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ORIGINAL RESEARCH PAPER

Application of wastewater with high organic load for saline-sodic soil reclamation focusing on soil purification ability

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ABSTRACT: Fresh water source scarcity in arid and semiarid area is limitation factor for saline-sodic soil reclamation. The reusing of agricultural drainage and industrial wastewater are preferred strategies for combating with this concern. The objective of current study was evaluation in application of industrial sugar manufacture wastewater due to high soluble organic compounds in saline-sodic and sodic soil. Also soil ability in wastewater organic compounds removal was second aim of present study. Saline-sodic and sodic soil sample was leached in soil column by diluted wastewater of amirkabir sugar manufacture in Khuzestan Province of Iran at constant water head. Sodium, electric conductivity and chemical oxygen demand of soil column leachate were measured per each pore volume. The experimental kinetics of wastewater organic compounds on two saline-sodic and sodic soil were also investigated by three pseudo second order, intra particle diffusion and elovich model. The results of current study showed that electric conductivity of saline-sodic soil was decreased to 90% during 3 initial pore volumes, from other side exchangeable sodium percent of saline-sodic and sodic soil decreased 30 and 71 percent, respectively. There were no significant different between wastewater chemical oxygen demand removal by saline-sodic and sodic soil in both batch and column studies. Wastewater chemical oxygen demand was decreased to 35% during pass through soil column. The results showed that the adsorption kinetics of wastewater organic compounds were best fitted by the pseudo-second order model with 99 percent correlation coefficient (r^2=0.99%).

KEYWORDS: *Organic load; Reclamation; Saline-sodic soil; Soil purification; Wastewater.*

INTRODUCTION

Soil is a thin layer that cover the solid earth and that determines the water, life forms, and chemical elements cycles (Mol and Keesstra, 2012; Keesstra *et al*., 2012). Moreover, the soil system supply goods services and resources for the humankind (Brevik *et al*., 2015) and is a key subject to understand the sustainability of the earth system such as the goals of the United Nations inform (Keesstra *et al*., 2016). Soil degradation resulting from salinity is a major obstacle to the optimal utilization of land resources. Salt-affected soils are widely distributed throughout the world, with around 20 percent of the world's cultivated land affected (Oo*et al*., 2013). Deterioration of soil quality by soil salinization and sodication is a global problem. Salt affected soils, are commonly occurring in arid and semi-arid regions (Pandey *et al*., 2011; Ferreira *et al*., 2015; Singh, 2016) and gradually spreading in various regions of the world (Lambers, 2003). Also, among the issues related to land degradation, soil salinization–sodication is widespread that is reducing crop yield and cultivated area (Fan *et al*., 2012; Setia *et al*., 2013; Ahmed *et al*.2016). According to extracted

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data from Iran soils map, nearly 34 million ha in Iran are saline lands. These soils because of non-suitable physico-chemical properties have many agricultural and environmental problems such as derangement in plant growth and water and wind erosion, while need best practical management for sustainable utilization. Removing soluble salts from soil profile or plant root development area and exchangeable sodium removal are main goal in saline-sodic soil reclamation. Several efficient methods such as leaching and phytoremediation of soluble salts (Qadir *et al*., 2000; Diamantis and Voudrias, 2008; Rengasamy, 2010; Chi *et al*., 2012), calcic reclamation agents (gypsum or $CaCl_2$), different organic and inorganic acids for increasing carbonate calcium solubility in soil for exchange sodium removal were proposed(Chun *et al.,* 2001; Sakai *et al*., 2004; Wong *etal*., 2009; Singh *et al*., 2013). Leaching is efficient and effective method for saline-sodic soil reclamation. Obtained results from several study of soil and water research centers of Iran showed that54% of soil soluble salts removed by leaching (Qadir *et al*., 2008). Fresh water resources scarcity especially in arid and semiarid climate is ahead challenges for saline-sodic soil leaching in these regions. Therefore, water source leads in limitation in leaching procedure for reclamation these soils. In global scale about 70% of fresh water resources used in agriculture. However, in some regions, this number reaches to 95%. Thus, one of the presented macro policies are using low water to agricultural sector and accordingly higher amounts of fresh water resources to non-agricultural sector such as industrial and domestic (Sato *et al.*, 2013; Janadeleh *et al.,* 2016). In this case, decrease the water consumption in agriculture while increase it in non-agricultural sectors caused to increase the wastewater volumes in different industrial and domestic activity. Reusing the produced wastewaters is proper strategy for resolve water scarcity in agriculture. Annually 3.54 km^3 domestic wastewater produce in Iran, while 0.821 km^3/year used in different section after treatment (Sato *et al*., 2013). Although industrial and domestic wastewater using in agriculture is a suitable strategy, but assessment the environmental effect of reuse these wastewater in agriculture in long and short term is necessary (Hu *et al*., 2005; Kaushik *et al*., 2005; Lado *et al*., 2012; Levy *et al*., 2014). Application of wastewater onto land is particularly attractive when water limit production and in areas where the environment is sensitive to the disposal of wastewater directly into waterways (Barton *et al.,* 2005). Land application is the oldest system for the disposal of wastewaters. It is based on the high biodegradative capacity of soils. Soil is a gigantic bio-digestion system developed over millions of years that is able to biodegrade animal and plant wastes to become part of the soil. Land treatment is based on the physical, chemical and microbiological interactions between the components and micro-organism of soils and wastewaters. In land treatment, the soil is taken as a medium to biodegrade wastewater, which is applied to the land when no crop is being grown (Cabera *et al*., 1996). After a period of biodegradation, soil fertility can be enhanced because the increase of organic matter and nutrient contents means that the land may then be used for agriculture, pasture or forest. Land application has become an increasingly popular approach for the treatment of wastewater. Land disposal of municipal and industrial wastewater with or without secondary treatment has been applied effectively for decades (Cong hu *et al*., 2005).Using the native calcium resources of soil such as pedogenic carbonate calcium of calcareous soil is proper method for providing soluble calcium aim to exchange with exchangeable sodium and soil desodification. Low solubility of carbonate calcium is restrictive factor in applying this method, therefore, sodic soil reclamation well not investigated. Gupta and Khan, (2009) reported that potential of applied wastewater for soil desodification was considerable.

The objectives of current study were 1) saline-sodic reclamation by sugar industry wastewater and, 2) land purification and treatment of wastewater over application of wastewater for soil reclamation. Hence wastewater decontamination ability by soil also investigated in parallel with soil reclamation experiment. The current study has investigated in column study and kinetic experiment. This study has been carried out in laboratory of soil department of Shahid Chamran university of Ahvaz, Iran in 2015.

MATERIALS AND METHODS

Soil sampling

Saline-sodic soil was sampled from 0 to 30 centimeter surface soil in khorramshahr region in south Khuzestan province of Iran. This study mainly aimed to investigation the soil reclamation in saline-sodic and sodic soils, a part of soils sample leached with deionized water.

Wastewater sampling

The wastewater sample used in this study was contain high organic load, therefore, the raw wastewater of sugar manufacture in Amir Kabir Sugarcane Production Complex was selected for this purpose. Wastewater sampling was performed by manual method with sample container in direct sampling. The distance between soil sample location and wastewater location is 7 km. Raw wastewater sample diluted with water in 1:1 volumetric ratio (v/v) and used for leaching experiment. Sampling was performed twice to preventing wastewater chemical oxygen demand (COD) changes due to microbial decomposition. COD of wastewater also measured per each 3 pore volumes during experiment.

Leaching experiment and wastewater decontamination:

Soil leaching and reclamation method in present study was constant water head (continuous pounding). Evaluation of the wastewater decontamination was performed through soil column in this procedure. Therefore, PVC tube with 7.5 and 20 cm inner diameter and height, respectively, was used and soil weight for each column was calculated based on column volume and soil bulk density. Two centimeters constant water head induced on soil column for collecting 1 pore volume (PV) with ± 20cc deviation per each 24 h(based on pretest determination). Soil pore volume for each soil column calculated based on soil column volume and porosity (Kirkham, 2005). The soil columns were saturated from bottom before leaching and then leached by wastewater. Electrical Conductivity (EC), sodium and COD of soil column leachate per each pore volume was measured over leaching experiment. After ten pore volumes leaching experiment have been stopped. Finally, EC and exchangeable sodium percent (ESP) of soils were measured as percentage. The ESP is calculated as Eq. 1.

$$ESP = \frac{Ex.Na}{CEC} \times 100 \quad (1)$$

Where Ex.Na is the exchangeable Na (meq/100g) and CEC (meq/100g) is the cation exchange capacity of soil. It should be noted that all soil samples, wastewater and leachate analysis were done based on the standard method in laboratory (Carter, 1993; APHA., 2005)

Kinetic studies

The adsorption kinetic study also was performed for evaluation the soil wastewater decontamination ability and surface adsorption. For this purpose, 5 gof soil and 25cc of diluted wastewater was suspended in centrifuge tube (1:5 ratio) and shaken with orbital shaker at 120 rpm in 0.5, 1,2,4,6,8,12 and 24 h. After each time interval and centrifuging the suspension, COD of liquid phase was measured. Adsorption of wastewater organic compounds to soil, q_t (mg/g) in t time calculated as Eq. 2.

$$q_t = \frac{(COD_0 - COD_t)}{w} V \quad (2)$$

Where C_0 and C_t are COD (mg/L) of wastewater and liquid phase, respectively, in t time. V and w, are wastewater volume (L) and soil weight (g), respectively. Kinetic adsorption of wastewater organic compounds in soil was investigated by three pseudo second-order, elovichand intra particle diffusion models as Eqs. 3, 4 and 5.

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \text{ Pseudo second order} \quad (3)$$

$$\frac{dq_t}{dt} = \alpha \exp(-\beta q_t) \text{ Elovich} \quad (4)$$

$$q_t = a + Rt^{0.5} \text{ Intra particle diffusion} \quad (5)$$

Where q_t and q_e are the COD adsorption at time t and at equilibrium, respectively, andk_2 is the pseudo second-order apparent adsorption rate constant (g/mg/h). Also, α is the initial adsorption rate (mg/g) and β is the desorption constant (g/mg). In the Intra particle diffusion model t is the contact time (h), and R may be taken as a rate factor, i.e., COD adsorbed per unit time. Higher values of R illustrate an enhancement in the rate of adsorption.

Correlation coefficient (r^2) was used to comparison the applied kinetic models as Eq. 6 (Lin and Wang, 2009):

$$r^2 = 1 - \frac{\sum_1^n (q_{t\ exp} - q_{t\ model})^2}{\sum_1^n (q_{t\ exp} - \overline{q_{t\ exp}})^2} \quad (6)$$

Where $q_{t,exp}$ and $q_{t,model}$ are the amount of adsorbed wastewater organic compounds in t time from experiment and model fitting, respectively and $\overline{q_{t\ exp}}$ is the average $q_{t,exp}$.

Soil physicochemical properties analysis

Soil physicochemical properties analyses were performed based on Soil Science Society of America methods (SSSA., 1996). Leachate and water analysis are based on standard method of water and wastewater analysis (APHA, 2005).Soil physicochemical properties was analyzed as Ca and Mg were measured by titration with EDTA, Na was measured by flame photometry, Cl was measured by titration with $AgNO_3$, Texture was analyzed by hydrometer method, EC and pH were measured by EC and pH meter respectively. CEC was measured by acetate ammonium method, $CaCO_3$ was measured by neutralization. Bulk density (ρ_b) was analyzed by core sampler method and COD was measured by closed reflux (Singh *et al*., 2013).

In present study both saline-sodic and sodic soil dominantly are mineral and have a negligible amounts of organic matter. For this reason, soil particle density of both soil samples assumed 2.56 g/cm^3. Besides, soil porosity calculated as Eq. 7.

$$f = 1 - \frac{\rho_d}{\rho_s} = 1 - \frac{1.55}{2.56} = 39.4\% \quad (7)$$

RESULTS AND DISCUSSION

The results of physicochemical analysis of saline-sodic soil properties are presented in Table 1. The results shows that the initial electric conductivity (EC) and exchangeable sodium percent (ESP) were 86.65dS/m and 78%, respectively. It should be noted that the soil salinity and sodicity characterization performed according to classification of salinity laboratory of America. Sodium and chloride are two main ions in soil solution. According to the results the sodic soil produced from saline-sodic soil leaching have relatively high ESP and low EC (Table 1). Although produced sodic soil differ from initial saline-sodic soil in soil solution properties, but some parameter such as $CaCO_3$, organic matter and soil texture almost constant. Also, high calcium carbonate content in both saline-sodic and sodic soil indicate that the source of calcium is natural. Chemical characteristics of raw and diluted wastewater are presented in Table 2. Based on the results obtained from Table 2, EC and sodium adsorption ratio (SAR(of raw wastewater were 1.92 dS/m and 1.15 (meq/L)$^{0.5}$ where indicates high ability of wastewater in calcareous saline-sodic soil leaching and desodification. High organic compounds (COD=8000 mg/L) and biodegradable organic compounds in wastewater may be induced to combusion reaction in soil. Therefore, raw wastewater was mixed with water in 1:1 volumetric ratio.

Table 1: Physicochemical properties of soils

Parameters	Unit	Saline-Sodic	Sodic
EC	dS/m	89.65	3.52
pH		7.61	7.97
ESP	%	78.1	28
OM	%	0.23	0.23
$CaCO_3$	%	44.3	42.1
ρ_b	g/cm^3	1.55	1.55
Na	meq/L	848	41
Cl	meq/L	650	13.75
SO_4	meq/L	66	15.76
HCO_3	meq/L	36.5	15.6
Mg^{2+}	meq/L	8.12	1.26
Sand	%	33	33
Silt	%	56	56
Clay	%	11	11
Texture		loam silty	loam silty
Porosity	%	39.4	39.4

Soil desalinization and desodification study

Leachate EC of saline-sodic soil from 103 dS/m in first PV reached to 10.8 in third PV (92 percentage decrease).This founding of the present study showed considerable amounts of soluble salts in soil. Therefore, the solution with low salinity (dilute electrolite) such as selected wastewater must be used for soil leaching purposes. Variation range of leachate EC in sodic soil was lower than that in saline-sodic soil. Maximum value of leachate EC was about 10dS/m and obtained in second PV. Therefore, the variations of leachate EC in sodic soil can be related to $CaCO_3$ solubility reactions, biodegradation of wastewater organic compounds and sodium exchange reactions. Despite whole of mentioned cases were happened in saline-sodic soil, but considerable amounts of soluble salts in saline-sodic soil are major factors that affect EC variations in saline-sodic soil leachate. Sodium leachate in saline-sodic soil was decrease from 425 meq/L in first PV to 91 meq/L in third PV. Also, high amounts of soluble sodium were removed from soil. Numerous amounts of sodium affect leachate EC

Table 2: Chemical characteristics of raw and diluted wastewater

Parameter	Unit	Raw	Diluted
EC	dS/m	1.92	1.65
pH		7.31	7.45
Na	meq/L	3.86	4.24
Ca	meq/L	19.31	23.4
Cl	meq/L	15	22
SAR	(meq/L)$^{0.5}$	1.15	1.17
COD	mg/L	8000	4600

of saline-sodic soil similar to another ion such as chloride. Two main stages were founded in leachate sodium of saline-sodic soil; first stage as function of releasing exchangeable sodium to soil solution during exchange reactions and leaching the soil soluble sodium. Second stage is created equilibrium between exchangeable and soluble sodium (Yazdanpanah and Mahmoodabadi, 2013; Gharaibeh *et al*., 2014). Fig. 1 shows the EC and sodium of leachate during soil leaching and reclamation experiment. First step was showed in first to fourth PV of sodium changes (Fig. 1). However, results showed that understanding of the exchangeable reactions from the first to fourth steps of PV changes is impossible, while the results showed that from fourth PV, equilibrium is created between exchangeable and soluble sodium. Conversely the sodium variations in sodic soil depend on exchange reaction due to negligible amounts of soluble salts. Maximum amounts of sodium were observed in three first PV, where explain exchangeable reactions between sodium and calcium in these stages.

Table 3 showed soil EC and ESP after leaching with sugar wastewater. The results obtained from Table 3 showed the high potential of used wastewater in soil desalinization and desodification. Diluted wastewater have relatively high organic load and contain biodegradable compounds. Therefore, biodegradation of the organic compounds and microorganisms of wastewater in soil lead to increase of CO_2 that can cause to produce carbonic acid in soil in both aerobic and anaerobic condition. Produced carbonic acid react with soil native calcium carbonate as Eq. 8 reaction.

$$CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2 + H^+ \quad (8)$$

Released calcium from above reaction can exchange with exchangeable sodium. Several studies such as Fa-Hu and Keren (2009), Qadir *et al*. (2005), Sadiq *et al*. (2007), Jalali and Ranjbar (2009) and Yazdanpanah and Mahmoodabadi (2013)with the aim of optimization above reaction (Eq. 7 reaction) were done. Gupta and Khan (2009) applied distillery effluent at different dilution factor for reclamation of sodic soil at varying texture and ESP (20 to 80%) class. The obtained results showed that the contents of calcium and magnesium of distillery effluent directly replaced sodium and improved the physical condition of sodic soil.

Table 3: Soil EC and ESP after leaching with sugar wastewater

	EC (dS/m)	ESP (%)
Saline-sodic	3.8	21.5
Sodic	3.6	19.5

Soil decontamination ability

Fig. 2 shows the values of soil column leachate and removal percentage. According to Fig. 2 the percentage removal of organic compounds in wastewater over pass through soil column. The results showed that trends of leachate COD do not follow any regular and distinctive trends. Maximum and minimum COD removal percentage in saline-sodic soil were 47% and 32%, respectively, and the mean of COD removal percentage was 38%. In sodic soil maximum, minimum and average of COD removal percentage were 45, 28 and 35%, respectively. This results indicated same wastewater decontamination ability of both saline-sodic and sodic soil. Physical mechanism (filtration and surface adsorption) and microbial decomposition are main factors in removal of soluble organic compounds during land filtration

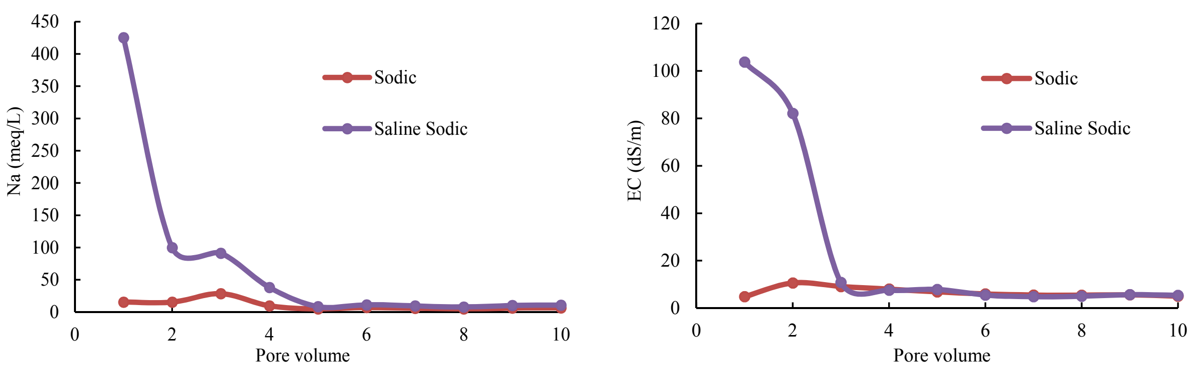

Fig.1: Changes of electrical conductivity and sodium in soil column leachate over leaching experiment at two saline-sodic and sodic soil

process (Zhang *et al*., 2007; Achak *et al*., 2009; Ak and Gunduz, 2013). The microbial decomposition in aerobic, anaerobic and anoxic conditions have important role. On the other, the role of physical and microbial mechanisms in organic pollutants removal by soil because of pore clogging and soil pores blockage need more studies (De Vries, 1972; Mottier *et al*., 2000; Lowe and Siegrist, 2008). Carbera *et al.* (1996) investigated the purification of olive oil mill wastewater by calcareous soil in lysemeter with 1m depth. The obtained results showed that the COD removal varied from 84 to 99 percentage (Carbera *et al.*1996). The results of current study showed that although organic pollutant leached from soil column but the leaching was lower than water quality standards. In addition, the results of this study showed that saline-sodic and sodic soil have purification ability of wastewater organic compounds removal and need different factors optimization for this purpose.

Kinetic study

Fig. 3 shows amounts of adsorbed organic compounds. Totally the kinetic data in this study showed two general steps; first step is fast due to adsorption reactions and second step is slow that indicated diffusion process on particle surface. This two kinetic steps were demonstrated in several studies in relation to removal of pollutants in soil (Calvet, 1989). On the other hand, the obtained results of current study showed that highest organic pollutant removal in saline-sodic and sodic soils were 44 and 49 %, respectively. Ligand exchange, cation-anion exchange, inner sphere complexes, cationic bridge and hydrogen bonding are surface adsorption mechanism

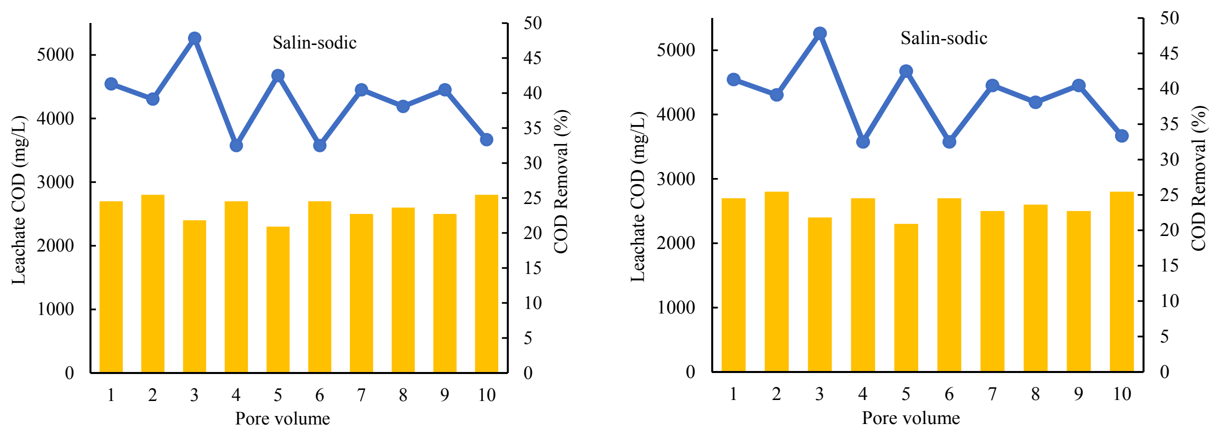

Fig. 2: COD values of soil column leachate and removal percentage over 10 pore volumes of leaching experiment

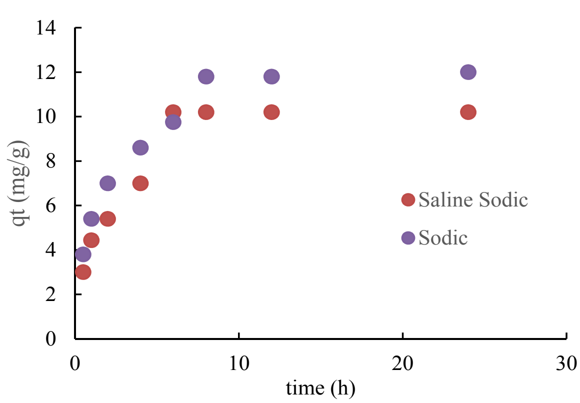

Fig. 3: Variations of wastewater organic compounds adsorbed to soil (q_t) over time

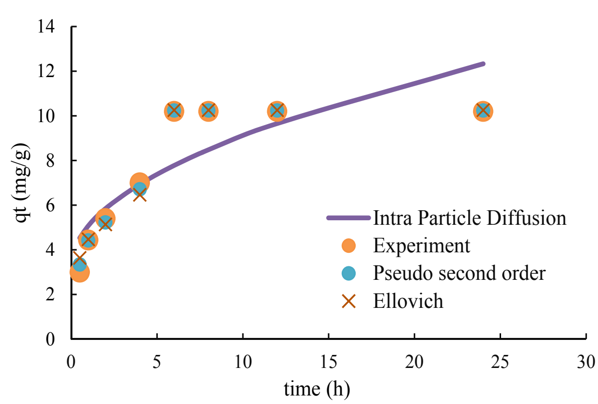

Fig. 4: Adsorption kinetic for wastewater organic compounds on saline-sodic soil

Table 4: Constants parameter of applied linear kinetic models for the adsorption wastewater organic compounds on soil

Model	Parameters	Unit	Saline-sodic	Sodic
Pseudo second order	q_e	mg/g	6.59	7.85
	k_2	g/mg/min	0.0363	0.03078
	r^2	-	0.996	0.995
Intra particle diffusion	a	-	3.215	3.975
	R	-	1.861	2.043
	r^2	-	0.737	0.817
Elovich	α	mg/g/min	2.359	2.8763
	β	g/mg	0.144	0.1205
	r^2	-	0.987	0.982

of soluble organic compounds to soil particle (Rashad *et al*., 2010; Mavi *et al*., 2012). Mavi *et al.* (2012) reported that EC and clay percentage of the soluble organic compounds adsorption were increased due to increasing of adsorption surface and cationic bridges. The obtained results from current study showed that there are no considerable difference between maximum adsorption of organic compounds in both saline-sodic and sodic soil. This can be resulted due to the high organic load of applied wastewater and adsorption mechanisms of organic compounds dominantly as function of soluble organic compound concentration, while soil properties as adsorbent are less importance. In compared with the current study, Krishna and Philip (2008) were reported that compost soil reach to adsorption equilibrium in 6 h and sandy soil reach to equilibrium at 2 h while the results of current study showed that intra particle diffusion model was best fitted. Kumar and Philip (2005) found that sandy soil reach to equilibrium at 1.5 h whereas clayey soil reach to equilibrium at 4 h. Therefore, the high adsorption rate in different study indicated surface adsorption of organic compounds in soil at low concentrations.

Modeling of the adsorption kinetics of wastewater organic compounds in soil by three pseudo second order (PSO), intra particle diffusion and elovich model showed that pseudo second order has better simulation in both saline-sodic and sodic soil based on r^2=0.99 (Table 4 and Figs. 4 and 5). The concentrations of adsorbed organic compounds at equilibrium (q_e) were 6.59 and 7.85 mg/g in saline-sodic and sodic soil, respectively. Therefore, there is a little difference in adsorption parameters between saline-sodic and sodic soil. Comparing the results of kinetic adsorption of organic pollutants (compounds) in saline-sodic and sodic soil with pseudo second order (PSO) showed

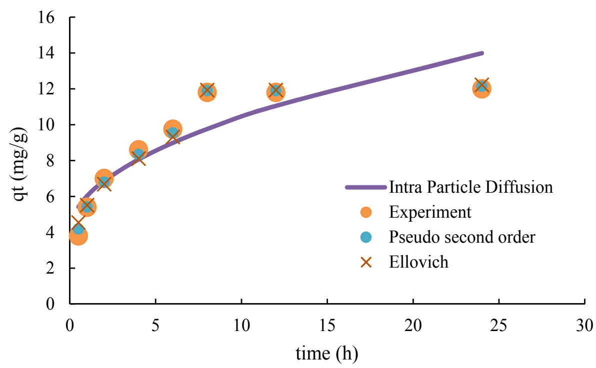

Fig. 5: Adsorption kinetic for wastewater organic compounds on sodic soil

that the adsorption capacity was dependent on activity of adsorption of soil. Actually, chemical adsorption from exchange or sharing electron is dependent on adsorption limitation factor in saline-sodic and sodic soil. Subramanyam and Ashutosh (2009) reported that comparison between the kinetic models of phenol adsorption by pseudo second order, elovich and intra particle diffusion models, the pseudo second order model was best fitted. Consequently, the mentioned result was in agreement with the results of the current study.

CONCLUSION

Leaching of saline-sodic soil as quick and effective method for reclamation saline-sodic soil has been limited due to water scarcity. Moreover, during leaching of saline-sodic soil the ionic composition of water was changed that cause rise up water salinity where finally cause another environmental concerns in downstream. Hence the reusing of different type of wastewaters in agricultural fields need environmental assessment for water quality and both saline-sodic and sodic soil. For example, reusing the wastewater with high organic load as presented in this study need effective strategy for removing organic pollutant before releasing to drainage. Therefore, the concept of safe releasing of reused wastewater to agricultural drainage must be considered in every type of wastewater pollutant (heavy metal, nitrate, phosphate, biological and etc., polluted wastewater) and agricultural land use. The results of the current study showed that, although applied wastewater has considerable ability in soil desalinization and desodification, but high level of leachate COD was challenge over this procedure. Therefore, wastewater organic pollutant removal before releasing wastewater to land or in situ purification is necessary.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

ABBREVIATIONS

%	Percent
$AgNO_3$	Silver nitrate
C_0	COD of wastewater
Ca	Calcium
$Ca(HCO_3)$	Calcium bicarbonate
$CaCO_3$	Calcium carbonate
CEC	Cation exchange capacity
Cl	Chlorine
COD	Chemical oxygen demand
Ct	COD of liquid phase
dS/m	Deci Siemens per meter
EC	Electric conductivity
EDTA	Ethylenediaminetetra acetic acid
ESP	Exchangeable sodium percent
Ex	Exchange
f	Soil porosity
g	Gram
g/cm^3	Gram per cubic centimeter
g/mg/h	Gram per milligram per hour
g/mg/min	Gram per milligram per minute
h	Hour
H^+	Hydrogen ion
H_2CO_3	Carbonic acid
ha	Hectare
HCl	Hydrogen chloride
HCO_3	Bicarbonate
k_2	Pseudo second-order apparent adsorption rate
km	Kilometer
km^3	Cubic kilometer
$km^3/year$	Cubic kilometer per year
L	Liter
meq/100g	Milliequivalents per 100 gram soil
meq/L	Milliequivalents per liter
Mg	Magnesium
mg/g	Milligrams per gram
mg/L	Milligram per liter
Mg^{2+}	Magnesium cation
Na	Sodium
OM	Organic matter
pH	Potential of hydrogen
PSO	Psuedo second order
PV	Pore volume
PVC	Polyvinyl chloride
qe	Equilibrium adsorption capacity
qt	Adsorption capacity
$q_{t,exp}$	Adsorbed wastewater
$q_{t,model}$	Model fitting
R	Rate factor
r^2	Correlation coefficient
rpm	Revolutions per minute
SAR	Sodium adsorption ration
SO4	Sulfate ion
uS/m	Micro siemens per meter
V	Wastewater volume
v/v	Volumetric ratio
W	Soil weight
α	Alpha
β	Beta
ρ_d	Soil bulk density
ρ_s	Soil particle density

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