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Prediction of Fecal Coliform Removal on Intermittent Media Infiltration by Varying Soil Content Based on FREN

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ABSTRACT: Current global water shortage and water pollution problem are some of the crucial issues in the world, especially in the arid zones. The wastewater reuse was investigated the efficiency of fecal coliform (FC) removal using the intermittent media infiltration (IMI) with varying soil content and natural porous media (sand, zeolite, vermicompost and charcoal), and its prediction was introduced by applying fuzzy rules emulated network (FREN). The physicochemical properties of the porous media were determined and the mechanisms of FC removal were discussed as the effect of fine particle size and increasing of ion charges. The compositions of soil and porous media at a ratio of 75/25, respectively, gave the best performance of FC reduction. The network architecture was constructed by the knowledge regarding to the relation between soil content (25, 50 and 75) and FC removal, and was introduced IF-THEN rules for FREN construction as their predicted curves at 20 iterations. The learning rate η was selected as 5 following the main theorem and the convergence of FREN prediction could be guaranteed. The results showed that the prediction methodology gave a good performance to forecast FC removal with the range of soil content (20-80%) and several compositions of porous media in IMI system.

Key words: Bacterial removal, Fuzzy logic, Infiltration, Porous media, Prediction

INTRODUCTION

According to the UNESCO (2009), water consumption in agriculture is by far the main user and expands rapidly due to population growth, rapid economic development and impact of climate change. Mexico is considered to be one of the ten largest water users in the world (CONAGUA, 2010). Therefore water reclamation and reuse is crucial to sustain water resource management, especially for agricultural irrigation.

However, one of the concerns to its application is related to hygienically safe for human health and the environment, due to the potential transmission of infection diseases of waterborne microorganisms (Salgot *et al.*, 2006). The observation of fecal coliform bacteria (FC) in wastewater is evidence of fecal contamination and possibility of having the pathogenic risks. FC is always present in the intestinal tract of warm-blooded animals and is the most used as biological indicator in wastewater reuse (Huertas *et al.*, 2008). Thus, the Mexican regulations NOM-001-ECOL (1996) limit the FC less than 1000 MPN/100 ml in the wastewater reuse for unrestricted irrigation, which is the same as the world health organization (WHO) guideline.

At present, technologies of wastewater reuse have developed dramatically for beneficial uses. It is important to consider cost-effective treatment system, standards, human health, environmental impact and reuse applications (Salgot, 2008). The infiltration-percolation process is the most effective filtration process that has highest removal percentages for physical and chemical parameters and improves microbiological quality due to physical processes, chemical reactions and biological transformations (Ausland *et al.*, 2002; Mosaddeghi *et al.*, 2009; Stevik *et al.*, 2004). Therefore, the intermittent media infiltration (IMI) was proposed in this research as an alternative for applying wastewater reuse into irrigation. Natural porous media (sand, zeolite, vermicompost and charcoal) have been widely use for

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water and wastewater treatment. The media mixtures of soil were prepared to investigate the quality of FC removal in reuse of domestic wastewater.

FC was considered as a colloid contaminated in wastewater but it differs from colloids due to the presence of cell structure (Scheuerman *et al.*, 1998). The mechanical removal of FC bacteria achieved by IMI with porous media during the wastewater passed through them is accomplished in two steps: transport and attachment. Transport mechanisms move a particle into and through a pore of filter media so it comes very close to its surface or existing deposits. Then attachment associate to remove the particle by contact with media surface or previously deposited solids by one or more phenomenon which are: straining, sedimentation, impaction, interception, adhesion, flocculation, chemical and physical adsorption and biological growth (Asano *et al.*, 2007). Physical and chemical forces between suspended particles promote the removal of particles from suspension (Zamani and Maini, 2009). The other mechanisms (interception, impaction and adhesion) participate with straining where smaller particle can be removed through the filtration mechanism by interception. The main transport and attachment mechanisms for FC removal are straining and physical adsorption by surface forces (van der Waals and electrostatic forces), respectively (Harvey and Garabedian, 1991).

Prediction methodologies are important for wastewater treatment in this case of FC removal. Artificial intelligent neural networks (ANN) have been successfully implemented to predict coliforms and escherichia coli on fruits and leaves (Keeratipibul *et al.*, 2011) and the concentration of BOD and COD of wastewater (Rene and Saidutta, 2008). ANN has ability to adjust its parameters according to the target signal obtained by the experimental results. Unfortunately, this ability cannot include human knowledge due to the system properties especially with IMI treatment. There is a relation between content of soil and porous media in the column for FC reduction (Khamkure *et al.*, 2011), that can be introduced by IF-THEN rules like fuzzy logic systems. The study of Treesatayapun and Uatrongjit (2005) represents a significant advantage of Fuzzy rules emulated networks (FREN) thus the prediction algorithm is developed by using FREN based on the IF-THEN rules to follow the knowledge of IMI system. Furthermore, the convergence analysis can be guaranteed by the main theorem with the parameter selection for learning algorithm.

Therefore, the objectives of this study were to evaluate the efficiency of FC removal by IMI, and to predict the FC removal according to IMI system with varying composited natural porous media and soil content by applying FREN.

MATERIALS & METHODS

In this research, 12 IMI columns were studied in different proportion of mixed porous media of 12 cm diameter by 30 cm height. The columns were prepared following the method described by Khamkure *et al.* (2011) and were set up in the laboratory at the Department of Soil Science in the Universidad Autónoma Agraria Antonio Narro located in an arid region to the south of Saltillo city, Coahuila, Mexico. Soil, sand and vermicompost were obtained from this location and others were local materials. Their compositions were prepared by mixing soils with different combination ratios (v/v) of other porous media as soil/sand (Ss), soil/zeolite (Sz), soil/vermicompost (Sv) and soil/charcoal (Sc). All of studied porous media were used without any additional pretreatment. Soil was added according to the proportion established in percentages of 25, 50 and 75 as IMI column number 1 to 3, respectively (Oladoja and Ademoroti, 2006). The porous media were analyzed as soils according to the method of Black *et al.* (1965a, 1965b) as summarized in Table 1. The soil texture was classified as loam but other media, except vermicompost, were classified as percentage of particle size. The saturated hydraulic conductivity (Ks) was measured for each porous media to evaluate the speed of water movement throughout the columns.

The particle size distribution (PSD) was applied because it is an important parameter for FC removal that give a the better understanding of filter performance (Ausland et al., 2002). Scanning electron microscopy (SEM, model JSM-8440; JEOL) was also carried out and cooperated by energy dispersive X-ray (EDX) to indicate the elemental analysis or chemical characterization of an interesting area of media samples. Furthermore, the porous media were characterized by X-ray diffraction (XRD, model D550; Bruker) a powder diffractometer with a graphite monochromator to identify their mineralogical and morphological characterizations.

Wastewater used in this study was from a municipal wastewater treatment plant (MWWTP) located to the South of Saltillo, Coahuila, Mexico. Raw wastewater and unchlorinated treated wastewater were collected from MWWTP twice a week and analyzed according to APHA (1998) and their FC averages were 199.2×10^3 and 30.0×10^3 MPN/100 ml, respectively. The mean effluent concentration for other parameters (TSS, BOD, Cu, Fe, Pb and Zn) fulfilled the Mexican regulations.

Table 1. Physical and chemical properties of the different porous media

Porous media	**Particle size (%)**			**pH**	**EC**[a]	**OM**[b]	**N**	CO_3^{2-}	**Ks**[c]
	>2 mm	0.02-0.002 mm	<0.002 mm		(dS/m)	(%)	(%)	(%)	(cm/h)
Soil	42	34	24	7.6	1.0	1.87	0.09	23.37	0.16
Sand	60	28	12	7.5	0.7	0.63	0.03	20.21	1.38
Zeolite	64	26	10	6.3	0.8	0.95	0.05	8.82	1.30
Vermicompost	-[d]	-	-	7.4	2.1	32.98	1.65	34.52	12.25
Charcoal	84	16	0	8.0	3.0	-	-	-	2.98

[a] EC=Electrical conductivity; [b] OM=Organic matter; [c] Ks=Saturated hydraulic conductivity; [d] not measured

The unchlorinated treated municipal wastewater was introduced into each IMI column, in a volume of 500 ml daily and passes through by gravity flow. Effluent samples of each column were collected manually in a 100 ml sterile bag (Whirl-Pak) and analyzed for chemical and biological parameters in the laboratory every week for four weeks. FC bacteria were analyzed by the most probable number (MPN) technique. Five 1ml aliquots of each three dilutions were examined by the A-1 medium (Becton, Dickinson and company, USA) accepted by the USEPA; this medium can be used in a single-step procedure (Standridge et al., 1981). The results of FC reduction percentage were statistically compared between treatments for each IMI column by one-way analysis of variance (ANOVA) and Tukey's HSD (Honestly Significant Difference) test at significance levels of $p < 0.05$. Statistical analyses were carried out using R statistic version 2.14.1 (R development Core Team, 2011). Regression analysis was applied to measure the reliability of a linear relation between the percentage of soil filling and FC reduction according to the functional model described by Koivunen *et al.* (2003).

The bacterial transportation in the porous media can be described by filtration theory for understanding the mechanisms of FC removal (Harvey and Garabedian, 1991). The colloid filtration theory was described Brown and Jaffe (2001) as follows:
Assuming that bacteria are removed at a constant rate along a flow path (x) in a porous media by

$$\frac{\partial C}{\partial x} = -\lambda C$$

where λ is the filter coefficient and C is colloid or bacterial concentration existing the filter column.
Integration along a column of length L, C can be obtained as

$$C = C_0 \exp(-\lambda L)$$

where C_0 is the initial colloid concentration (inlet). The parameter λ is dependent on the porous media and can be determined from the experiment.
During the transportation of bacteria on the column, the collector efficiency (η_c) can describes the approach of the bacteria to the surface of porous media (Brown and Jaffe, 2001) and is written as

$$\eta_c = 4A_S^{1/3} N_{Pe}^{-2/3} + A_S N_{vdW}^{1/8} N_R^{15/8}$$
$$+ 0.00338 A_S N_G^{1.2} N_R^{-0.4}$$

where A_S represents the influence of neighboring collector on the flow, and N_{pe}, N_{vdW}, N_R and N_G are dimensionless numbers accounting for diffusion, van der Waals, interception, and sedimentation. This equation can describe the phenomenon for FC removal as discussed above.

Electrostatic interactions play an important role in bacterial attachment to their porous surfaces and can be explained by the classical Derjaguin, Landau, Verwey and Overbeek (DLVO) theory, which consider the balance between the attractive van der Waals and the repulsive electrostatic interactions with bacterial and solid surfaces (Adamczyk and Weronski, 1999; Jucker *et al.*, 1996). Moreover, the DLVO theory is based on concept of diffusion double layer (DDL), which is a layer of counterions that forms around a charge surface, is given by the Debeye length (K^{-1}). The DDL thickness as a function of ionic strength (*I*) at 20 °C of aqueous system, it can be written as:

$$\kappa^{-1} = \frac{0.301}{\sqrt{I}}(nm)$$

The Debeye length has the inversely relation with the ionic strength. In the case of bacterial transportation, ionic strength increases and thus bacterial attachment increases and transport decreases (Jucker *et al.*, 1996; Brown and Jaffe, 2001).

FREN is an automatic self-adjustable network which can include the human knowledge about the system and material properties (Treesatayapun *et al.*, 2005; Treesatayapun, 2009). In this application, the percentages of each composition are assigned to be the inputs of FREN and log removal is denoted as the network's output. Let consider the relation between log removal with the percentage of soil, we desire to use this percentage as the first input of FREN and the second input is type of other materials (sand, zeolite, vermicompost and charcoal).

According to this implementation, these IF-THEN rules are firstly defined as follows:

"For compositions Ss or Sz or Sv or Sc"

1.IF %Soil is small AND another material is Sand or Zeolite or Vermicompost or Charcoal THEN log removal is Low,

2.IF %Soil is middle AND another material is Sand or Zeolite or Vermicompost or Charcoal THEN log removal is Medium,

3.IF %Soil is massive AND another material is Sand or Zeolite or Vermicompost or Charcoal THEN log removal is High.

Thus, the network configuration can be illustrated as in Fig. 1.

In Fig. 1, according to these defined rules, "S", "m" and "M" denote as "small", "middle" and "massive", respectively and LCs are linear consequence nodes which can be tuned theirs parameters inside by the learning algorithm (Treesatayapun, 2010). Those membership functions can be designed in Fig. 2, according to the knowledge based on the level of soil percentage which can take the effect with FC removal together with another composition.

The back propagation technique is performed for off-line tuning parameters. Let the log removal value "*y*(*k*)" at "*k*" iteration be calculated by

$$y(k) = \sum LC_a(k)\mu_a(k) = \beta^T F,$$

when $\beta = [\beta_S, \beta_m, \beta_M]^T$ and $F = [f_S, f_n, f_M]^T$ where β_S denotes as the linear parameter that needed to be tuned at the membership grade f_S and so on.

Those adjustable parameters β are considered as the time varying as $\beta(k)$ which can be tuned by the following algorithm. Let consider the

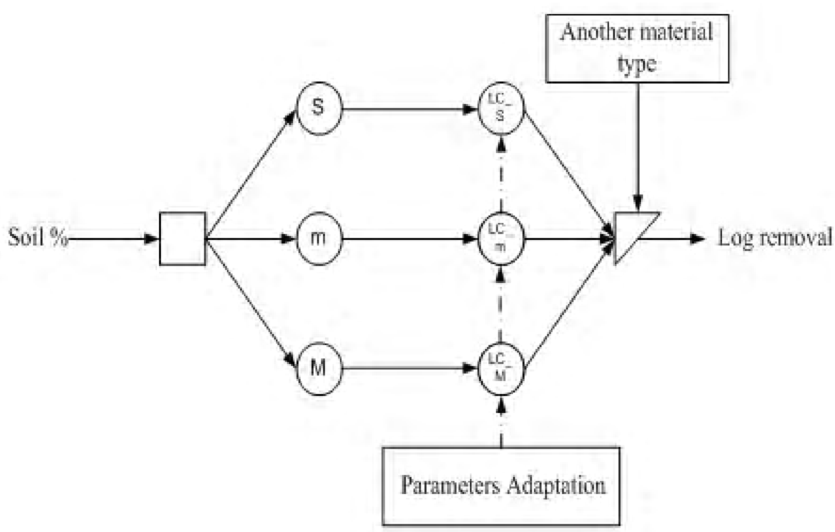

Fig. 1. FREN configuration for FC removal

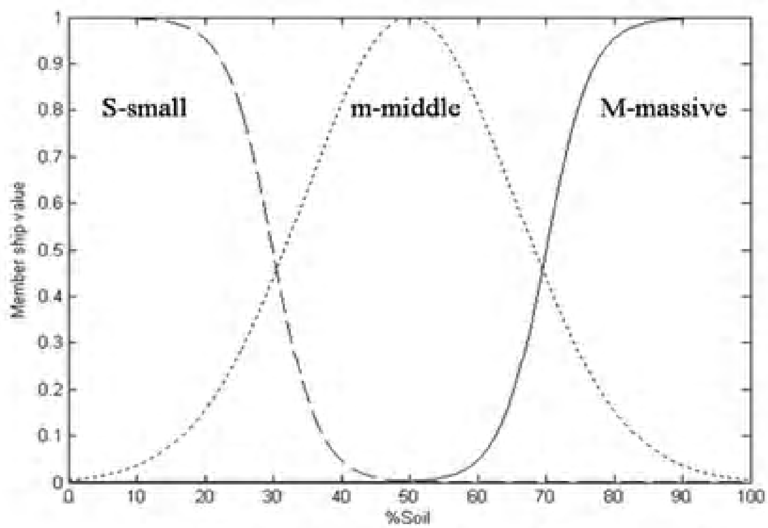

Fig. 2. Membership functions of percentage of soil

target point or setting log removal as $y_p(k)$ thus the error function can be obtained as

$$e(k) = y_p(k) - y(k)$$

where $y_p(k)$ is the desired response and $y(k)$ is the prediction output of FREN at time index k, respectively. The system configuration can be briefly represented in Fig. 3.

The proposed algorithm needs only "Soil%" as the input signal during the computation process. This system can be designed by using only one FREN model to predict "FC log removal". The learning mechanism can tune parameters inside FREN with difference natural filter materials. The common membership functions given in Fig. 2 have the ability to predict the FC removal effect on different filter media types in each IMI

It is desired to adjust $\beta(k)$ such that $e(k)$ becomes zero. The value of parameter is updated at each time k by

$$\beta(k) = \beta(k-1) + \alpha(k)\gamma(k)$$

when

$$\gamma(k) = \frac{F(k)}{\|F(k)\|^2}\left(1 - \eta\frac{|e(k-1)|}{|\alpha(k)|+\epsilon}\right)$$

and

$$\alpha(k) = y_p(k) - \beta(k-1)^T F(k)$$

where η and $\epsilon > 0$ are predefined constants.
The convergence property of FREN prediction can be demonstrated by the following theorem with that parameter adaptation for $\beta(k)$.

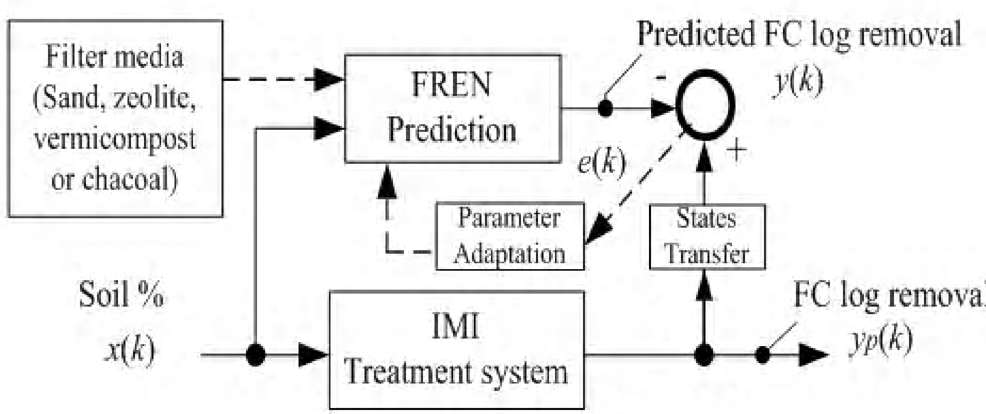

Fig. 3. Block diagram of FREN prediction for IMI treatment system

Theorem : If the error $e(k)$ is finite for all k and all parameters are adjusted according to the proposed learning algorithm with $\eta < 1$, then $\lim_{k\to\infty} |e(k)| = 0$.

Proof : The output of FREN $y(k)$ is calculated by,

$$y(k) = \beta(k)^T F(k)$$

Substitute in to the error equation, we obtain

$$e(k) = y_p(k) - y(k),$$
$$= y_p(k) - \beta(k)^T F(k) = y_p(k) - \left[\beta(k-1)^T + \alpha(k)\gamma^T(k)\right] F(k),$$
$$= y_p(k) - \beta(k-1)^T F(k) - \alpha(k)\gamma(k)^T F(k).$$

Recall $\alpha(k) = y_p(k) - \beta(k-1)^T F(k)$ again, we have

$$e(k) = \alpha(k) - \alpha(k)\gamma^T(k)F(k) = \alpha(k)$$
$$- \alpha(k)\frac{F^T(k)F(k)}{||F(k)||^2}\left(1 - \eta\frac{|e(k-1)|}{|\alpha(k)|+\epsilon}\right),$$
$$= \eta\frac{|e(k-1)|}{|\alpha(k)|+\epsilon}\alpha(k).$$

By using the absolute, it can be rewritten as

$$|e(k)| = |\eta|\frac{|\alpha(k)|}{|\alpha(k)|+\epsilon}|e(k-1)|$$

Since $|\eta| < 1,\ |\alpha(k)| < |\alpha(k)| + \epsilon$ and $e(k)$ is finite for all k, thus, we obtain $\lim_{k\to\infty} |e(k)| = 0$. Moreover, the learning rate parameter η can be determined to guarantee the convergence with the following.

Let us define Lyapunov function $V(k)$ as

$$V(k) = e^2(k)$$

Thus the change of Lyapunov function can be obtained by

$$\Delta V(k) = V(k) - V(k-1),$$
$$= e^2(k) - e^2(k-1),$$
$$= \frac{\eta^2\alpha^2(k)}{(|\alpha(k)|+\epsilon)^2}e^2(k-1) - e^2(k-1),$$
$$= \left[\frac{\eta^2\alpha^2(k)}{(|\alpha(k)|+\epsilon)^2} - 1\right]e^2(k-1).$$

According to the decreasing of Lyapunov function for , this following argument must be obtained as

$$\frac{\eta^2\alpha^2(k)}{(|\alpha(k)|+\epsilon)^2} < 1$$

or

$$|\eta| < \frac{|\alpha(k)| + \epsilon}{|\alpha(k)|}$$

This statement can be acquired until $|\eta| < 1$ or in such a case $0 < \eta < 1$.

This performance proof guarantees the convergence of the FREN prediction and does not have the relation with filter media materials. Furthermore, the experiment results will confirm this theorem and the prediction property with difference filter media by using only one FREN prediction model, which will be discussed in the next section.

RESULTS & DISCUSSION

The physical and chemical parameters (pH, conductivity, TSS, TS and heavy metals) of the effluents were lower than the values established in Mexican regulations.The FC reductions of effluents had a great variation because the FC concentrations in the influent were highly variable during the sampling periods. The FC log removals of effluents were in a range of 0.35-2.46 as presented in Table 2. The results show that the composition of soil and porous media at a ratio of 75/25 (IMI no.3), respectively, gave the best performance of the FC removal for all of the IMI columns in accordance with the results of a previous study (Oladoja and Ademoroti, 2006). The Sc composition performed the highest FC removal efficiency (2.19-2.46 log) among other 3 compositions of Ss, Sz and Sv. Regarding to IMI-Sc (1-3) columns, their FC were reduced from 4.48 to 2.12 log unit and the effluent FC concentrations were lower than the

Table 2. FC (log MPN/100ml; mean ± standard deviation) of IMI influent and effluent and FC log removal

Parameter		Influent	Effluent											
			Ss1[a]	Ss2	Ss3	Sz1[b]	Sz2	Sz3	Sv1[c]	Sv2	Sv3	Sc1[d]	Sc2	Sc3
FC	Mean	4.48	3.80	3.39	2.88	2.41	3.03	3.58	4.02	3.87	3.26	2.15	2.31	2.12
	SD[e]	4.05	0.51	0.84	0.65	1.94	1.02	0.09	0.54	0.46	0.09	0.28	0.38	0.26
FC log removal	Mean	-[f]	0.35	0.56	1.25	0.60	0.64	0.75	0.35	0.53	1.21	2.19	2.20	2.46
	SD	-	0.43	0.97	0.60	2.06	0.91	0.20	0.55	0.47	0.11	0.40	0.39	0.29

[a] Ss = soil/sand; [b] Sz = soil/zeolite; [c] Sv =soil/vermicompost; [d] Sc = soil/charcoal; [e] Standard Deviation; [f] not calculated

limitation (3 log unit) that met these criteria during the monitoring periods.

Each composition of IMI (Ss, Sz, Sv and Sc) at different soil filling percentage (25, 50 and 75%), were no different in the treatment of effects on FC reduction, only IMI-Sc was statistically significant from IMI-Ss1 and IMI-Sv1 ($p < 0.05$), as illustrated in Fig. 4. However it was observed that when percent of soil increased (from 25-75%), the FC reduction percentage also increased, especially in the composition of Ss and Sv, their FC reductions were increased about 40% (Fig. 4). As a result of the increase of the soil filling percentage, it had an influence on porous media (sand and vermicompost) due to the association of clay particle to reduce large pore of these porous media and to expand the retention time in the IMI column. These results agreed with those reported by Jamieson *et al.* (2002) for FC transport in a finer grained soil.

The regression analysis was applied to measure the reliability of the linear relationship between the percentage of soil filling in each IMI columns and FC reduction as shown in Table 3. Their correlation coefficients of Ss, Sv and Sz indicated a clearly significant relationship (R^2 = 0.99, 0.98 and 0.95, respectively), but relationship lower coefficient was shown for Sc (R^2 = 0.78). Table 1 shows that Ks of vermicompost had the highest ability to transmit the water than other porous media. Because of porosity and permeability, vermicompost contained large pore space and particle size, and had the lowest residence time in the IMI column than the other media. It was observed that Ks decreased when clay content in filter media increased ($Ks_{soil} < Ks_{sand} < Ks_{zeolite}$). When the IMI column had high Ks and consequently, the residence time of each column was low because it directly affected the relationship with their soil structure and porosity and small microorganism removal (Gonçalves *et al.*, 2007). In contrast, charcoal seemed to work well as filter media without composed of soil because their relations when soil mixing was less significant. Although the fine particle was the most important mechanism of FC removal, charcoal was largely pure carbon and composed of roughly porous structure which was a highly efficient media for adsorption due to more surface area available for attachment (Scheuerman *et al.*, 1998). Moreover, their surface morphology could be identified that their sizing of micro pores was appropriated and more easily attached the bacteria onto their surface (Park *et al.*, 2003).

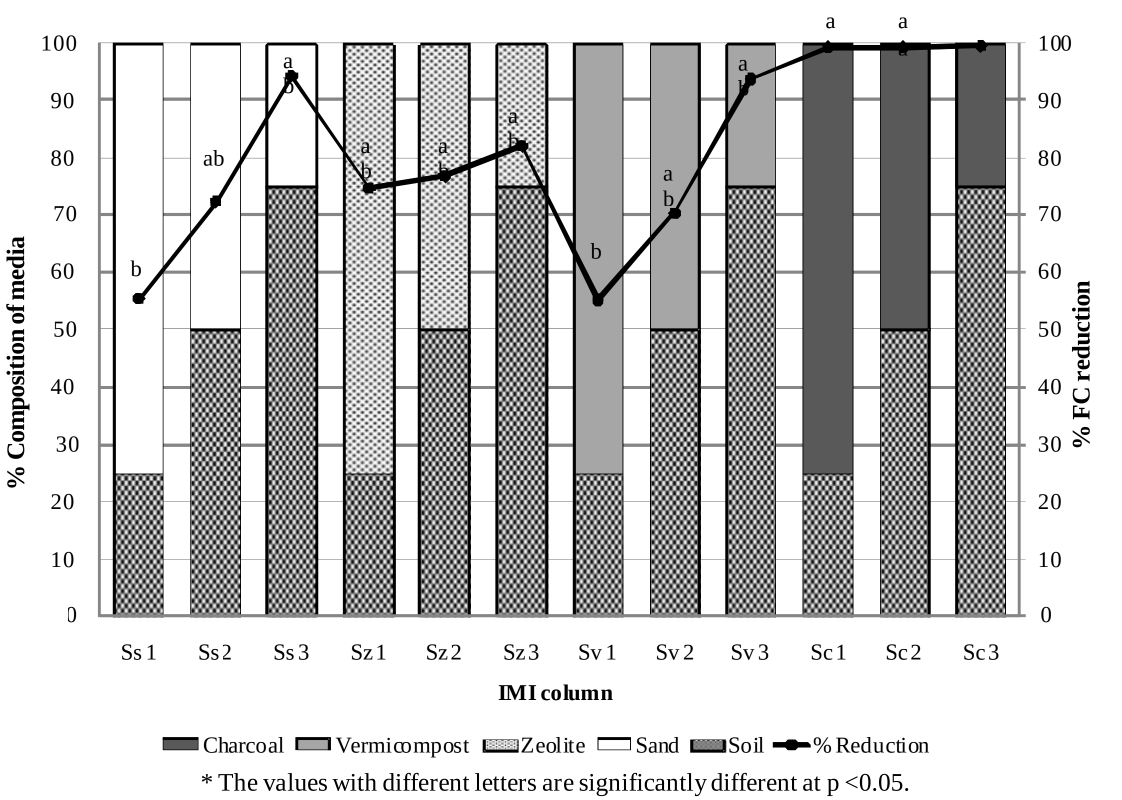

Fig. 4. The percentage of FC reduction and composition of Ss (soil/sand), Sz (soil/zeolite), Sv (soil/ vermicompost) and Sc (soil/charcoal) in IMI columns

Table 3. Linear regression between the percentage of FC reduction (y) and soil filling (x); Ss (soil/sand), Sz (soil/zeolite), Sv (soil/vermicompost) and Sc (soil/charcoal)

IMI	Regression equation	R^2
Ss	y = 0.7772x + 35.273	0.99
Sz	y = 0.1506x + 70.457	0.95
Sv	y = 0.7715x + 34.650	0.99
Sc	y = 0.0059x + 99.162	0.78

The average grain size at 50% finer particle (d_{50}) of soil, sand, zeolite, vermicompost and charcoal were 0.20, 0.12, 0.20, 0.32 and 0.85 mm, respectively. On this study, texture analysis of porous media defined the finest particle size as soil and PSD defined the coarsest particle as charcoal. The effect of soil filling into IMI columns can be explained that soil contained high percentage of clay (Table 1), which considered as colloidal particles. Their surface area and surface charge of soil are the most reactivity and surface area is a direct result of particle size and shape (Bohn *et al.*, 2001). Not only the finest particle sizes give the highest surface area but also a great potential for adsorption. To evaluate clay content influence on filtration, XRD was applied for identifying mineral compounds in porous media (Oladoja and Ademoroti, 2006) and their powder diffraction patterns are illustrated in Fig. 5. It can be observed that the most abundant primary minerals in soil and sand were quartz (SiO_2) (Fig. 5a, b) and similar contained crystalline mineral components at 70%. Composition of soil was considered as mineral and obtained as quartz (32.94%), calcite (10.80%), albite low (11.16%), illite (12.03%), merlionite (2.17%) and amorphous material (30.90%). Calcite ($CaCO_3$) was the most carbonate mineral of soil and sand at 10-13% which is common in semiarid and arid region soil. Moreover, this soil has high concentrations of $CaCO_3$ and has high ability of Ca^{2+} for exchangeable capacity, which affected to soil filling in other composition of IMI columns and their FC reductions also. It has been found that natural zeolite (Fig. 5c) composed most of clinoptilolite (87%) in crystal phase, is one of most minerals found in Mexico. Natural zeolite normally includes another crystalline phases and a significant amount of an amorphous phase. 73% of charcoal was in amorphous phase thus charcoal has the highest surface area and low degrees of crystallinity than other media.

Regarding the negative charge of bacteria cell and the negative charge of media surface (clay particles), it can be described that FC removal is account for the bacteria interactions with porous media. They can be attached each other by electrostatic forces of positive charge around the edge of media surface and this could be consequence of bacterial removal in the IMI columns also (Van Loosdrecht *et al.*, 1989). This behavior can be explained in term of the element composition which detected by EDX (Fig. 6) following the function of K^{-1} as mentioned above. It was found that the principal elements of porous media were C, O, Al, Si, K, Ca, Mg and Fe. The chemical composition percentage of soil (%wt) was Ca (25.96%), O (21.36%), Si (16.43%), Fe (11.30%), P (9.41%), Al (6.08%), Mg (3.11%) and K (2.30%). Not only the presence of cations (Ca^{2+}, K^+ and Mg^{2+}) can associate the adsorption of FC to the solid surface but the metallic cation in solution (Fe^{3+}) can enhance bacterial adsorption also (Stevik *et al.*, 2004). Their cations increased more positive charges in the electrolyte solution; at the same time, it was significantly reduced their thickness of double layers at the media surface. It meant that ionic strength increased, Debeye length decreased and affected to decrease the capacity of bacterial transportation then bacterial attachment increased therefore it can obtain high quality of the effluent with lower FC contamination. According to the highest content of Ca in soil, FC can be efficiently removed when soil filling percentage increased.

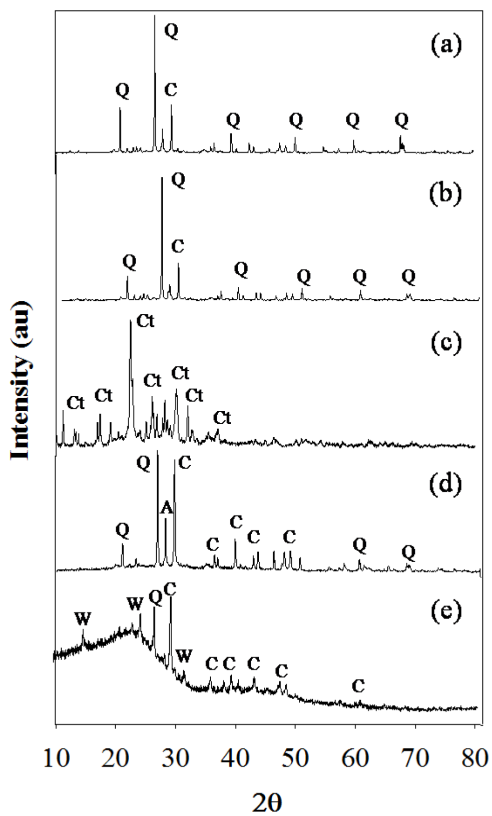

Fig. 5. XRD analysis of porous media (a) soil; (b) sand; (c) zeolite; (d) vermicompost (e) charcoal. Calcite (C), quartz (Q), clinoptilolite (Ct), albite (A), and whewellite (W).

Therefore the physicochemical process by adsorption can occurred at the surface reaction between bacteria and clays. The biological process can be explained in terms of the microbial attachment and growth at the porous media to retain the bacteria in the IMI columns. In the other hand, the solids removal efficiency is affected by the changes in the pores due to deposit, which are both time and depth dependant. Then biological clogging in the porous media was found from operated IMI column since 4 weeks ago due to the excessive growth of bacteria (Kim *et al*., 2010), which should be recommended for further research.

In this application, levels of soil percentage (25, 50 and 75%) were selected as the learning points to FREN. The conventional back propagation was realized to tune those linear parameters inside LC nodes. According to those testing points, the prediction curves for Ss-composition could be illustrated in Fig. 7 with 10 and 20-iteration, respectively.

According to the above results, we selected to test the FREN prediction at 20 iterations for the rest of material compositions. The prediction curves can be illustrated in Fig. 8 for Sz, Sv and Sc, respectively.

In those experimental results, the learning rate η has been selected to follow the main theorem as $\eta = 0.5$. With this setting, the convergence of FREN prediction can be guaranteed. Refer to the main theorem again, another parameter ϵ doesn't play important role for the convergence. The propose of this parameter is to prevent the division by zero when $\alpha(k) = 0$. In this study, $\epsilon = 0.02$ was selected when $|\alpha(k)| < 0.05$. Furthermore, the better performance can be obtained with the increasing of iteration number.

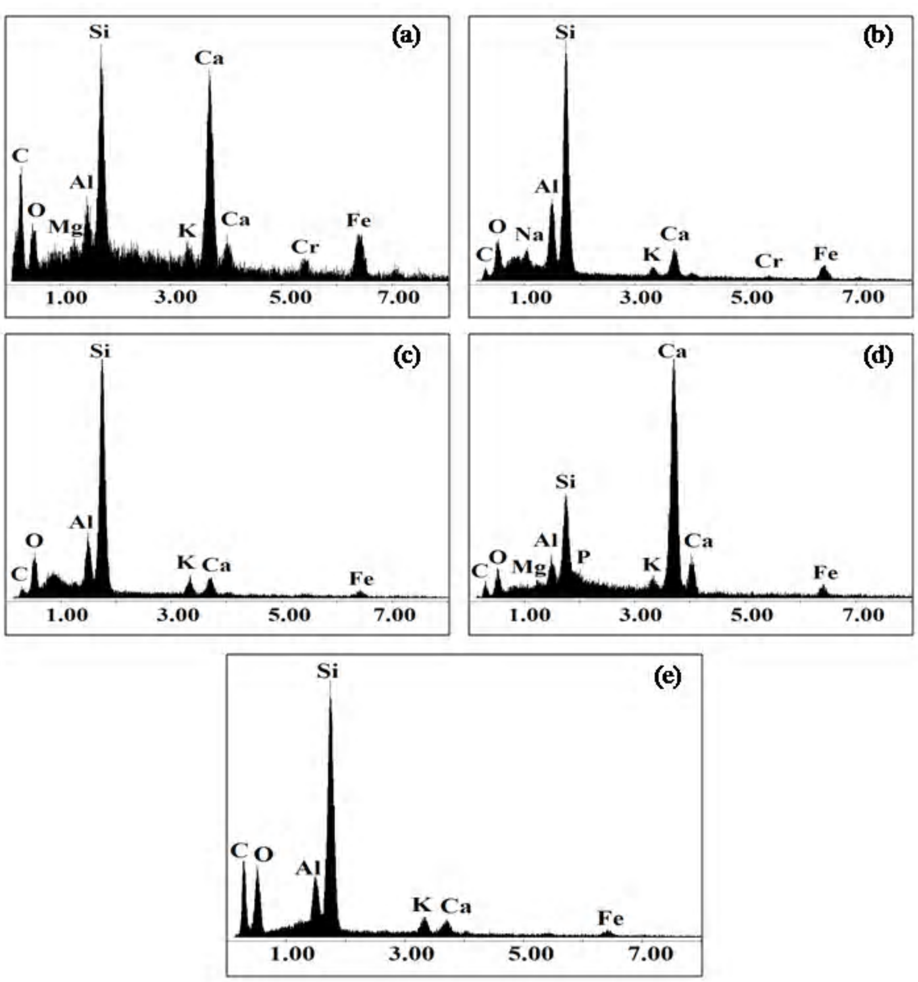

Fig. 6. EDX images of porous media (a) soil; (b) sand; (c) zeolite; (d) vermicompost (e) charcoal

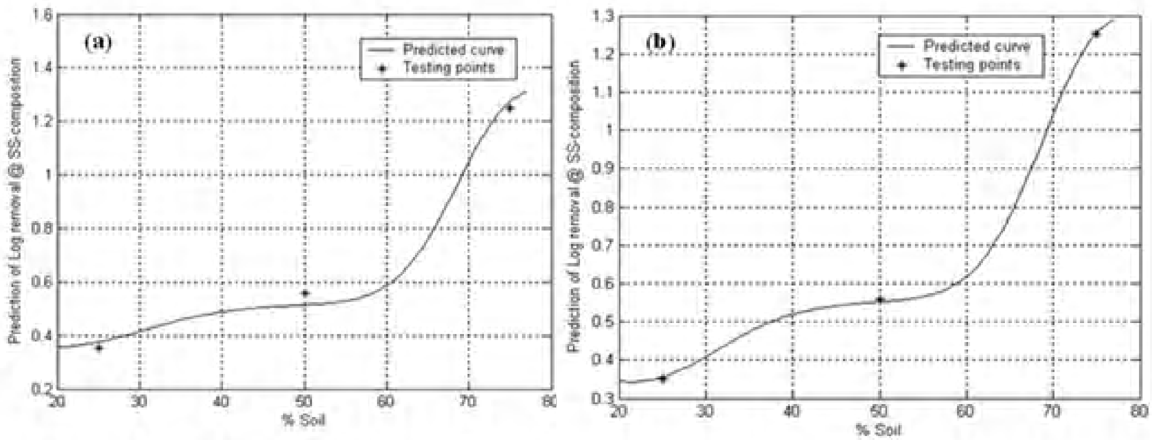

Fig. 7. Predicted curve for Ss with (a) 10 iterations and (b) 20 iterations

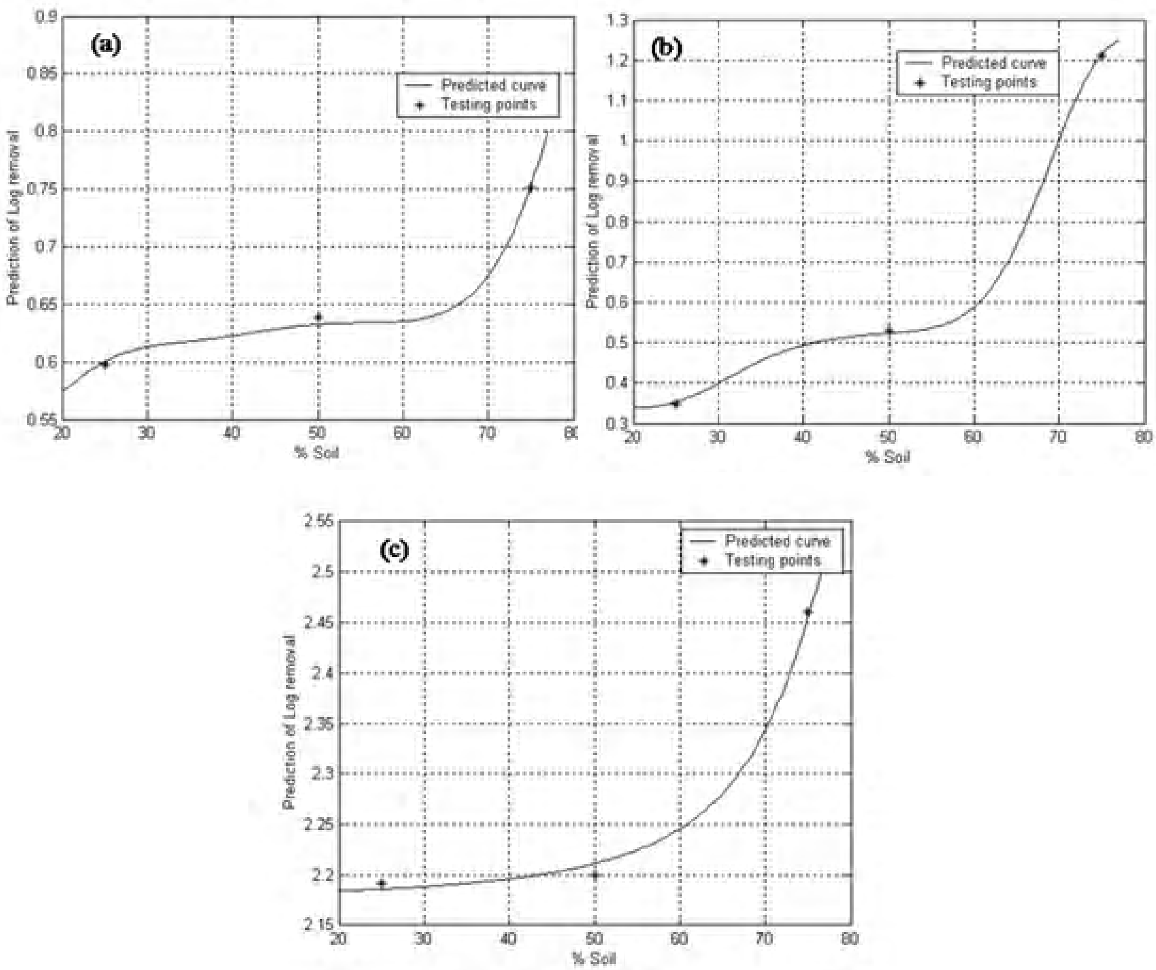

Fig. 8. Predicted curve with 20 iterations for (a) Sz, (b) Sv and (c) Sc

CONCLUSION

The IMI demonstrated the greatest FC removal of the compositions of soil and porous media at a ratio of 75/25, respectively. The effect of soil filling on FC bacteria removal depends on the fine particle size and the increasing of ion charges. FC attraction on filter surface increase and ionic strength in the electrolyte solution increase also. The proposed IMI system with simplicity of treatment technology and operation, low capital and operating cost, had significant FC bacteria reduction. It was possible to achieve wastewater reuse with the FC established in the Mexican regulations required for agricultural irrigation. This technique gave a forecast for the performance of FC removal between the range of soil content as 20-80% with difference type of the compositions Ss, Sz, Sv and Sc. Unlike the linear interpolation, the predicted curves obtained by the proposed algorithm are mostly nonlinear relation regarding to the nature of IMI. The robustness could also be counted because of the learning algorithm for its parameters. The human knowledge related on the treatment materials and FC removal can be included directly as the IF-THEN rules and membership functions. Furthermore, the convergence of prediction could be guaranteed by the proposed theorem and this algorithm can be implemented to predict the FC removal as the application of agriculture irrigation.

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