cd, Cu.

Finally, a neural network is designed using as inputs the variables obtained in the PCA analysis, but using as output signal the BOD/DQO ratio, which indicates the percentage of organic matter that is biodegradable, and tries to decrease as the landfill ages.

RESULTS

The parameters that measure the biodegradability of landfill slurry are: COD and BOD while pH adjusts the microbial growth rate [32].

The variables of the cells of the sanitary landfill São Giácomo were analyzed by the exploratory method of multivariate analysis of a set of data using principal components method (PCA) [33]. The results of the PCA analysis describe the structure and interrelationships of the original variables in the phenomenon of biodegradation of organic matter from the principal components (PCs) obtained by grouping the variables that provide similar information, which are highly correlated.

The parameters considered important for the degradation of organic matter are: pH;

alkalinity; COD and; BOD. The parameters that measure biodegradability are: COD and BOD while pH adjusts the microbial growth rate [34].

Cell C1, a 1989 implementation project, is characterized by the beginning of the remediation process of the area, where there was the co-disposition of degraded waste with new waste. It has no base waterproofing system, thus allowing the infiltration of water from springs in the area and consequent dilution of percolated liquid.

The disposal of solid waste in cell C1 was completed at the end of 1992, which allows us to state that the disposed waste is in an advanced phase of the anaerobic digestion process, which is characterised by the generation of a percolated liquid with a lower organic load.

The BOD/ COD ratio, which indicates the percentage of organic matter that is biodegradable, assumes values higher than 0.4 during the acid phase and lower than or equal to 0.4 during the methanogenic phase. Applying this relationship to the data of the present study, eliminating the influence of the dilution factor, the percolated liquids in cell C1 present predominantly methanogenic characteristics (76% of the cases the BOD/ COD relationship remained below 0.4).

C3and C4 cells, initiated in 1992, in relation to BOD/ COD, present methanogenic characteristics (70% of the cases remained below 0.4) and as for the pH parameter, there are signs of stabilization, since the phase is between neutral and alkaline. The C1, C3 and C4 cells are in phase 4, range of 8 to 40 years.

Cells C6 initiated in 1997 (disposal over cells C4 and C5), C7 initiated in 1999 (disposal over C6 and C5) and C9 initiated in 2001 are in the unstable methane phase, presenting BOD/ COD values above 0.4, indicating the presence of material to be degraded. The average pH value is 6.8, which is ideal for the development of microorganisms and characterized according to Millot, (1986)[35] as a young landfill. According to (Gandolla,; Acaia & Fischer,(1995) [36], the C6, C7 and C9 cells are in the unstable methane phase (less than 10 years).

Cells C1, C3, C4, C5, C7, C8, C9 and C10 have in common the alkalinity variable that is related to the control of the acidity of the medium for the development of the biological activity of bacteria.

Using the 5-3-1 perceptron to determine the COD values and the BOD/CBD ratio, predicted values close to the expected response were obtained.

The calculated values of the correlation coefficient R, within the range 0.91 - 0.93, confirm that the degree of association between the prediction and the experimental observations of the data taken at the De Caxias Do Sul-RS landfill is reliable.

Initially, the simulation was carried out taking into account as input to the neural network all the data presented in the original Excel table for the landfill cells and as output the COD value.

Figure 5 corresponds to a representation of the validation error (RMSE: Root mean squared error) as a function of the number of neurons in the hidden layer. It can be seen that a minimum validation error of approximately 0.7 is achieved with a neural network architecture with approximately 14 neurons in the hidden layer (blue curve).

Figures 6 and 7 represent the evolution of COD as a function of the sample (each sample corresponds to a time instant), corresponding to the validation data (neural network model) and to the real data (model obtained with the measurement data).

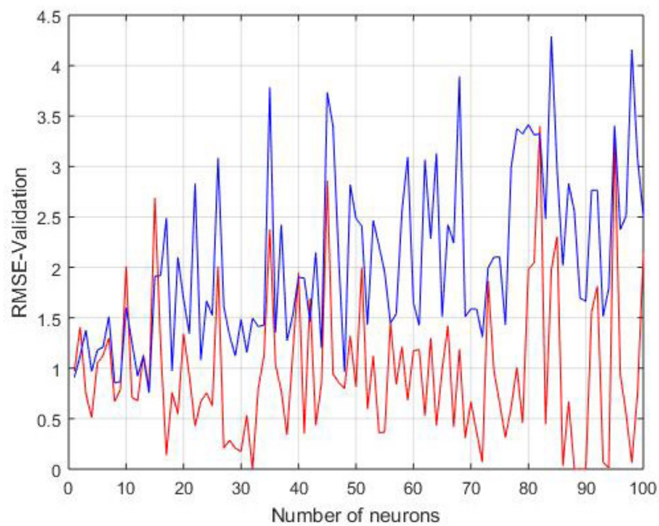

Figure 5. Training errors (red) and validation errors (blue)

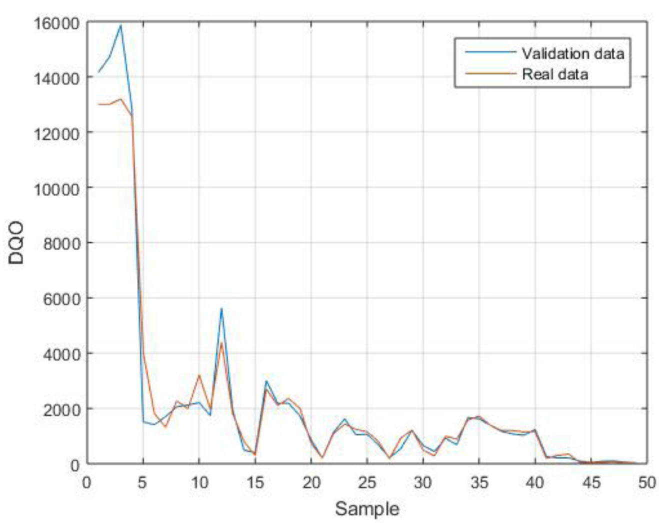

Figure 6. COD evolution as a function of samples. Neural network model (blue) - measurement data (red). 13 neurons in the hidden layer.

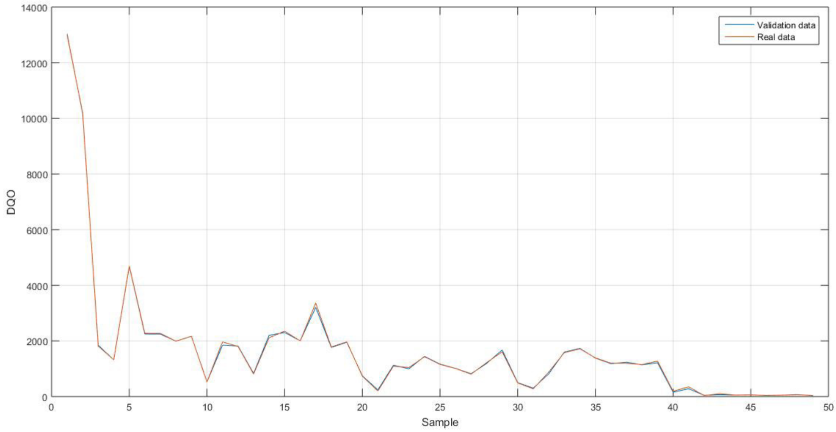

Figure 7. COD evolution as a function of samples. Neural network model (blue) - measurement data (red). 14 neurons in the hidden layer.

A better prediction of the COD signal is observed when using 14 neurons in the hidden layer (Figure 8), with a better R value (0.95). Subsequently, taking into account the inputs obtained from the analysis of the PCA algorithm, networks were designed taking into account these inputs and as outputs initially the COD value and then the BOD/CBD ratio. Figure 9 corresponds to a representation of the validation error (RMSE: Root mean squared error) as a function of the number of neurons in the hidden layer obtained for the prediction of the COD values. It can be seen that a minimum validation error of approximately 0.8 is achieved with a neural network architecture with approximately 3 neurons in the hidden layer.

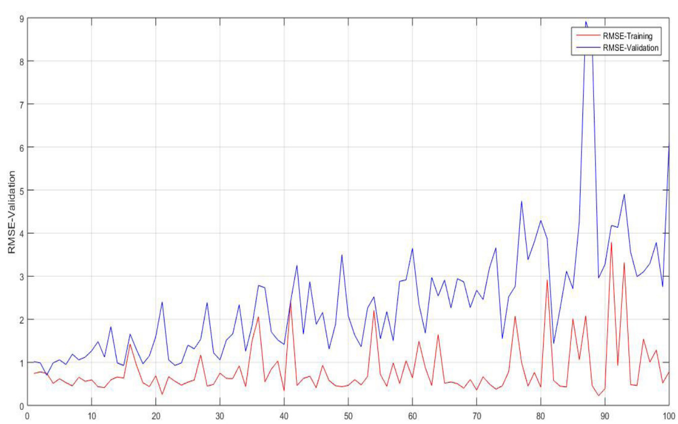

Figure 8. Training and validation errors using input data obtained from the PCA analysis

Figures 9 and 10 present the COD modelling for 3 and 6 neurons in the hidden layer respectively.

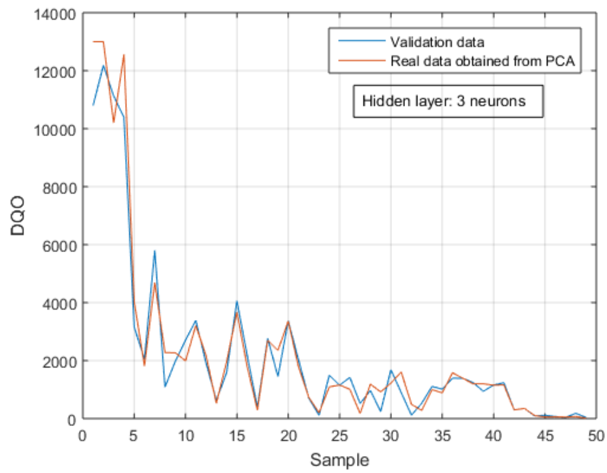

Figure 9. Evolution of COD as a function of samples. Neural network model (blue) - measurement data obtained from the PCA (red). 3 neurons in the hidden layer.

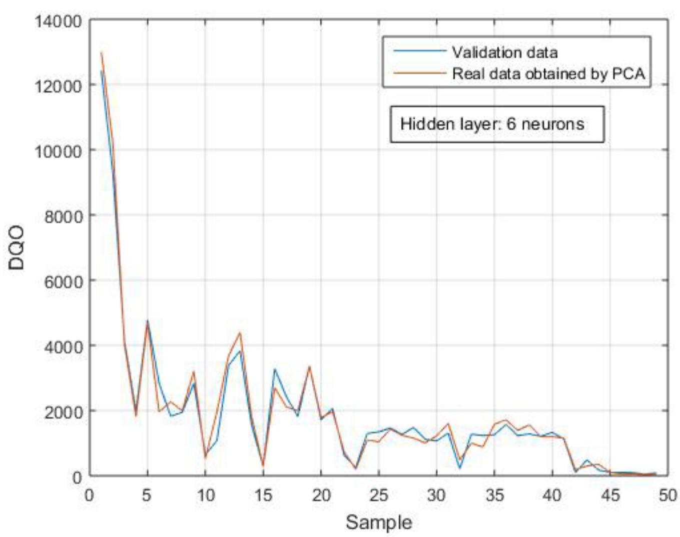

Figure 10. Evolution of COD as a function of samples. Neural network model (blue) - measurement data obtained from PCA (red). 6 neurons in the hidden layer.

A better fit of the COD signal is observed when using 6 neurons in the hidden layer (Figure 11), with a better R value (0.93).

Finally, results are presented for the prediction of the BOD/COD value, a variable that shows the biodegradability and that at some point can indicate the amount of microorganisms available for degradation. Figure 12 corresponds to a representation of the validation error (RMSE: Root mean squared error) as a function of the number of neurons in the hidden layer obtained for the prediction of the BOD/CBD values. It can be seen that a minimum validation error of approximately 0.16 is achieved with a neural network architecture with approximately 2 neurons in the hidden layer.

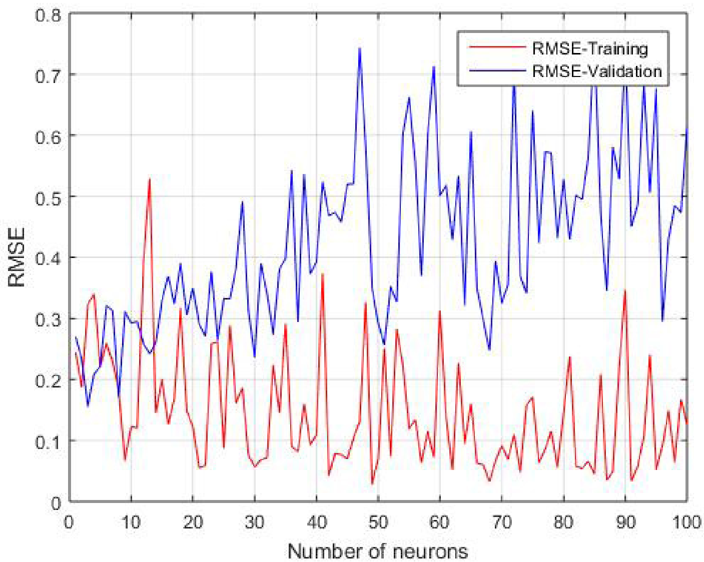

Figure 11. Training and validation errors for the BOD/COD ratio using input data obtained from the PCA analysis.

Figures 12 and 13 show the modelling of the BOD/COD ratio for 6 and 10 neurons in the hidden layer respectively and using measurement data obtained from principal component analysis (PCA). A better approximation (prediction) of the model is observed when using10 neurons in the hidden layer, reaching an R-value of 0.96.

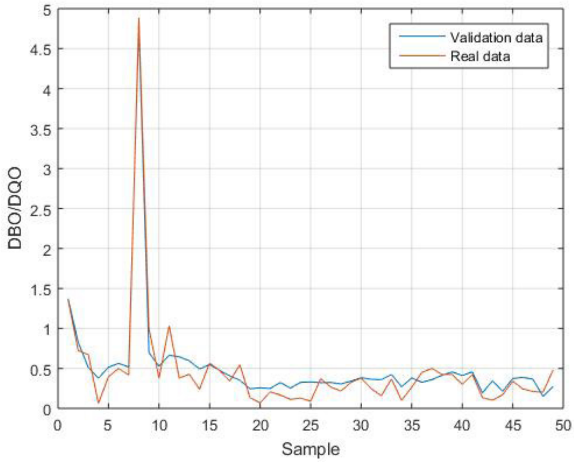

Figure 12. Evolution of the BOD/COD ratio as a function of the samples. Neural network model (blue) - measurement data obtained from the PCA (red). 6 neurons in the hidden layer.

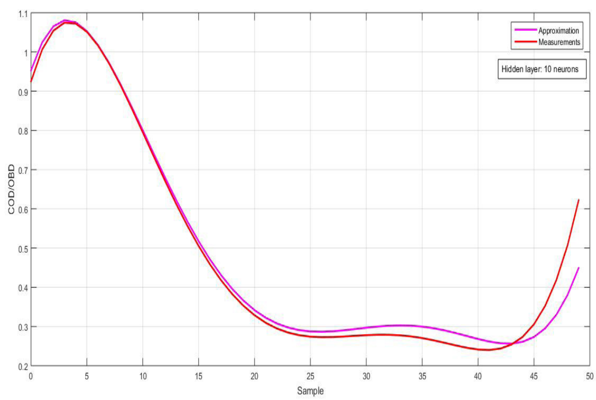

Figure 13. Polynomial approximation of the model obtained from the neural network designed with 10 neurons in the hidden layer, for the BOD/C COD ratio as a function of the samples.

The polynomial model predicting the evolution of the BOD/CBD ratio values is given by:

Polinomio: $COD/OBD=0.0010x - 0.0195\, x^2 + 0.0997x^3 + 0.9249$ [3]

CONCLUSION

The entire physical, chemical and biological process that takes place inside a sanitary landfill and that results in the degradation of the organic components of the landfilled solid waste mass can be monitored through the collection of data, which serve as an indication of the decomposition state of the landfilled mass and the transformations that take place there.

The landfill can be considered a biological reactor, where suitable conditions are offered for the growth of bacteria responsible for the biodegradation of matter.

The analysis of the biodegradability of organic matter is of fundamental importance in studies on the abiotic factors that act in the ecosystem of the landfill. This analysis has the potential to demonstrate the anaerobic microbial activity, and the slurry from cells C1, C3 and C4 present predominantly methanogenic characteristics (in 70% of the cases the BOD/D COD remained below 0.4).

Cells C5, C6, C7, C9 and C10, cells with a shorter life span, are in the unstable methane phase (BOD/ COD >0.4), and the overlapping of the stabilization phases can be observed over time in the degradation process due to the heterogeneity of the material disposed of in the landfill.

The alkalinity, is related to the biological activity in relation to time.

An ANN was proposed for the simulation of the Caxias Do Sul-RS landfill system, capable of predicting COD and BOD/DQO values, minimising the error rates in the response. The optimised network structure consisted of a 5-3-1 multilayer perceptron, and 5-6-1 with logistic sigmoidal transfer function in the hidden layer and linear activation in the output layer, trained with the Levenberg-Marquardt algorithm.

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