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Research paper

Removal of Inorganic Contaminants Using Manufacturing Porous Media

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Abstract

The objective of the experimental work performed in this study is to analyze the adsorption of the total organic carbon from aqueous solutions using a manufacturing porous media of Activated Ceramic (ACR) in a continuous flow system, consisting of horizontal PVC pipes of 150 mm diameter and 6 m length without membranes. The discharge of the polluted water in the system was varied at values of 10, 20, 40, 60, 80 and 100 L/hr while the contaminants were changed in concentrations of high and low with the measurement of pressure. The results show that in order to increase the removal efficiency of heavy metals, the detention time and the length of the pipe must be increased. The decrease in flow discharge results in an increase in the removal efficiency of the heavy metals while the results for the removal process of the ACR media were: Mn^{+2}> Cr^{+3} > Fe^{+2} > Cu^{+2} > Zn^{+2}.

Keywords: *Activated ceramic, Adsorption, Heavy Metals, Inorganic Contaminants removal, organic carbon, Porous Media.*

1. Introduction

The removal of heavy metals such as iron, manganese, copper and chromium from aqueous solutions is essential due to recurrent presence of these metals in various waste streams which arise from several industries. Common examples of these industries include electroplating, metallurgical, tannery, chemical manufacturing, metal finishing, mining and battery manufacturing. In recent years, the issue of the presence of heavy metals in waste streams has become a significant problem which needs addressing immediately. This is because the presence of heavy metals in waste streams can have detrimental effects on the marine life. In addition, the marine life has direct relations to the human food chain and thus the presence of heavy metals in waste streams can also have a huge impact on human beings due to the high health risk posed by metals on consumers **[1]**.Several technologies have been developed over the last few years in order to reduce the contaminated effluents. Prominent techniques depend on reverse osmosis, ion- exchange, membrane systems, chemical precipitation and filtration. However, all these techniques have various advantages and limitations associated with their application. In the recent past, it has been shown that adsorption is an alternative method for treating the dissolved metal ions from liquid wastes **[2]**.Due to their efficiency in the removal of pollutants, the adsorption techniques for wastewater treatment have become a popular method as compared to the traditional biological methods. This is also due to the increased stability of adsorption techniques for treating and removing pollutants. "Adsorption is a process which occurs when a gas or liquid solute adheres to a surface (adsorbent), forming a molecular or atomic film (adsorbate). This process differs from absorption, in which a substance diffuses into a liquid or solid to form a solution". In order to overcome the hazardous waste in wastewaters or purify drinking water, the industrialists have perfected adsorption methods. Also, it was revealed that adsorption methods are superior to many other techniques for water re-use in terms of initial cost, ease of operation flexibility, insensitivity to toxic pollutants and simplicity of design **[3]**. Similar to the surface tension, surface energy also results in adsorption. To elaborate, atoms on the surface of adsorbent are not wholly surrounded by other adsorbent atoms. Therefore, they can attract the adsorbate **[4]**. Generally, there are two categories of adsorption mechanisms; chemical adsorption or physical adsorption. The intermolecular forces which interact between the adsorbate and the adsorbent represent thePhysical Adsorption. The van der Waals force consists of weak attraction and repulsion through "dipole – dipole" interactions and dispersing interactions with hydrogen bonding included in the physical forces. "Dipole – dipole" interactions are the result of polar compounds orienting themselves that they charge result in a lower combined free energy. Consequently, the attractive forces between the nuclei of a molecular system and electrons results in the dispersing interactions. The van der Waals force is a primary physical force which drives adsorption **[5]**. When the forces between the molecules of the liquid stream are less than the intermolecular forces between a chemical molecule in a liquid stream and a solid (the adsorbent), the chemical substance is adsorbed onto the adsorbent surface **[6]**. Also, the chemical and physical adsorptions have similar mechanisms. Yet, often stronger chemical adsorption is produced by the transfer of electrons and the formation of chemical bonds between the adsorbate and the adsorbent. This is due to the high adsorption energies and may be an irreversible reaction **[7]**.

The main objectives of this study are to modify the adsorptive porous media to remove inorganic contaminants (heavy metals) such as Cu^{+2}, Mn^{+2}, Fe^{+2}, Cr^{+3} and Zn^{+2} and to understand the effects of the activated ceramic on the hydraulic pressure and the flowrate for the horizontal flow of the wastewater.

2. Material and Methods

2.1Laboratory Model

The physical model used in this study consists of PVC horizontal pipes of 6 m length and 15 cm diameter filled with a manufacturing porous media (ACR) as present in

Figure 1 and

Fig.2. At each of 1.5 m there is a fixed outlet point with a water pressure gauge and a valve for sample collections. The pipe is connected to the flow measurement system with two parallel flow meters to control the inflow discharge. The model has a large tank of a **2500 *l*** capacity used to collect the contaminants and then pumping to the system again by an electric pump. The system is designed and installed in order to estimate the pressure drop, flow rates and the concentrations of the following metals in the effluents; Zinc, Copper, Chromium, Iron, Manganese.

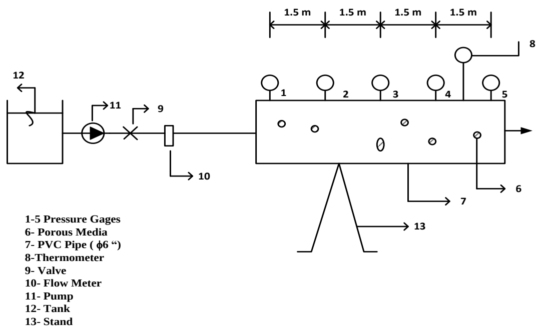

Figure 1: Laboratory Schematic diagram (Laboratory model).

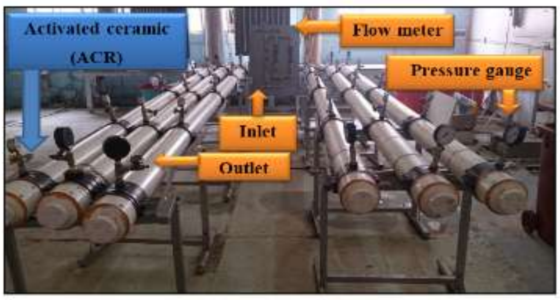

Fig.2: Photographic image of the experimental set up (Laboratory model).

2.2 Manufacture porous media (Activated Ceramic, ACR)

Activated ceramic is a modified structural adsorptive material, which was manufactured for the high adsorption process. It has a large surface area, high porosity and is formed of mega pores interconnected by filaments, as evident in **Fig.3**. The structure of the media has a low resistance to fluid flow, which makes it appropriate for use as a biofilter. With a volume ratio of 1:6:4 of bentonite powder, kaolin and crushed coal were mixed with water by a volume ratio 1:1. Then the mixture is formed thermally at different vacuum furnace temperatures while being exposed to ozone for a period of thirty minutes before using for activation.

The effect of thermal treatment and ozonation period on physical and chemical properties of Activated Ceramic was studied under various temperatures of 300, 500, 700, 900 and 1100 °C. The Physical properties of ACR are represented in **Table 1** while the distribution curve of Grain-size for Activated Ceramic porous media was also achieved and is further explained in **Fig.4**.

Fig.3: Activated ceramic porous media.

Table 1: Physical properties of activated ceramic porous media.

Properties	Test Results
Porosity	0.37
Bulk Density (kg/m^3)	1661
Particle Size Distribution (ASTM)	0.2
Effective Size D_{10}(mm)	
Mean Grain Size D_{50} (mm)	6
Uniformity Coefficient	

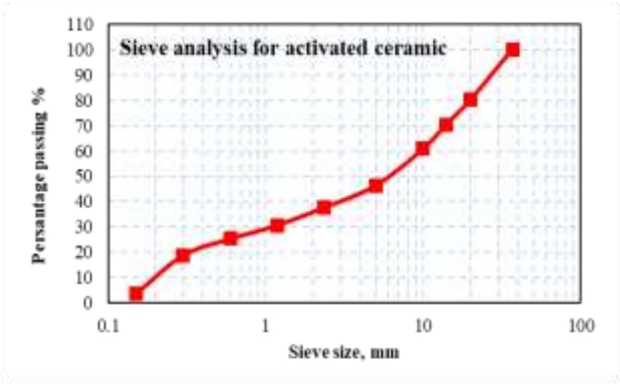

Fig.4: Sieve size distribution curve of the activated ceramic of porous media.

2.3 Wastewater Preparing

Wastewater was prepared by mixing of organic waste (Vegetables, Fruits), limiting quantity of heavy metals, as well as, a leachate of an organic waste which was buried for two months. Thereafter, all buried materials were mixed and stored in a **2500** *l* tank, using 80% tap water against 20% of the wastewater. As a results this manufactured wastewater is already contains many contaminates of heavy metals under the study likes[Cu^{+2}, Mn^{+2}, Cr^{+3}, Fe^{+2} and Zn^{+2}].

3. Results and Discussions

3.1 Hydraulic parameters - removal efficiency relationship

3.1.1 Flowrate change

Fig.5 explains the effect of the flowrate on the removal efficiency of the heavy metals using ACR media. In this case, six levels of flowrates were used starting from 10 ***l/h*** to 100 ***l/h*** by the following steps; 10, 20, 40, 60, 80 and 100 ***l/h***. As shown in the figures, the highest percentage removal takes place with the lower flow rate of 10 ***l/h*** while the lowest is at 100 ***l/h***. This is because when the contaminant crosses the media with a low flowrate, it will stay within the media for an enough time which will help the porous media to adsorb the contaminant in a perfect manner.

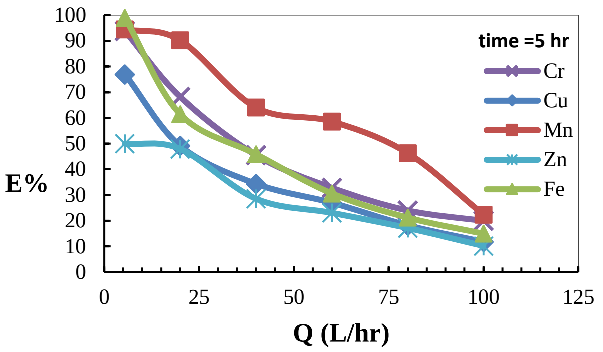

Fig.5: Effect of flowrate on removal efficiency of the heavy metals.

3.1.2. Detention time

In general, the detention time depends on the porosity and the value of the contaminant's discharge flowing through the media. Therefore, it differs from a media to another for the same flowrate and from one flowrate to another in the same media. Also, the detention time is expected to increase as the porosity increases or as the flowrate decreases or as both the processes occur. **Fig.6** shows the variation between the detention time and the removal efficiency of the heavy metals in ACR media. Based on the results, it is very clear that as the detention time increases the removal efficiency also increases.

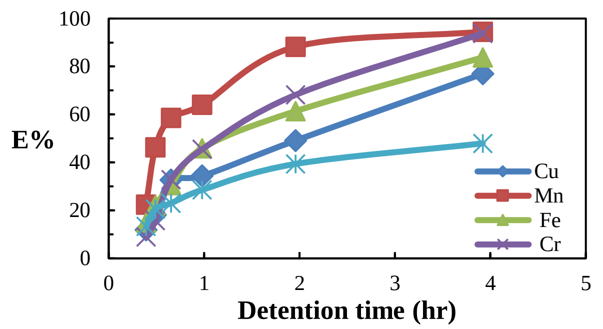

Fig.6: The variation between the detention time and the removal efficiency of heavy metals, (Q= 10 *l/hr*).

3.1.3. Pressure drop

Fig.7 shows the variation of pressure along the pipe through the period of the test with different flow discharges. It was found that while the system is operating, the pressure at each point gauge is also continuously increasing. This is because of the increase of the removable contaminants along the time which result in the increase of the concentrations inside the porous media. Therefore, the pressure inside the media is also expected to increase.

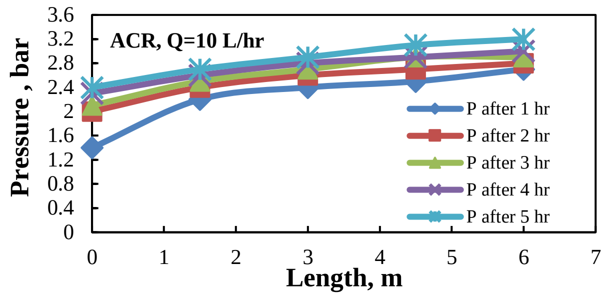

Fig.7: The pressure distribution along the pipe.

3.2 Heavy metals and TOC removal efficiency.

3.2.1. Copper (Cu^{+2}) removal efficiency.

The variations of Cu^{+2} concentrations along the length of the pipe for the period of 5 hours, discharge of 10 L/hr, average value of 1.65 mg\l are presented in **Fig.8**. As shown, the removal efficiency of Cu^{+2} increases with the increase in the pipe's length and time where the maximum value was stablised at a value of 77%.

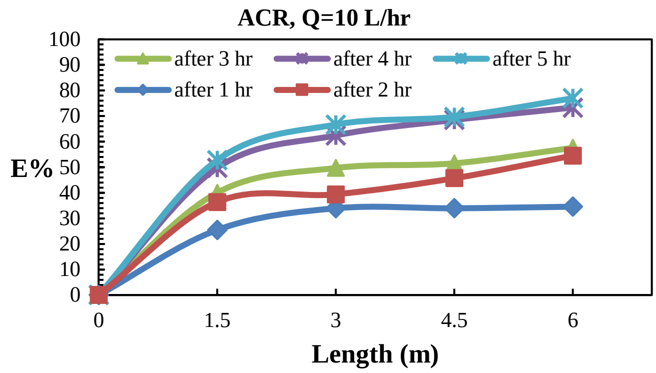

Fig.8: Variation of Copper (mg/l) removal efficiency with the pipe's length.

3.2.2. Zinc removal efficiency

With the same condition and initial value of 0.66 mg/*l*, the tests were carried and the results were represented in **Fig.9**. The figure illustrates the time and distance and the results indicate that the maximum removal efficiency of Zn^{+2} was achieved up to 52%.

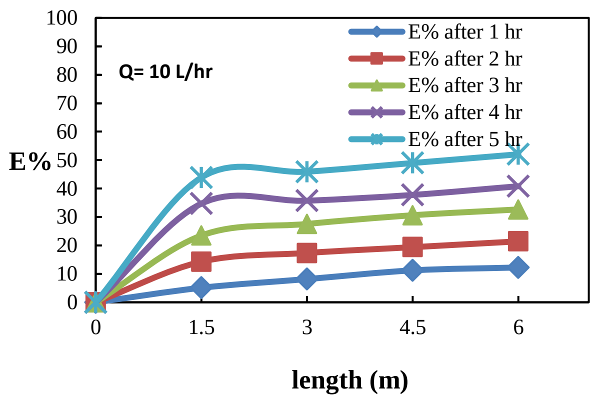

Fig.9: Variation of Zn+2 (mg/l) removal efficiency with the length.

3.2.3. Chromium (Cr^{+3}) removal efficiency.

Chromium is one of the major heavy metals presents in wastewater and has toxic effects on soil and plant. The results of this test are provided in **Fig.10** starting with initial values of 827 mg\l. The maximum value of the removal efficiency of Cu^{+2} was noted to be about 94%.

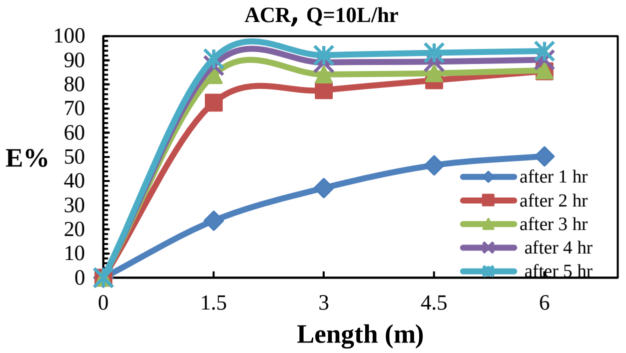

Fig.10: Variation of Cr^{+3} (mg/l) removal efficiency with the length.

3.2.4. Manganese (Mn^{+2}) removal efficiency.

Fig.11shows the results with the same condition at the check point along the pipe with different operation times and starting from initial value of 20 mg\l. The figure indicates that the final removal efficiency was recorded at 95%.

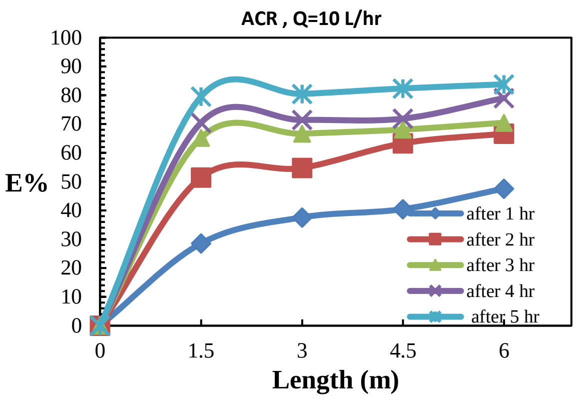

Fig.11: Variation of Mn^{+2} (mg/l) removal efficiency with the length.

3.2.5. Iron (Fe^{+2}) removal efficiency.

Starting from initial values of 21 mg\l and the same condition above all the results of this test are represented in **Fig.12**. The figure indicates that the final removal efficiency was recorded at 84%.

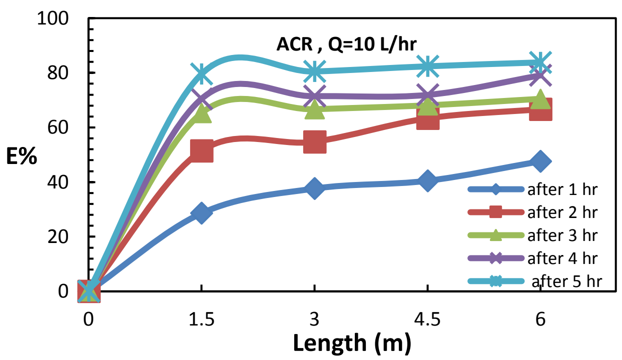

Fig.12: Variation of Fe^{+2} (mg/l) removal efficiency with the length.

4. Conclusions

This study successfully proved that heavy metals [Cu^{+2}, Mn^{+2}, Cr^{+3}, Fe^{+2} and Zn^{+2}] can be adsorbed from an aqueous solution in significant amounts by the use of manufactured porous media of activated ceramic, ACR, with the following conclusions:

- Removal efficiency of the heavy metals increases with an increase in the detention time, length of the pipe and the pressure.
- Removal efficiency of the heavy metals increases with any decrease of flowrate.
- The results of removal efficiency using ACR were: Mn^{+2}> Cr^{+3}> Fe^{+2}> Cu^{+2}> Zn^{+2}.

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