



Stochastic Modeling of Filtrate Alkalinity in Water Filtration Devices: Transport through Micro/Nano Porous Clay Based Ceramic Materials

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Abstract

Clay and plant materials such as wood are the raw materials used in manufacture of ceramic water filtration devices around the world. A step by step manufacturing procedure which includes initial mixing, molding and sintering is used. The manufactured ceramic filters have numerous pores which help in water filtration. These filters fare well in microbial filtration but are plagued with alkalinity of filtrate during early use. Change in alkalinity between the water influent and effluent is defined by the difference in their corresponding pH. The development of alkalinity is a function of filtration time and the material property of the ceramic filtration devices discussed in this article. Macroscopic parameters such as degree of change in turbidity, electrical conductivity and temperature between the filter influent and effluent are the electro kinetic variables also used in the prediction of alkalinity. Flow rate through porous filtration devices influence alkalinity. The electro kinetic variables, flow and time are interdependent on each other. Multivariate stochastic regression technique is used to demonstrate the individual effect of these predictor variables.

Key words: Clay, Wood, Water, Filter, Alkalinity, Regression

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INTRODUCTION

Water transport through porous materials is a major area of study in various interdisciplinary applications namely ground water flow in soils and agriculture, cooling of water using clay ceramic water storage devices, drilling oil, food processing, filtration, nanotechnology and many more to list. Transport through porous structures has helped in filtration and purification of water. Clay based ceramic filters are used around the world by millions of people for water filtration (Plappally et al. 2009). These micro/nano-porous ceramic structures are basically made of clays (Plappally 2010). Water flow through ceramics will be affected by micro pore structural changes (Churaev 1990; Derjaguin et al. 1987). The compositional changes of the material surface due to dissolution also affect water flow (Churaev 1990; Derjaguin

et al, 1987). Water flow through porous media may be modeled by continuum models, capillary bundle models, pore scale network models, and other numerical stochastic models (Philip 1986; Sochi 2009; Trussell et al. 1999). A model solution is still inexistent connecting flow with material as well as compositional aspects of the fluid varying with time.

Flow through clay based porous materials occurs due to non equilibrium conditions between the material surface area and fluid volume (Bachmann et al. 2002; Marmur 1992). Non equilibrium conditions hint towards irreversible processes responsible for the increase in entropy (Onasager 1931). Entropy production rate in any system can be expressed in terms of mass or molar fluxes (Onasager 1931; Kjelstrup et al. 2001; Prigogine 1977). The experimental findings of

oxygen dissolution by Lantagne in 2001 and increase in alkalinity in filtrate during filtration by Halem in 2006 represent examples of irreversible processes. There is a need to account for flow under concentration gradient ΔC , electric potential ΔE , temperature gradient ΔT and pressure gradient ΔP while dealing with porous flow through membranes (Sonune et al. 2004).

Porous flow and temperature

Flow of the liquid through the ceramic pores due to temperature difference is defined as thermo-osmosis (Churaev 2000; Trussell et al, 1999). The solvent flux S_f in mole per unit area per second will be given as

$$S_f \approx a \nabla \mu_p + b_1 \nabla T / T \tag{1}$$

where a is the constant related to filtering capacity of the porous media, b_1 is a constant related to flow due to temperature gradient ∇T . Here $\nabla \mu_p = -m_v \nabla P$ and $a = k / \eta m_v$, where m_v is the molar volume of the water (liquid), ∇P is the pressure gradient across the thickness of the porous media, η is the viscosity of water (liquid) and k is filtration coefficient. Hence Eq. 1 can be written as,

$$S_f \approx -k \nabla P / \eta + b_1 \nabla T / T \tag{2}$$

The second term on the right hand side of Eq. 2 is equal to the mass flow rate through the porous media due to temperature difference on both sides of the porous media. Temperature difference of the influent water and effluent filtrate of the clay ceramic filters tested at Delft by Halem in 2006 is shown in Fig 1.

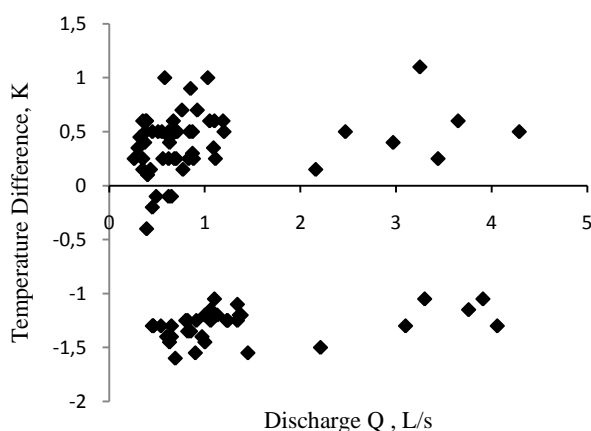


Figure 1 Temperature gradient with respect to discharge Q from the filters irrespective of the location of manufacture, Ghana, Cambodia and Nicaragua taken together (Halem 2006).

The atmospheric temperature depends upon the climatic changes of that geographic location. Filter manufactured in moderate places may not behave as desired in temperate climates (Halem 2006).

Influence due to change in concentration

Solid-liquid separation is the major process for which the ceramic water filters are used. The degree of filtration plays a major part in defining transport influenced by concentration differences ∇C (Churaev, 2000). Hence solvent flux,

$$S_f \approx -k \nabla P / \eta + b_2 \nabla C \tag{3}$$

where b_2 defines the velocity of the capillary flow due to concentration gradient ∇C , which is a measure of the electrical conductivity. The presence of dissolved ions may cause deviations from Darcy’s law in porous media due to capillary osmosis (Churaev 2000).

The amount and mobility of ions determines conductivity. The ions such as Cl^- , NO_3^- , SO_4^{2-} , PO_4^{3-} , Na^+ , Mg^{2+} , Ca^{2+} , and Fe^{2+}/Fe^{3+} can be used to indicate impure water. The ionic strength greatly influences microbial activity (Paulsen et al, 1997; Morales et al, 2007).

Electric conductivity of water

Clay ceramics show electro-kinetic properties when in contact with water (Worrall 1986). Charge develops on clay ceramic surfaces in water basically due to diffusion. When water flows through any porous media it generates streaming current. This current is directly proportional to water conductivity (Paillat et al, 2001). This may also indicate the possible dissolution of reflux ions present in clay such as K, Na, Mg, Ca Al etc (Halem 2009). Specific conductance indirectly measures the presence of dissolved ions.

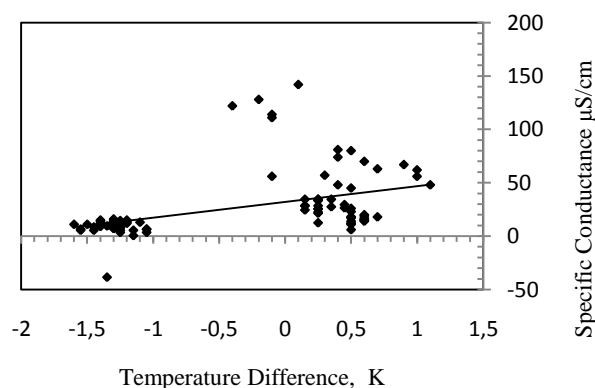


Figure 2 The variation of specific conductance (∇E) between influent and filtrate effluent as a function of temperature (Halem 2006).

Due to the weak chemical binding in the porous ceramics, the variation in specific conductance or electrical conductivity becomes pronounced with time (Philip 1986; Zhu et al, 2000). This process will increase the potential difference within the clay ceramic ware and atmosphere.

This potential difference will induces a flux of solute through the porous media. For dilute solutions under negligible thermal influence this flux of solute S_f is,

$$S_f \approx -k\nabla P/\eta + b_3\nabla E \tag{4}$$

where $b_3 = -\kappa/\sigma\eta m_v$, defining the velocity of exchange of charge between molecules across the ceramic ware or porous media (Abramson et al, 2007). Considering the thermal influences in Eq. 4, the capillary pressure difference in clay ceramic porous media will be greatly influenced by temperature changes in the environment rather than just by the temperature of influent water (Bachmann et al, 2002).

Turbidity

The potential difference exerts a linear electro-osmotic pressure within the porous media (Srivastava et al., 1977). Electro-osmosis influences the exchange of materials within cellular organisms in water.

The cellular organism in unfiltered water such as E.coli and other microbes (biological colloids) affect the velocity of exchange of charge between molecules (Bradford et al 2007; Churaev 2000; Kjelstrup et al, 2005). Turbidity (Nephelometric units or NTU) defines the degree of microbial, organic/inorganic chemical as well as colloidal contents of water (EPA 1997).

The variation of turbidity between the PCCW filter influent and the effluent is shown in Fig. 3 for a time span of 5 weeks.

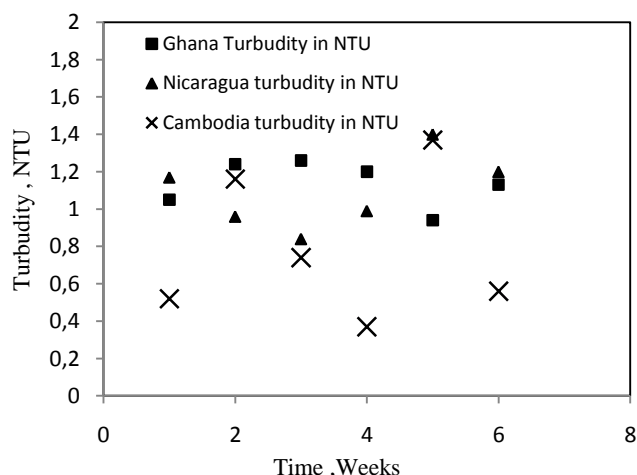


Figure 3 Turbidity variations with respect to time from the filters irrespective of the location of manufacture (Halem 2006).

From Eq.1, Eq.3 and Eq.4, the solute flux can be written as,

$$S_f \approx -k\nabla P/\eta + b_1\nabla T/T + b_2\nabla C + b_3\nabla E \tag{5}$$

The expression in Eq.5 satisfies the non equilibrium thermodynamic conditions proposed by Onasager (Srivastava et al, 1972). The solute flux variation is analogous to development of alkaline pH in the filtrate.

A mechanistic or chemist’s view of porous flow in itself will not be able to capture a model solution for transport in clay based porous media. Multi-predictor regression has been proposed to predict the leaching characteristics of the clay ceramics filter during filtration, thus proposing possible coupling of chemical dissolution and transport. Based on the models developed here, the errors or variances have been examined and quantified. This probabilistic approach provides us the tools to quantify higher error rates and poor repeatability of experimental results in micro/nano porous fluid transport in clay ceramic filtration devices (Plappally 2010).

MATERIALS AND METHODS

The filters were manufactured by combining specific volume ratio of materials namely, sawdust and clay. Sawdust was obtained from a local saw mill (Hamilton Supplies, Hamilton, NJ). Clay was procured from Resco Products Inc. Pittsburg, PA. Clay to sawdust mixes of 75:25, 65:35, 55:45, 50: 50 and 55:45, ratio by volume were used in the manufacture of the PCCW filters used for the experiment. The step of manufacturing the PCCW filters has been explained clearly by the author in another article (Plappally et al. 2009).



Figure 4 Manufactured frustum shaped clay ceramic filtration device

Many researchers have done filtration tests focusing on the behavior of filtrate pH through similar filters (Halem 2006; Swanton 2008; Lantagne 2001). It is necessary to understand this behavior due to material modifications and

surface interactions taking place during the transient flow through filter media.

The sintered filters of each volume fraction were fully saturated with water by dipping them in a water bath containing purified water (Barnstead/Thermolyne, EASYpure uv/uf, Model D8611) for about 12 hours. This is done to simulate the actual discharge from the ceramic composite filter in a fully working condition.

The experimental setup shown in Fig. 5 consists of three major components. First, a ceramic composite filter filled with water. Secondly, a vessel for collection of discharged filtrate from the filter.



Figure 5 Model experimental setup for flow experiments conducted for different filter variants.

Experimental setup was covered in a plastic wrap to prevent evaporation as well as external influences and impurities. Finally, the filtrate collection vessel sits on a load cell (Model LSC 7000-50, Omega Engineering Incorporated, Stamford, CT).

The complete draining of pure water (Barnstead/Thermolyne, EASYpure uv/uf, Model D8611) under gravity from a fully filled composite ceramic filter is considered as one experiment. The filtrate pH is measured with a digital pH meter, Omega PHH224. The pH measurement was done at half hour duration after the start of the filtration process. The measurements were recorded for each of the 6 filters manufactured from different clay and sawdust configurations (75:25, 65:35, 55:45, 50:50 and 55: 45 by volume).

The first objective is to establish the basic variables and their mutual interactions influencing the pH of the filtrate from the filters. The experiment focuses on the material constituents and time affecting the filtrate pH.

Analysis of Experimental Data from Halem, 2006

The compositional properties of influent water, temperature change and time are assumed to influence filtrate pH. The data used to analyze this assumption is referenced and cited from the MS Thesis of Doris Van Halem in 2006, at Delft University of Technology in November 2006 and can be retrieved from Potter for Peace website (PFP 2007).

Each filter was made of locally available clay and sawdust (50: 50 by volume) respectively and manufactured in Ghana, Cambodia and Nicaragua. These filters were geometrically similar to the filters depicted in Fig 4. The pore sizes of these filters ranged from 0.001µm to 100µm (Plappally et al, 2009).

A total of 6 PCCW filters each imported from Ghana (Type1), Cambodia (Type 2) and Nicaragua (Type 3) were loaded daily by Halem with 6 liters of water from canal Schie flowing through Delft city (Halem et al, 2007). Gravity driven flows emptied the compositionally uniform filters automatically. For 12 weeks the influent and filtrate were tested for temperature, turbidity, flow rate, pH and electrical conductivity. The procedure is elaborately explained in Halem et al, 2007 and Halem et al, 2009.

Halem in 2006 elaborated the influence of dissolution of the chemical constituents of porous clay ceramic ware on the pH with flow occurring over a period of time. The figures Fig. 6, 7 and 8 represent the pH as a function of time. Only 5 week data has been used for analysis. Filters were cleaned after 5 weeks which may disturb the flow process (Halem 2007). The experimental results are plotted in Fig 1, Fig 2 and Fig 3.

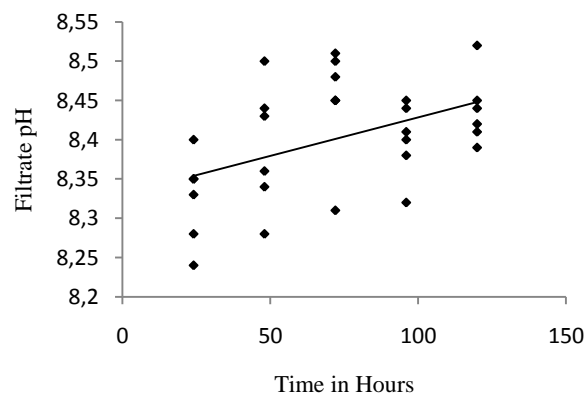


Figure 6 Filtrate pH in Type 1 filters from Ghana (Halem 2006; Plappally 2010).

Table 1 The summary of constants a and c₁, coefficient determination R² and error S of the model illustrated in Eq 7.

Predictor Variables/Model Coefficients	a	c ₁	S	R ²
X ₁	1.07	0.105	0.0015	0.982

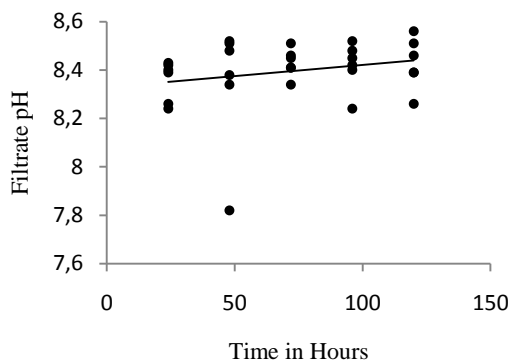


Figure 7 Filtrate pH in Type 2 filters from Cambodia (Halem 2006;Plappally 2010).

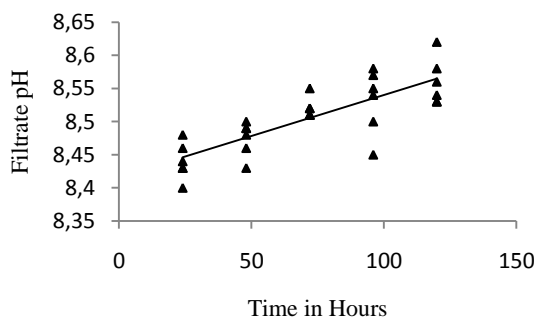


Figure 8 Filtrate pH in Type 3 filters from Nicaragua (Halem 2006; Plappally 2010).

RESULTS AND DISCUSSION

Material Influence

Fig. 9 Illustrates the experimental results from the filters with clay to sawdust configurations 75:25, 65:35 55:45, 50:50 and 55: 45 by volume respectively (Plappally 2010).

The increase in pH of the filtrate, delta symbol pH = Y may be the result of dissolution of chemical ions from the filter material. The predictor variable X_i is transformed as shown in Eq.6 (Plappally et al, 2009; Tiller and Hsyung 1991; Sussman 1977).

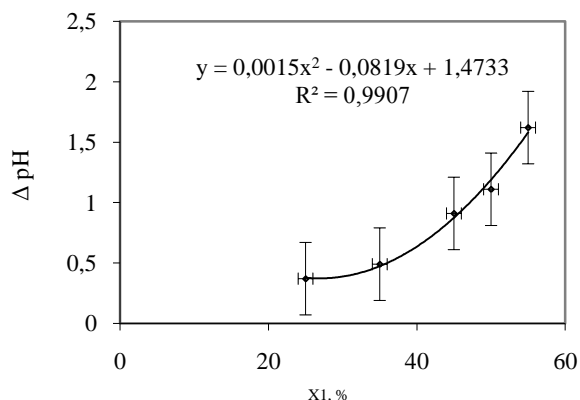


Figure 9: Variation of the pH in the filtrate with changes in volume fraction (Plappally 2010).

Volume of sawdust (X_i for i=1) used to manufacture the clay ceramic is a minimal order statistical property (Ganapathysubramaniam et al, 2007). This theoretical development of the transformation is expressed as,

$$Y = X_i / (a + \sum_{i=1}^k c_i X_i) \text{ for } i = 1 \tag{6}$$

This can be written as follows

$$Z_i = X_i / Y = a + \sum_{i=1}^k c_i X_i \text{ for } i = 1 \tag{7}$$

where a, is a constant related to the ceramic material in contact with percolating pure water.

The coefficient of the predictor variable (X_i for i= 1) c₁ provides us information about the importance of the influence of the predictor variable X₁ on the response Z₁ in this case (Bulmer 1957).

The Ydata as plotted in Fig. 9 may be modeled as shown in Table 1.

With decrease in clay content (by volume) in the filter, there is decrease in compaction between the sawdust and clay. This may result in loose adhering of clay and sawdust which may result in enhanced dissolution of reflux ions in clay. This is clearly seen from the model in Table 1 and also from Fig 9.

Modeling Time and Material influence on pH change

From Fig. 6, Fig 7, Fig 8 and Fig 9, the pH change is found to increase with time of flow and it fits an increasing hyperbolic relationship with quantity of additive material constituent used to manufacture any individual filter. Therefore, change in pH (ΔpH) may be assumed to follow the relationship.

$$(\Delta pH) = Y = X_1 / (A + \sum_{i=1}^k c_i X_i) \text{ for } k=1 \quad (8)$$

The data for Type 1, Type 2 and Type 3 filters were pooled separately and conformed for modeling. Each type had 6 filters and filtrate pH data was collected for 5 weeks. This modeling approach would clearly analyze the behavior of filtrate pH influenced by different materials by which the Type 1, Type 2 and Type 3 filters were manufactured respectively.

Table 2 represents the results of regression analysis. It also gives the coefficient of determination R^2 and standard deviation of the model S. The R^2 value development was found encouraging for all the three types tested.

Table 2 The summary of constants a and c_1 , coefficient of determination R^2 and error S of the model illustrated in Eq 8 written as.

$$Z_i'' = X_1/Y = A + \sum_{i=1}^k c_i X_i \text{ for } i=1$$

PCCWs	Model	A	c_1'	R^2	S
Type 1	Z_1''	0.00165	0.118	99.9	0.0026
Type 2	Z_2''	0.00206	0.118	99.9	0.0053
Type 3	Z_3''	0.00267	0.116	99.9	0.0016

When considering multi-material constituents, the chemical behavior of the location specific clays has a great influence on the working of the filters (Kattamuri et al, 2005; Wilson et al, 1995).

In order to study influence of materials specific to Type 1, Type 2 and Type 3 respectively, Eq.8 is transformed to include material specific parameter M_{123} (Soboyejo et al, 2001). The new model may be written as $Z = f(X_1, X_2)$

$$Z = A + c_1' X_1 + c_2' M_{123} \quad (9)$$

where $M_{123} = a$, here a is derived from the Table 2 (Soboyejo et al, 2001). Now the independent variables X_1 and M_{123} are pooled for regression as per requirements for Eq. 9 as shown above.

Table 3: The summary of constants a and c_1 , coefficient of determination R^2 and error S of the model illustrated in Eq 8 written as.

$$Z_i'' = X_1/Y = A + \sum_{i=1}^k c_i X_i \text{ for } i=2$$

	A	c_1'	c_2'	R^2	S
Z_i''	0.355	0.00119	-0.167	99.9	0.0038

Fig. 10 plots points of the normally distributed Z_1'' value which confirms the goodness of prediction of the model represented in Eq. 9. From the Table 3, it is clear that coefficients c_1 and c_2 reflect the influences of the corresponding predictor variables. The values of model coefficients c_1 and c_2 confirm a higher influence of time than the material property parameter. The material parameter M_{123} applies a negative effect on Z_i'' .

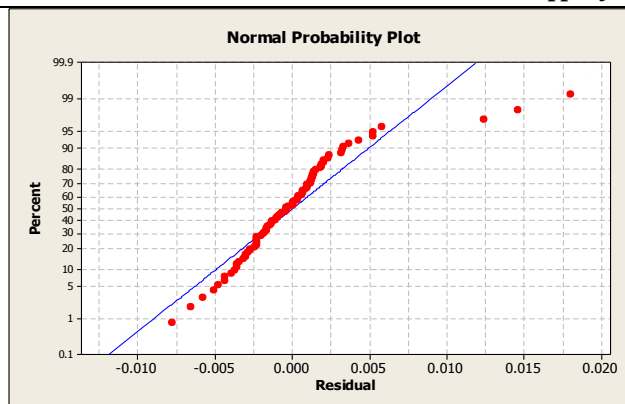


Figure 10 Normal probability plot of the transformed response variables Z_i'' (Minitab 15, 2009)

Modeling Time, Thermal and Compositional Aspects of fluid on pH change

The framework of non equilibrium thermodynamics as elaborated by Onasager is used here for predicting leaching in clay ceramics (Onasager 1931).

Leaching can be confirmed from the increasing pH values of the filtrate with respect to the influent water pH. For this analysis, (ΔpH) is represented as the response variable N.

There is always a feasible environment for microbial (bio-colloids) bio-film growth on the water surface as well as on the surface of these porous ceramics (Klarman 2009; Petrasch 2008). The possible dissolution of exchangeable cations present in clay influence ionic transport. The other contributors for the changes in pH would be lignin and humic acid which may be formed in the process of filter saturation and filtration due to presence of sawdust. The change in turbidity plays an important role in quantifying the organic and inorganic material dissolution. Since turbidity defines colloidal nature of water, it is a major variable defining the colloidal statistics which follows characteristics of the problem explained by theory of probability after effects proposed by Smoluchowski (Chandrasekhar, 1943). L_1 is the change in turbidity between the influent water and effluent filtrate.

The change in the pH of the water to be filtered may change the hydraulic conductivity of the clay ceramic material and vice versa (Santiwong et al, 2008). The gravity driven water flow rate discussed in this technical article encompasses pressure variation occurring within the thickness of the porous ceramic material (Fausey et al, 1986). Flow rate Q is taken as second predictor variable L_2 instead of pressure variation across the porous media.

An increase in variation of pH is seen with increase in temperature difference in Fig.11. This trend is common for all the experiments performed on ceramic filtration devices around the world irrespective of shape and size (Plappally 2010).

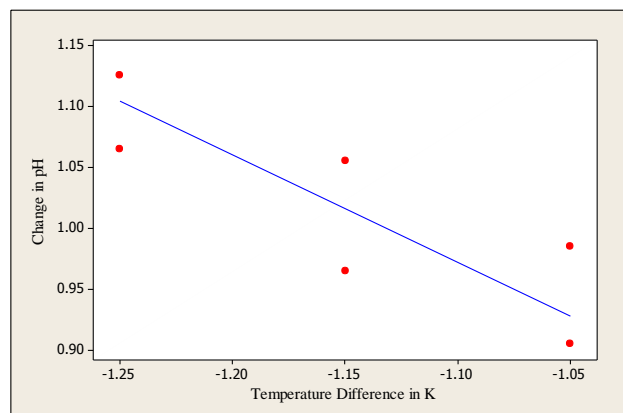


Figure 11 ΔpH is plotted as a function of temperature difference between the influent water and effluent filtrate measured in week 2 for Type 1 filters (Minitab 15, 2009).

The temperature difference is the third variable L_3 considered. Presence of dissolved ions affects the flow rate of the filters. This flow rate Q variation with time influences electrical conductivity (Palliat 2001). Hence the fourth predictor variable L_4 is the change in electrical conductivity between the influent and effluent filtrate from the clay ceramic filters. From Table 2, filtrate pH is found to increase with time. It is also seen the pH behaves as shown in Fig.8 and elaborated by Eq. 6. The fifth predictor variable is time L_5 . These five parameters are strictly dependent on each other.

Table 4 Correlation coefficient $\rho_{L_{i,j}}$ between the predictor random variables L_1, L_2, L_3, L_4 and L_5 .

Predictor Variables	L_1	L_2	L_3	L_4	L_5
L_1	1	-0.139	0.471	0.874	-0.409
L_2	-0.139	1	-0.102	-0.223	-0.145
L_3	0.471	-0.102	1	0.421	0.257
L_4	0.874	-0.223	0.421	1	-0.421
L_5	-0.409	-0.145	0.257	-0.421	1

The correlation matrix in Table 4 also confirms that the various transport processes occurring simultaneously during gravity based filtration process are dependent on each other with time. A negative correlation is evidence that large values of the predictor variables L_i are associated with small values of the other counterpart predictor variables L_i (Bulmer 1957). Table 4 also relates specific conductivity L_4 negatively to turbidity L_1 as confirmed by Kohlrausch (Goodwin 1899).

From Table 4, the higher interdependence between L_1 and other predictor variables L_2, L_3, L_4 and L_5 is visible. Therefore change in pH (N) is assumed to follow a

transformation similar to Eq. 7 but with multi-parametric extension to include the predictors mentioned in Table 4.

This extension is shown in Eq.10 below,

$$N = \frac{L_1}{\theta + m_1 L_1 + m_2 L_2 + m_3 L_3 + m_4 L_4 + m_5 L_5} \tag{10}$$

where N is the change in pH (ΔpH), L_1 is the difference in turbidity of the influent and filtrate (NTU), L_2 is the filtrate discharge rate (l/h), L_3 temperature difference of the influent and the filtrate in K, L_4 is the difference in electrical conductivity of the filtrate and the influent ($S \cdot 10^{-8}/m$), L_5 is the time in hours. The data from experiments performed on Type 1, Type 2 and Type 3 filters are pooled together to conform to the requirements of Eq. 10. Eq. 10 can be reformulated as below,

$$Z' = L_1/N \tag{11}$$

Since the predictor random variables have different dimensions, Eq. 10 can be mathematically reformulated as

$$Z' / Z'_{io} = \sum_{i=1}^k (m_i L_i / L_{io}) / Z'_{io} \tag{12}$$

where L_{io} and Z'_{io} is any reference constant with the same units as L_i and Z' respectively. This will help in achieving dimensional similarity.

Regression is to be carried out with independent variables. Therefore the correlated predictor matrix column elements in Table 4 with correlation coefficient $\rho_{L_{i,j}}$ are linearly transformed as independent variables $LV_{i,j}$ and is scaled as (Haldhar et al, 2000; Krishnamoorthy 2006),

$$\frac{([L_{i,j} - \mu_{L_{i,j}}])}{\sigma_{L_{i,j}}} = [LT] \left[\frac{[LV_{i,j}]}{\sqrt{\lambda_{L_{i,j}}}} \right] \tag{13}$$

The left hand side of Eq. 13, are standard normal variates of the predictor variables $L_{i,j}$ for $i \neq j$ and $i=1, 2, 3$ having zero mean and unit standard deviation. Here $\mu_{L_{i,j}}$ and $\sigma_{L_{i,j}}$ are the parameters of normal distribution. The correlation coefficient of the standard normal variates is now $\rho_{LV_{i,j}}$, where $\rho_{LV_{i,j}} = F$ parameter * $\rho_{L_{i,j}}$ (Kiureghian et al, 1985). The F-parameter for Eq. 13 in case of large ($n=90$) and normally distributed pH data is unity (Haldar et al, 2000).

Table 5 Multivariate stochastic regression model constants for Eq.12,

$$N = \frac{L_1}{\theta + m_1 L_1 + m_2 L_2 + m_3 L_3 + m_4 L_4 + m_5 L_5}$$

Predictor Variables	θ	m_1	m_2	m_3	m_4	m_5	R
L_1	1.67	0.824	-0.318	-0.081	0.405	-0.73	97.9

Table 5 provides a consolidated study irrespective of the manufacturing raw material or process or geo spatial property changes inherent in the clay ceramic filter. Table 5 tabulates the model constants m_1, m_2, m_3, m_4 and m_5 which elaborate the individual influences of the predictor random variables, L_1, L_2, L_3, L_4 and L_5 .

It is found that m_2 is negative which indicates a negative effect of flow rate L_2 on Z' . This confirms that diffusion changes with time. The difference in turbidity parameter, L_1 , has maximum impact on the pH value. A non parametric analysis of variance validation of the model is shown below

$$Var(G) \approx (m_1^2)VarL_1 + (m_2^2)VarL_2 + (m_3^2) VarL_3 + (m_4^2) VarL_4 + (m_5^2) VarL_5 \tag{14}$$

$$1.992 \approx \begin{matrix} 1.8054 & + & 0.0113 & + & 0.0147 & + \\ 0.0242 & + & 0.040 & = & 1.8956 & \end{matrix} \tag{15}$$

From Eq. 14 and Eq. 15, turbidity plays an important role in defining the pH increase in the filtrate of a filter.

A Kolmogorov Smirnov (K-S) test was performed at a 99% level of confidence to test the validity of the assumed transformation and is shown in Table 6 below,

Table 6 D_n and D_n^α for Kolmogorov Smirnov Test for the different models for N (Ang et al, 1975).

	Kolmogorov Smirnov Test at $\alpha=0.01$				Critical Value D_n^α
	N	ln N	L_1/N	n	
D_n	0.158	0.169	0.156	90	0.171
P value	<0.010	<0.010	<0.010	90	

From the results of the K-S test in Table 6 the proposed distribution of L_1/N is acceptable at the specified significance level of 0.01. This is true with long and continuous percolation of water through any specific clay based ceramic micro/nano porous material.

CONCLUSION

Novel phenomenological multivariate stochastic models have been proposed to predict leaching characteristics in filter manufactured locally in Ghana, Cambodia and Nicaragua. New models connecting flow with material as well as compositional aspects of fluid varying with time are proposed.

Major results are summarized as follows,

1. Filtrate pH is influenced by time of filtration process as well as the type of material used in the manufacture of the filtration device.

2. Parameters of change in turbidity, temperature, mass flow rate and electrical conductivity of fluids percolating any clay based porous media system are interdependent on each other with time.
3. A novel stochastic multi parameter model has been proposed for the prediction of filtrate alkalinity of the filters irrespective of material of manufacture and time.
4. A novel hyperbolic relationship has been developed between change in pH and predictor variables including changes in turbidity, temperature, electrical conductivity, flow rate and time.

This model is applicable to predict the multi-physics taking place in similar porous systems with micro/nano size pores distributed randomly throughout the material volume.

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