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Adsorption of Iron Metal Using Laboratory Multiple Porous Media System

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Abstract

In this work, the focus was done on the study of the transport and absorption of Iron metal (heavy metal) through various multiple porous media. A physical model of a laboratory system similar to the filters system was established consisting of a 4-meter pipe, each meter of which is placed in a specific type of soil, which are sandy, organic, calcareous and sandy gravel soil respectively. The characteristics and the adsorption of the media were tested and the pollutant was prepared and pumped as an aqueous solution through the physical model continuously for more than 50 hours. The results showed that the adsorption process and consequently the removal efficiency are higher in the first porous medium contained in the first part until the saturation is near. Then the second media begin to play the major role for the adsorption and the removal efficiency and so on for the third and fourth media respectively. The results also showed that the adsorption efficiency depends on the arrangement and type of the porous medium. The system of a multiple porous medias provides a very good technique to getting rid the heavy metals with a very low cost.

"Keywords: Heavy metals ;adsorption;pourous media;soil."

1. Introduction

All terrestrial ecosystems rely on the soil as a key component. It supports plant life by providing a nutrient-rich environment and is critical for biomass degradation and transfer. Soil is a complex heterogeneous medium made up of solid phases containing minerals and organic materials, as well as fluid phases (soil water and soil air) that interact with each other and ions entering the system. The ability of soils to adsorb metal ions from aqueous solution is of particular interest, as it has implications for both agricultural and environmental issues, such as polluted soil remediation and waste deposition [1]. Heavy metal ions are the most harmful inorganic contaminants found in soils, and they can be either natural or man-made. Some of them are poisonous even at extremely low concentrations, and their toxicity rises as they accumulate in water and soils [2]. The buildup of heavy metals is caused by a process called adsorption. As a result, knowing how heavy metals are carried from a liquid mobile phase to the surface of a solid phase requires a thorough understanding of adsorption processes [3,4]. Inorganic colloids such as clays, metal oxides, and hydroxides are the most prominent interfaces involved in heavy metal adsorption in soils. Phosphates and metal carbonates Living organisms such as algae and bacteria, as well as organic colloidal matter of detrital origin, provide surfaces for heavy metal adsorption [5-9]. Soil type, metal speciation, metal concentration, soil pH, solid: solution mass ratio, and contact duration are the most critical characteristics affecting

Heavy metal adsorption and dispersion between soil and water. At high soil pH, metal retention and solubility are often higher [10-12]. By reviewing many previous literatures, it was noted that there are no

Pollutants and the adsorption process through multi-layered soils. There are two primary

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approaches to analyzing the transport of contaminants in porous media in terms of responses. These are referred to as random and deterministic approaches, respectively [13,14]. Stochastic techniques or methods that deal with response coefficients are deemed "static prcesses" and may be confirmed at the site with adequate amounts of their own by the random hydraulic conduction field [15, 16]. Sadiq S. Muhsun et al [17], constructed physical and simulated models using a computational fluid dynamic (CFD) technique to study the solutions of contaminant transport problem within the saturated porous media under a hydraulic structure. Reliable statistical indexes error showed that the CFD simulated model provides a good acceptable with the results of the laboratory work. The purpose of this research is to study the process of transporting heavy metal pollutants (iron) in multiple porous media, which includes 4 types of soil arranged in the following manner (sand soil, organic soil, calcareous soil and sandy gravel soil) by creating a system that simulates the reality in the pollutant transfer process in the soil. Verification of porous media and the possibility of using it as a filter system to reduce concentrations of heavy metals at a low cost.

1.1 adsorption theory

Adsorption is a common surface phenomena that explains the attachment of particles (ions, atoms, and molecules) from the gas phase or a solution to a solid material's surface [21,22]. The adsorbate is the material that is adsorbed, and the adsorbent is the surface that adsorbs it, such as silica gel, resins, porous clays, alumina, zeolite, activated carbon, and so on. Purification of drinking water and elimination of dangerous contaminants from wastewater are part of the application. It's also used in air pollution management and a variety of chemical engineering procedures [23].

1.2 Adsorption Mechanisms

A mass transfer of contaminated particles happens on the outer layer of the solid item inside it, and many methods of adsorption occur. Diffusion is used to adsorb contaminated particles on active sites on the solid surface, and then melting happens on active sites in the pores of the solid surface, where practical travel to the surface of the pores is accomplished by surface diffusion [24]. a figure(1) that illustrates this.

2. Experimental

2.1. Porous media

In this research, four types of soil were used to simulate the process of soil adsorption through the flowing of the pollutant in multiple porous media, see figure (٢). The Medias were arrangement to be as sand, organic, calcareous and Sandy gravel. The second media (organic material) was consisting of (sand, clay and silt as well as peat moss soil) in equal proportions. The third media (calcareous soil) was consisting of 65 % of sand and 35 percent of lime. While for the fourth media (sandy gravel) was made using gravel soil consisting of sand soil of 60 percent and gravel of 40 percent. All types of soil were washed and dried and then some tests were done to estimate the basic properties of the Medias as the bulk density, permeability, porosity and percentage of sulfates as listed in table (1**).**

Table.1. It shows the properties of the four porous media used

Soil	permeability(m/s)	porosity	*Bulk density(g/cm3)*	*PH*	*sulfate in soil (g/kg)*
Sandy	0.0033	0.35	1.26	7.82	2.06
Organic	0.0024	0.38	1.02	7.19	16.95
Calcareous	0.0045	0.29	1.37	7.94	10.15
Sandy gravel	0.0068	0.3	1.48	7.54	3.36

Fig. 2. Types of soil used in laboratory model

The following equations were used to calculate the permeability:

$$k = QL/Ath \qquad (1)$$

K: the coefficient of permeability in cm/sec.
L is the specimen's length in cm.
t = discharge time in seconds.
Q = discharge volume in cm^3/sec.
A = permeameter cross-sectional area in cm^2
h = difference in hydraulic head over length L, in cm of water.

The following equations were used to calculate the porosity:

$$P = Vp/(Vp + Vs) \quad (2)$$

P=porosity

Vp= volume of pore.

Vs=volume of sample.

The following equations were used to calculate the Bulk density:

$$\rho = w/v \quad (3)$$

ρ = Bulk density

w=Wight of dry soil (g)

v= The volume of the container containing the soil(cm^3)

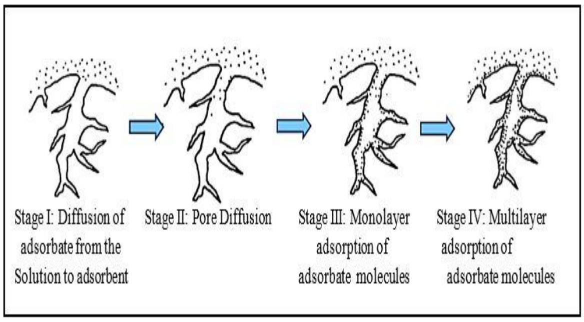

Fig. 2 Types of soil used in laboratory model.

2.2. Contaminated water Preparing

In this research, the powder of the Ferric Trichloride ($FeCl_3$)compound was used Which has a molar mass of 162.2g/mol and a purity of 99% and is supplied by Thomas Baker, and to obtain the iron element at a concentration of 50 mg/L. Were taken 36.3 g of the Ferric Trichloride compound was dissolved in a 250-liter water tank at a temperature of 30 degrees Celsius and ph water at 7 measured by ph meter. Distilled water was used in this research because liquefied water contains a high amount of salt that leads to the precipitation of the pollutant at the bottom of the tank.

2.3. adsorption coefficient experiment (Kd test)

The adsorption coefficient (kd) The quantity of chemical material adsorbed onto soil per unit of water is measured. Freundlich solid-water distribution coefficients are another name for it. adsorption coefficients are expressed in units of l/kg, or ml/g [18]. In this research, the adsorption coefficient of the four used medias was estimated using batch experiment method, [19]. Where, three different concentrations (12.5, 25, 37.5) mg/L were prepared. Each of these solutions was placed with one gram of each type of soil in a 100 ml bottle of solution. After that the shaker device was used for 3 hours and at a speed of 250 rpm. This device is a sample vibrator whose purpose is to mix the pollutant with the soil .Then, the final concentrations were calculated after the adsorption process was done. Finally, The following equations were used to calculate the adsorption coefficient:

$$q = ((ci - ce) / mass) * v \quad (1)$$

$$kd = \Delta q / \Delta ce \quad (2)$$

q: equilibrium concentration, mg/g.

Ci: Primary concentration of iron ion, mg/l.

Ce: final concentration of iron ion, mg/l.

Kd: coefficient of adsorption, l/g.

V: The volume of iron ion solution, ml.

W: Soil weight, g.

2.4. laboratory system of porous media

Figures (3) and (4) explain the physical model that was designed and built in the lab to simulate the process of the transfer of pollutants in the soil. The model consists of a 4 m polyethylene pipe length and 0.08m diameter. It was divided to four parts of 1 m length where each part was customized to each one media of the four used media (sand, organic, calcareous and sandy gravel) respectively. The pipe was placed on an iron stand 1.5 meters high. For every one meter, there is a small tube of 3 cm long and 1 cm in diameter used to withdraw samples of the pollutant at a certain period during the continues operation. The pipe was connected to a 250 liters tank used to pumped the pollutant water of a constant 50 mg/l Iron concentration to the pipe through a pump with a capacity of 30 l/min. at the other side, there is also another 250 liters tank used to collect the pollutant water disposed from the end of the pipe. The discharge through the system was estimated depending on the quantity of the disposal water drained from this end pipe using volumetric method.

Fig. 3. Diagram of a laboratory system for the physical model.

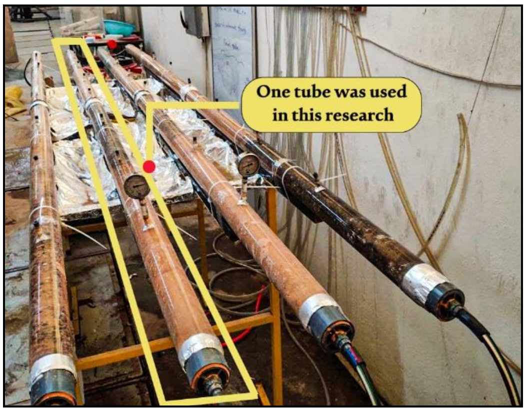

Fig. 4. The real laboratory system of porous media

2.5. Work of the laboratory system of porous media

As mentioned earlier, the pipe was filled with the four porous media in such a way that they occupied pipe in the following sequence. The first meter was for sandy soil, while the second, third and fourth meters were for organic, calcareous and sandy gravel soils respectively. The soil compaction was made during the filling to reduce the voids. After that, the pollutant was pumped to the pipe with an outflow of 0.058 Liters per minute. The process of withdrawing influents samples were done using a syringe enters inside a small tube fixed at the end of each meter of the pipe (at the end of each length of the four media). The needles of the syringes were reach to center of the pipe and the withdrawals influent sample were done at different periods from each small tubes simultaneously for about 50 hours of the continuous operation of the physical model. The samples were collected in special containers. Then they were coded and the measurement time and distance were fixed on each one and sent to the laboratories of the College of Agriculture, University of Baghdad.to measure the concentration of the pollutant of each sample. Figure 5 shows before and after the adsorption process in sandy soil.

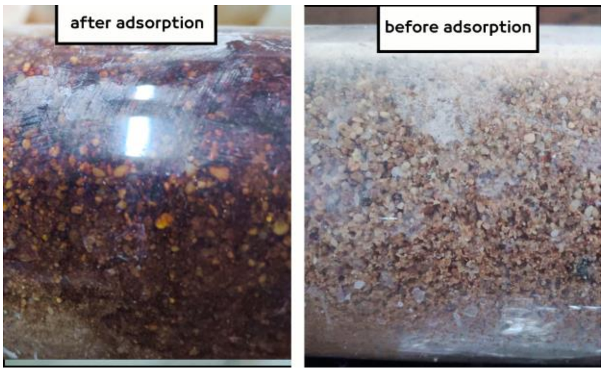

Fig. 5. Show before and after adsorption in sand soil

2.3. Some important experimental problems and their solutions

Many tests were done before the start of the real experiments to get the most accurate results and also to take the part as useful for future projects to avoid mistakes.

1- One of the important problems of the process of transporting pollutants in the porous medium found in the pipe is the process of slipping the pollutant that occurs between the surface of the soil and the circumference of the pipe, especially if the pipe is smooth which causes a creating void between the pipe and the soil that results to pass a significant quantity of the fluent through this void without treatment by the media. To solve this problem, two solutions have been used, the first is the process of wetting the pipe and then filling the soil, and thus the adhesion between the soil atoms and the pipe makes it rougher. And the second solution is to use the soil compaction process using a hand-made tool for the process of compacting the soil to fill all the circumference of the pipe. Figure (6) and (7) illustrates the process.

Fig. 6. Show compaction process

Fig. 7. Show after compaction process

2-The second problem is the process of withdrawing samples from the holes. Because of the phenomenon of slippage that was mentioned previously, if it occurs, even in a small way, it will affect the results. The pollutant collects from the small suction tube of 3 cm in length and 1 cm diameter as mentioned above. To ensure accurate results, the suction process must be carried out from the middle of the soil through an injection needle as in Figure (6).

3-The third problem is related to soils that contain gravel or a large gradient in the soil. In this case, when filling the soil in the pipe, the soft soil will fall to the bottom due to gravity, while the gravel will remain at the top. Thus, the two parts of the media will be separated which does not recommended to occur. To solve this problem, the soil must be moistened in such a way that there is adhesion or agglomeration between the two parts and all the soil particles which preventing the separation between the particles of the two parts to happen.

4-The fourth problem is the process of using drinking water for pollutant mixing. The pollutants will interact with the salts already existed in water. Thus, the pollutant is deposited at the bottom of the tank. Therefore, a distilled water free of salts is recommended to use.

5-One of the problems that may affect the system is the formation of bacteria and algae between the soil particles when the system is left without work for long periods. These bacteria cause a blockage in the porosity of the soil and thus change the amount of outflow. However, it was noted that after some time of the operation with a good pumping, these bacteria will be vanished or reduce to a low quantity due to washing and the flow returns to its normal state. Therefore, it is recommended to make a washing process bu pumping after each new operation or test. Figure 7 shows the formation of bacteria and algae in our work.

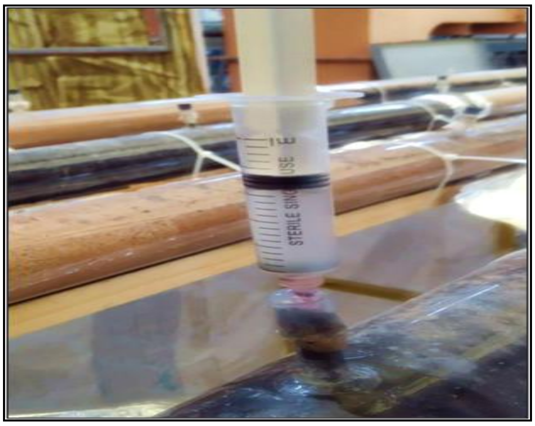

Fig. 8. Pulling pollutants out of the soil

Fig. 9. Bacteria and algae are inside the porous soil

3. Results and Discussion

3.1 Kd test results

The results of the coefficient of the adsorption, (kd) test for the four porous media are follow in Figures (10 to 13). The Figures show the results of the adsorption experiment, where the x-axis represents the final concentrations and the y-axis represents the equilibrium concentration (q). The adsorption coefficient (kd) represents the slope of the best fitting line. For the four media, the results showed an adsorption quantity of 0.0693 mg/g for sand soil and 0.0996 mg/g for organic soils and 0.0758 mg/g for calcareous soils and for gravel sandy soils the result was 0.0637 mg/g. From the above results it is clear that the adsorption rate of the organic soil has a highest kd value. This is because it contains a high quantity of ions and the chemical diversity that capable to make a very good adsorption processes more than the others three medias. While, the adsorption results of the fourth media (sandy gravel soils) showed the lowest adsorption rate.

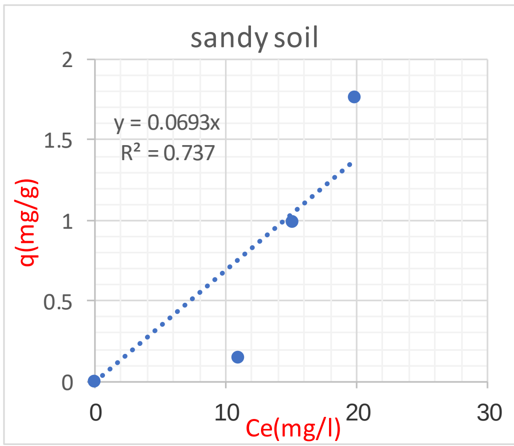

Fig.10.Iron adsorption coefficient (kd) in sandy soil, part 1

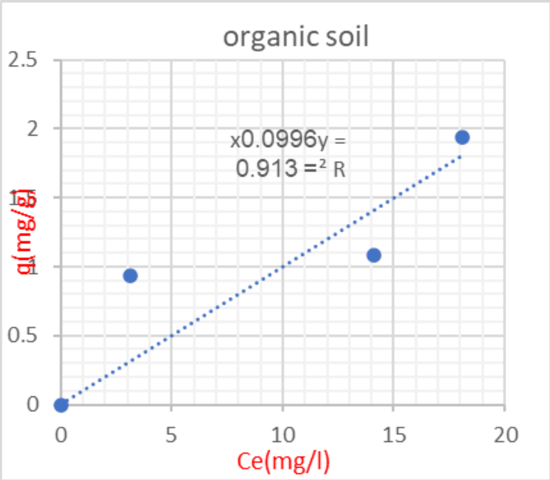

Fig. 11. Iron adsorption coefficient (kd) in organic soi, part 2.

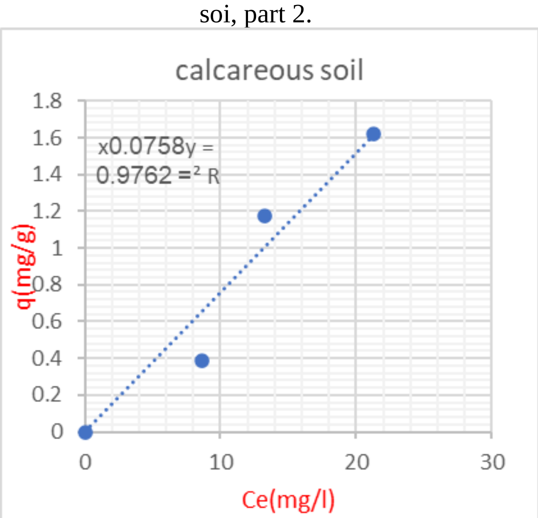

Fig.12. Iron adsorption coefficient (kd) in calcareous soi, part3
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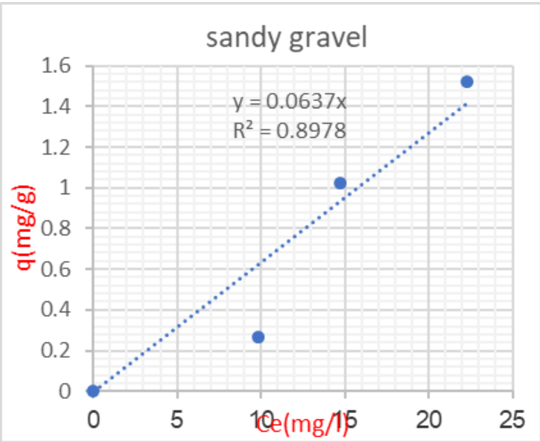

Fig.13.Iron adsorption coefficient (kd) in sandy gravel soil, part 4

3.3. Adsorption effect

Figures 12 to 15 show the adsorption process along multiple four medias through aa operation period of 50 hours. As the Figures indicate the values of concentrations in any part of the soil are constantly increasing with time, The reason for the increase with time is that the soil gradually begins to saturate and is unable to absorb, so there is an increase in the concentration of the pollutant that is withdrawn from the soil with time, but they are decreasing with the distance at any moment in time, due to the adsorption effect that works to adsorb pollutants from the solution the longer the distance the pollutant moves. Where the soil in the first meter absorbs the largest possible amount of the pollutant and the remainder is transferred to the second soil in the second meter and so on until the first soil reaches a near equilibrium, and the second part of the soil takes over the task, and thus the process continues. For clarity, note Figure 1٨ and Table 2.

Table.2. Shows the results of the adsorption process for the four porous media.

	sand	**organic**	**calcareous**	**sandy gravel**
time(h)	**Con(mg/l)**	**Con(mg/l)**	**Con(mg/l)**	**Con(mg/l)**
0	0	0	0	0
0.5	0.188	0.157	0.229	0.219
1	0.219	0.219	0.237	0.221
2	0.241	0.317	0.256	0.236
3	0.996	0.451	0.316	0.286
4	1.967	0.461	0.358	0.294
5	2.939	0.472	0.386	0.302
10	2.845	0.563	0.391	0.334
15	3.765	0.586	0.421	0.395
20	5.896	1.126	0.781	0.561
25	7.698	2.677	0.925	0.747
30	9.352	4.104	2.845	2.231
35	19.672	7.113	4.37	3.598
40	28.87	9.531	7.197	5.66
45	34.67	13.373	8.368	7.113
50	44.435	23.931	16.485	8.452

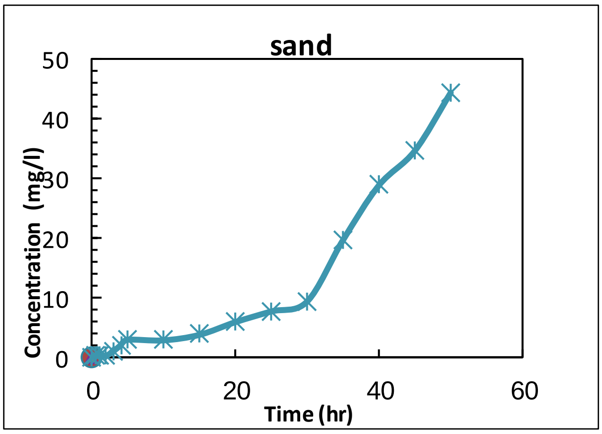

Fig. 14. Iron adsorption process in organic soi, part 1

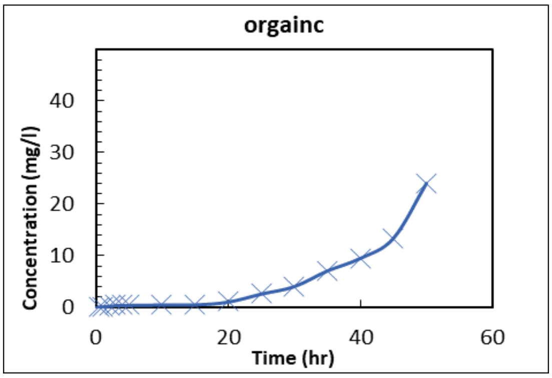

Fig. 15. Iron adsorption process in organic soi, part 2

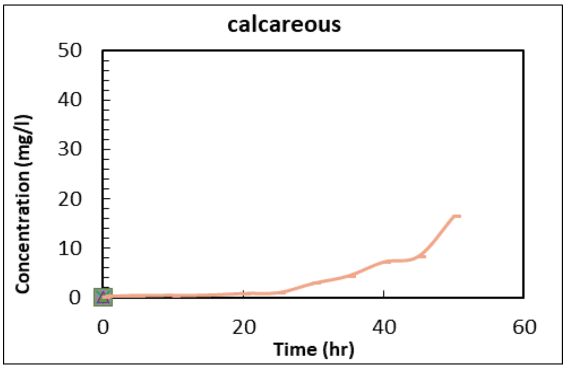

Fig. 16. Iron adsorption process in calcareous soil, part 3.

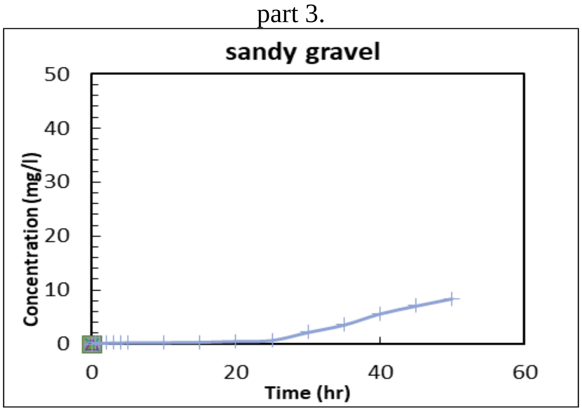

Fig17. Iron adsorption process in gravel sandy soil, part 4.

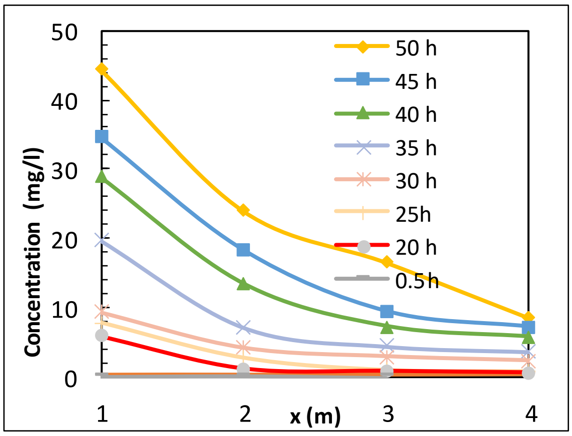

Fig18 the effect of distance on Iron adsorption process

3.4. Adsorption efficiency

Figure No. 19 shows the efficiency of the adsorption process for the four porous medias through the time. From the chart, we note that the adsorption efficiency is higher in the first meter of soil (first media), which is sandy soil. The efficiency decreases over time due to soil saturation with the pollution. It is noted that after 35 hours the soil has reached an efficiency of about 60 percent and then decline until it reaches an efficiency of 11 percent at the time of 50 hours. After which the second meter of soil begins, and its efficiency gradually increases with the decrease in the efficiency of the first media, and so on for the rest of the other two soils. This means that the first type of the soil bears the greater percent of the removal until it loses its capacity and its efficiency decreases. Then the second type of the soil begins to bear the removal process, and its efficiency begins to increase until it also reaches the point of saturation. So that the third type of the soil bears the removal process, and so on. The reason for this is that the sandy soil (the first part of the system) bears the most burden in removing the pollutant, even as it is located in the foreground so that it adsorbs the largest possible amount of the pollutant and transfers small concentrations to the part after it until it reaches a state of saturation and loses the adsorption advantage. For this reason, it is recommended to arrange the soil according to its efficiency in the adsorption process. In other words, obtaining a higher removal efficiency is to arrange the porous media from the highest Kd value to the lowest.

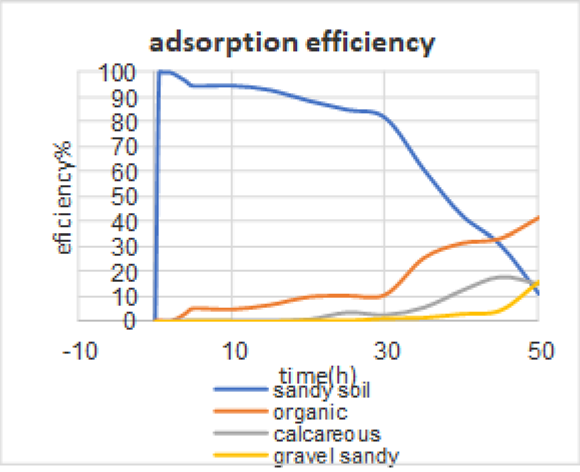

Fig19. Iron adsorption efficiency for all parts

Conclusions

From the results, adsorption coefficient experiment shows that organic soil is the most capable of adsorption and sandy gravel soil is the least capable of adsorption. The results of the physical model showed that the adsorption process occurs largely in the first part of the multi medias and then gradually begins to saturate with the passage of time and the adsorption moves to the second meter and then the third and fourth and so on. The adsorption efficiency depends on type and the arrangement of the porous medium, where the first media bore the bulk of the pollutant's removal, and when the process of saturation is near, the effectiveness of the second medium begins to talk its role 0f removal process, and so on. The system of multi layers porous media is a very good technique that could be used as a filter system to purify and reduce concentrations of heavy metals from aqueous solutions with a very low cost.

Recommendation

Using the same system could be used to study a two-phase flow through multiple porous medias. CFD simulated model is a very necessary step to simulate the contaminants transport through multiple porous medias and comparing the results with that of the physical model

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