ADVANCES IN AGRICULTURAL AND FOOD RESEARCH JOURNAL

Original Research Article

Development and Fabrication of Groundwater Filtration System Using Coconut Shell Activated Carbon

Siti Khadijah Che Osmi, Zuliziana Suif*, Adam Muhammad Ezzat Aripin

[1]Department of Civil Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Sg. Besi Camp, 57000 Kuala Lumpur.

*Corresponding author: Zuliziana Suif, Department of Civil Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Sg. Besi Camp, 57000 Kuala Lumpur; zuliziana@upnm.edu.my

Abstract: This paper presents the design and fabrication of activated carbon (AC) filters from agricultural coconut shells for groundwater filtration systems. The AC had been acting as a filter medium to filtrate the water. The production of AC from local agricultural wastes is the most environmentally friendly solution by transforming negative value wastes into valuable materials. The chemical and physical characteristics of AC produced were tested by adsorption capacity using Freundlich Adsorption Isotherm. Test results showed that AC with favourable physico-chemical properties can be produced locally from agricultural waste. Moreover, four parameters were measured to determine the filter's effectiveness: pH, turbidity, total suspended solids (TSS), and ammonia (NH3 –N). Consequently, the percentage removal of turbidity is 62% to 63%, TSS is 82% to 79%, and NH3-N is 12% to 4%, meeting the water quality standard. Overall, removing water quality parameters in groundwater filtration systems is more efficient with powdered AC than with granular size.

Keywords: activated carbon; groundwater; filtration system; filter medium

Received: 30th May 2023

Received in revised form: 20th November 2023

Available Online: 15th February 2024

Published: 28th June 2024

Citation: Osmi, S. K. C., Suif, Z., Aripin, A. M. E. Development and fabrication of groundwater filtration system using coconut shell activated carbon. *Adv Agri Food Res J* 2024; 5(1): a0000420 https://doi.org/10.36877/aafrj.a0000420

1. Introduction

Water is essential to all life, especially in times of need, and it also goes for humans. The water we consume should be pure, safe, and free from contaminants, but land use in watershed areas is associated with numerous potential sources of groundwater contamination (Mohammadi *et al.*, 2020). In commercial and residential regions, pollution is caused by industry, agriculture, and other human activities.

Water treatment is a process used to improve water's suitability for a particular end use. These may be implied by usage in things like medical procedures, industrial operations, and drinking water. This entails eliminating and enhancing existing water components for potential use in all water treatment procedures. Treated water can be safely released into the environment without adverse environmental consequences. One effective method for achieving this is using activated carbon, which boasts the highest adsorption capacity and the largest specific surface area among all the adsorptive agents.

When it comes to groundwater treatment, the field of industrial chemical processes (IPC) faces many challenges similar to those faced by the potable water sector. Small quantities of volatile organic contaminants (VOCs), particularly chlorinated aliphatic and aromatic solvents, are found in drinking water aquifers (Love *et al.*, 1986). All of these distinct contaminants are VOCs. Limits for eight of these chemicals have previously been established. These substances are highly controlled in drinking water. Many of the VOCs listed, which are present in roughly 20% of the supply of drinkable groundwater (Love *et al.*, 1986), might be detrimental to the IPC's operations and output.

The term activated carbon (AC) is frequently used to refer to a class of crystalline absorbing materials with significant internal pore structures that increase the carbon's absorption capacity (Tadda *et al.*, 2016; Thinojah & Khetheesan, 2022). AC plays a crucial role in water treatment, as it can effectively eliminate particles and organic impurities. The utilization of an AC layer in water filtration has a significant impact on reducing water pollution (Suif *et al.*, 2022).

The treated activated carbon from local agricultural waste, which transforms the waste into valuable resources, is one of the greenest methods. The study's primary objectives are to design a filter medium utilising AC and assess how well manufactured AC performs in treating groundwater, focusing on achieving the highest possible percentage reduction for the parameter under investigation.

2. Materials and Methods

The chosen agricultural wastes were transformed into AC using a chemical activation process with a predetermined period of 2 hours and a combustion temperature of 600°C. After AC is created, it is divided into two unique sizes, granular and powdered, using a sieve analysis test. As an alternative, an adsorption test was also used to assess the properties of the AC. The water filtration system then achieved the second objective. The creation of high-quality water was made feasible by an effective filtration procedure. A filter was produced specifically for this investigation. Filters are made of sand, fine gravel, and coarse gravel, with AC as its main component.

2.1. Production of Activated Carbon

In the Universiti Pertahanan Nasional Malaysia manufacturing lab, activated carbon was produced using coconut shells' chemical activation (CS). The coconut flesh was scraped clean of the CS. The coconut shell has undergone a 24-hour air drying at 110°C after being properly cleaned with distilled water to remove debris and clay. The coconut shell was crushed and then put through several sieves. For further treatment, particles between 500 and 250 µm in size were chosen. For the adsorption test, the AC was divided into two distinct sizes, powder (PAC) and granular (GAC), using a sieve analysis. An adsorption test was used in laboratory tests to assess the performance characteristics of the AC.

The coconut shell was refluxed with a 1.0 M (one molar) sodium hydroxide (NaOH) solution for an hour to minimise the ash content in the sample before being used as the zinc chloride ($ZnCl_2$) activation agent from CS. The CS was saturated with $ZnCl_2$ and water in varying ratios. ZnCl has an impregnation ratio that ranges from 1/1 to 2/1 for the activation agent mass concerning the dried coconut shell mass (weight/weight). The mixture was heated using pure nitrogen at a ten °C/min heating rate in the heat treatment furnace. The oven was heated to 600°C for two hours until it showed an ambient temperature of around 28°C. After that, acid washing was performed using a 3M (HCl) hydrochloric acid solution with a pH range of 6.70 to 7.00. After that, the mixture was dried in an oven at room temperature for 24 hours.

2.2. Adsorption Measurement

The iodine number measures the AC filter’s capacity to remove organic compounds. This considers the amount of iodine (in mg) absorbed by 1.0 g of AC filtrations under set conditions, where a higher iodine number generally indicates greater adsorptive capacity (Bruce & Sharon, 2013). Strong evidence was uncovered demonstrating the effectiveness of an alternating current filter in removing organic molecules based on the iodine content.

The objectives of the test were to determine the best contact time and maximum wavelength. 0.1 g of methylene blue powder, 1000 ml of distilled water, and 200 ml of a 0.1 g/L methylene blue solution were deposited in the five sets of 250 ml conical flasks used for the batch adsorption experiments. Once added, the 0.1 g of activated carbon with a 200 m particle size was shaken at 30°C in an isothermal shaker at 120 rpm until equilibrium was attained. The samples were shaken for 10, 20, 30, 60, and 120 minutes. The solutions of aqueous samples were taken and evaluated. All samples were thoroughly filtered to lessen the influence of the carbon particles throughout the examination. Concentration Methalyne blue in the solutions before and during adsorption was discovered using a double beam UVvis spectrophotometer (UV-1601 Shimadzu, Japan) at its maximum wavelength of 565 nm and most efficient contact period of 120 minutes.

2.3. Adsorption Isotherm

As Dang *et al*. (2011) outlined, the Langmuir isotherm is employed in the context of the mass action law, ultimately yielding the thermodynamic equilibrium constant. This relationship establishes a connection between the concentration of intricate sites on the adsorbent surface and the concentration of available sites in the solution, as elucidated by Dang *et al*. (2011) in their study. On the other hand, the essential and frequently used empirical Freundlich equation is utilised to represent multilayer adsorption (Violante *et al*., 2008). In addition to being employed in solution adsorption, saturation adsorption is frequently used in chemical and physical adsorption. For isotherms in liquid conditions, the Freundlich equation is frequently given as an explanation. Furthermore, as Weber (1972) advocates, the empirical Freundlich adsorption isotherm establishes a connection between the quantity of contaminants in the solution state and the quantity of impurities in the adsorbed state.

$$ {}^{x}\!/_{m} = kc^{\frac{1}{n}} \tag{1} $$

The adsorbed state concentration where x/m is shown in Equation 1. The adsorption capacity, *k*, is expressed in (mg/g) (L/mg) units. Where *c* is the concentration of pollutants in the water, *m* is the weight of carbon supplied, and *x* is the quantity of impurity adsorbed at equilibrium. In a linear plot of log (x/m) vs log(C), k is obtained from the intercept, and 1/n (a dimensionless variable) is related to the gradient of the graph. Giving both sides of logarithms results in:

$$ \log (x/m) = \log k + 1/n \log C \tag{2} $$

The quantity of carbon added was calculated by dividing the contaminants removed from the sample by the carbon loading (x/m).

2.4. Design Filter

A 15 mm diameter PVC connecting pipe, a 6-litre water bottle with a 15 cm diameter, an effluent retaining container with a 15 cm diameter, and a 10-litre water bottle with a 15 cm diameter made up the model filter (for storing water). There are two valves between the filter and effluent container and between the storage tank and the filter. Three layers of filter pads were combined into the cylindrical filter. The intended filter is loaded with granular AC in a plastic jar at the entrance. The collector is fixed to the reservoir so that water is available. The filter media model system is depicted in Figure 1 below as layers of gravel, sand, and activated carbon.

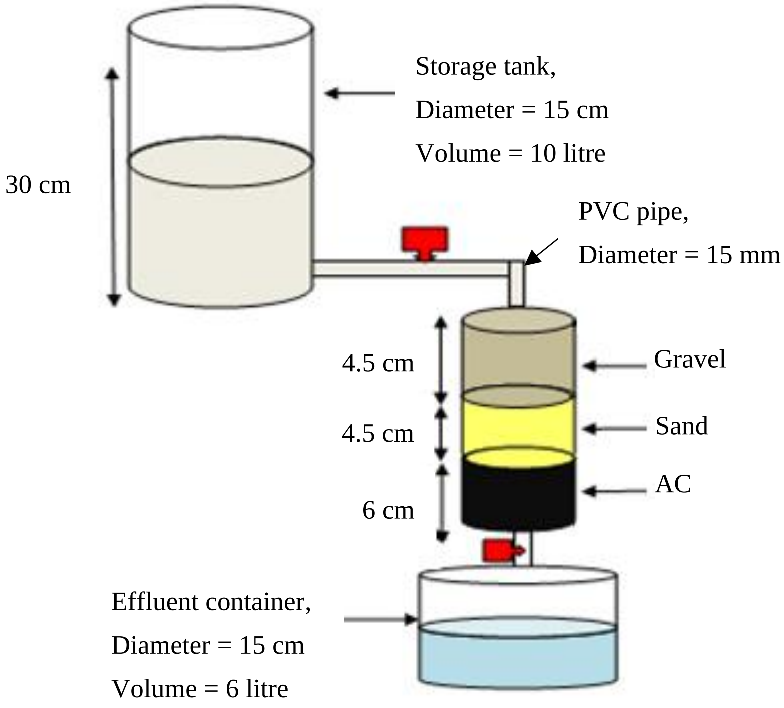

Figure 1. Water filter media consists of gravel, sand and activated carbon layers

2.5 Laboratory Test

This study tested raw water in the lab before and after filtration, with or without AC. Prior to being treated for household purposes, such as drinking water, raw water samples were tested to establish their qualities. The testing may include both physical and chemical components. The parameters measured for the water in this study were pH, turbidity, total suspended solids (TSS), and ammonia (NH3-N).

Following the standard test methods, the TSS and NH3-N were examined. In order to determine the filtering system with the highest percentage of removal and the most effective performance, a comparison and interpretation of the influent and effluent from the filters were conducted, taking into account the results of all parameter tests.

3. Results and Analysis

3.1. Efficiency of Carbon Sources

Different filter cartridges were filled with the two activated carbons, PAC and GAC. An approximation of the cumulative quantity of adsorbed contaminants was determined through the utilization of PAC. The results of the absorbance analysis indicate that PAC demonstrates superior effectiveness in removing undesirable particles from water compared to GAC. Key factors influencing the choice of carbon type, as emphasized by Clark (1989), include particle size, total surface area, void spaces between particles, and pore structure. In contrast to GAC, PAC features smaller particles, a larger surface area, increased void spaces between particles, and a more extensive pore structure. Consequently, PAC displayed a greater adsorption capacity than GAC.

The impurity concentration, C, and the quantities of impurity adsorbed at equilibrium, x/m, were compared using the equation method. The consequences of the isothermal plots in Figure 2 are demonstrated by the log (x/m) plot versus log C in equation (2). The isotherm plots showed that the carbon loading (x/m) varied linearly with the impurity concentration. The constants k and 1/n came from the graph, and n was related to the gradient of the graph, which is shown in Table 1 as an outline. The intercept on the x/m-axis, which produced between 2.509 and 2.781 for the carbon GAC and PAC, was linked to the k. The k value and adsorbent capacity are related. At the same time, the adsorption strength is related to the value of n (Weber, 1972). The mass of the adsorbate per dry unit weight of carbon (x/m) (mg/g) is immediately and exponentially influenced by k and n. The values determined by n and k (Table 1) have revealed a striking discrepancy in the carbon size's absorption capability. As opposed to GAC, PAC has an excessive adsorbent capacity.

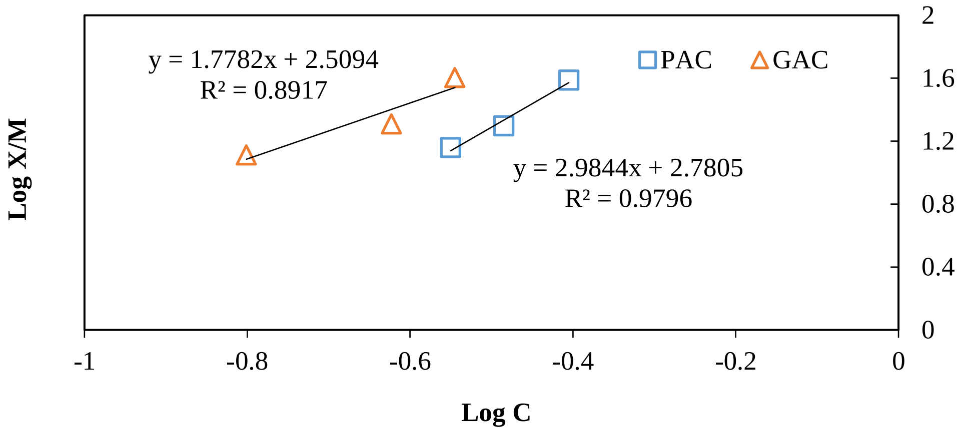

Figure 2. The plot of impurities discards versus impurities present.

Table 1. Results from Isotherm Plots

Carbon Type	Adsorbent Capacity, n	Strength of Adsorption, k
GAC	1.918	2.509
PAC	2.959	2.781

The slope and data points presented in the Freundlich Adsorption Isotherms, as discussed by Davis and Robert (2002), provide a comprehensive assessment of the performance of one type of carbon relative to others. Moreover, the isotherm data depicted in Figure 2 illustrate that existing contaminants are significantly reduced when using PAC compared to GAC. In contrast to carbon GAC, this levelled carbon PAC has outstanding absorptive strength.

An almost vertical isotherm shape exhibits poor adopting properties, particularly at low impurity concentrations. Notably, the use of AC powder, as opposed to granular forms, resulted in a substantial reduction in contaminant levels after multiple tests involving the placement of ACs in the filters for treating water. This could result from a disproportionately high AC adsorption capacity derived from powder rather than granular.

3.2. Water Filtration System Design

The groundwater samples were subjected to chemical and physical testing. Additionally, a media-treated sample of effluent water is passing through a filter.

3.2.1. pH

Figure 3 represents the pH parameter result. The pH level was increased in water filtered using AC as a layer in filter media at 60-minute retention intervals, per the results. After filtration, the pH level was reduced from 6.26 to 5.83 to 6.13, or 6.87% to 2.08%, by using AC. Using AC in the filtration process resulted in a lower increase in pH compared to filtration without AC. The pH increased by a range of 3.68% to 8.47%, showing variations between the highest and lowest percentage increases in pH following AC-assisted filtration and the smallest pH increment observed when AC was not used. Achieving a pH level close to the desired range of 6.70 to 7.00 proved challenging after washing AC that had undergone high-temperature treatment. After filtering, the pH of construction water was affected by the acidic characteristic of AC.

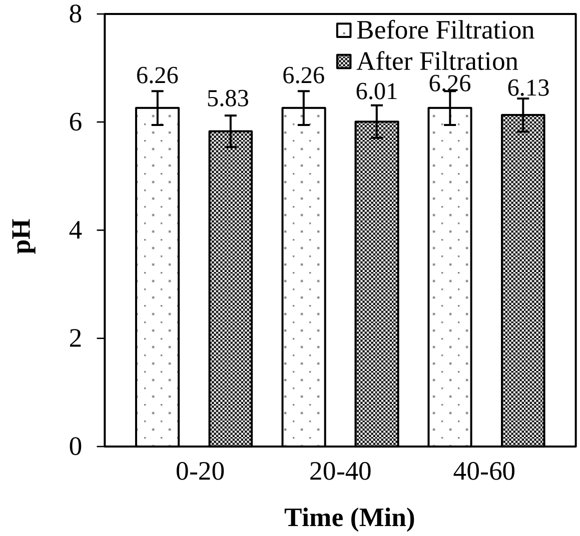

Figure 3. pH Testing Results on Groundwater Using AC.

3.2.2. Turbidity

Figure 4 displays the turbidity parameter result. The turbidity parameter was reduced at a 60-minute retention period by using AC as a layer in the filter media. After filtration, the initial turbidity concentration was reduced from 7.93 mg/L to 2.96 mg/L to 3.05 mg/L, or from 62.67% to 61.54%. The percentage of turbidity removed after using AC filtration was greater than that of not using AC, which increased from 9.97% to 11.1%. The lowest result for the percentage of turbidity removed after not using AC filtration was higher. According to Berg (1996), AC had taken the place of sand in the final effluent in the range of less than 0.1 NTU (Nephelometric Turbidity Unit).

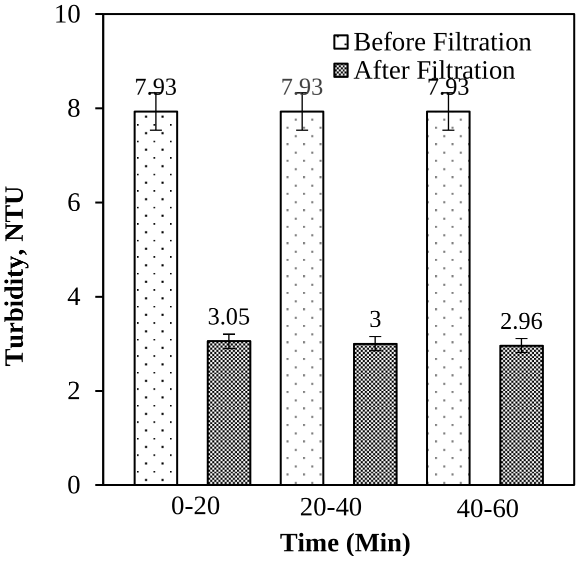

Figure 4. Turbidity Testing Results on Groundwater Using AC.

3.2.3. Total suspended solid (TSS)

The graph in Figure 5 illustrates the TSS parameter's results. The outcome demonstrates that the TSS parameter was successfully eliminated by using AC as a layer in filter media. After filtering, the initial TSS concentration was reduced by applying AC from 12 mg/L to 2.2 mg/L to 2.5 mg/L, or from 81.67% to 79.17%. This reduction aligns with findings from a previous study, which indicated that activated carbon application can effectively eliminate TSS characteristics. In the study by Phillips and Shell (1969), it was observed that granular activated carbon successfully removed suspended solids, with an average removal rate of 25%.

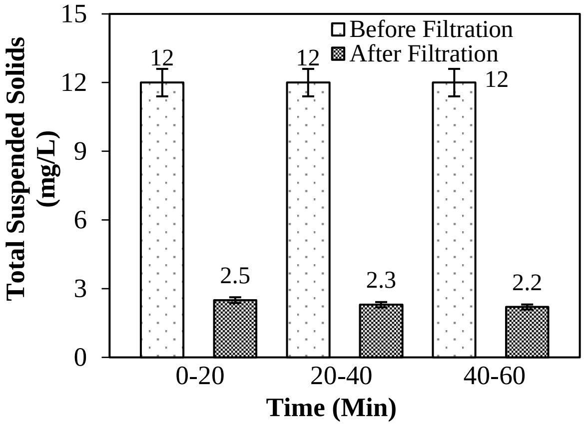

Figure 5. TSS Testing Results on Groundwater Using AC.

3.2.4. Total ammonia nitrogen (NH3-N)

Figure 6 indicates the NH3-N parameter outcome. The parameter ammonia of filtered water is reduced as a result. The use of AC unaffected the initial NH3-N concentration of 0.25 mg/L at 20-minute intervals. The aim was attained with AC at 40 and 60 minutes by reducing the initial NH3-N concentration to 0.22 mg/L and 0.24 mg/L, or a removal percentage of 12% to 4%, resulting in decreased NH3-N elimination due to pH's influence. The NH3-N adsorption was most significant at pH = 9 and least effective or not eliminated at pH = 5. The AC was cleaned from pH 6 to pH seven after that. Therefore, removing the NH3-N from the utilised AC has little benefit.

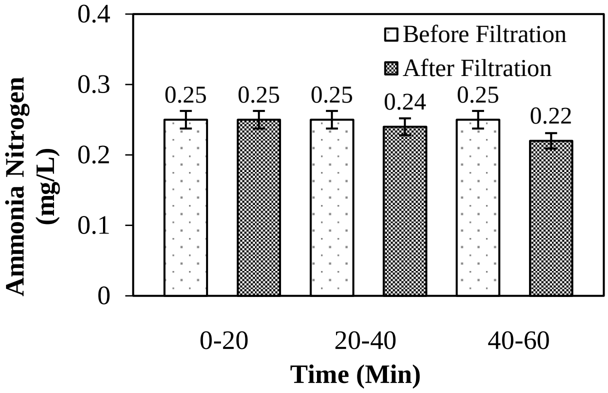

Figure 6. NH3-N Testing Results on Groundwater Using AC

5. Conclusions

Laboratory adsorption testing was used to assess the effectiveness of the AC formed from coconut shells of various sizes (granular and powder) as in the filtration process. On a laboratory scale, waste coconut shell that had been pyrolyzed was converted into activated carbon. The adsorption capacity of the AC produced in powder form was higher than that of the AC produced in granular form. Nevertheless, the AC in powder form exhibited a vital ability for adsorption compared to the granular size. The outcomes indicate a substantial difference from one another. The test result is mathematical evidence, and because there is a very minor variation between their mean % impurity removal rates, this discrepancy may be ignored.

AC filters are not advised for metals and other ions that could also be common in drinking water contaminants. Of course, these are some of the challenges that need more research. The choice of an AC filter should be made after thoroughly examining the homeowner's experience, a water study, and other relevant factors. The water flow rate through the filter determines the appropriate filter depth. The better the removal, the slower the flow rate. The filter's poor performance might be caused by the AC blocking pores or by the depth of the filter being too shallow. In addition to its complex structural network, AC's extraordinary capabilities make it possible to capture poisons, toxins, heavy metals, pesticides, offensive tastes and odours, chemical impurities, and other unwanted things in liquids and gases.

It should be highlighted that no treatment technology can control all water contaminants. Both forms of care have their limitations. Integration of treatment processes is required for effective water treatment for human consumption. It is possible to say that various carbon filter types remove various contaminants. For instance, AC filters or other substances cannot remove microbiological pollutants (bacteria and viruses), calcium and magnesium (hard water minerals), and fluoride nitrate. Therefore, the sedimentation method is first advised to reduce turbidity before adding water to a filter. This is due to the need to pre-treatment surface water to reduce turbidity, which has the added benefit of extending the saturation and life of filters.

Author Contributions: Conceptualization, Osmi, S.K.C., Aripin, A.M.E..; methodology, Osmi, S.K.C., Aripin, A.M.E.; data analysis, Osmi, S.K.C., Aripin, A.M.E.; data analysis, Osmi, S.K.C., Aripin, A.M.E.; writing-original draft preparation, Osmi, S.K.C., Aripin, A.M.E.; writing-review and editing, Suif, Z.

Funding: No external funding was provided for this research.

Acknowledgments: Special thanks to all respondents involved in this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

Berg, G. (1996). Virus transmission by the water vehicle. *Virus Removal by Sewage Treatment Procedures, 3*(2), 90–100.

Bruce, I. D., Sharon, O. S. (2013). *Drinking water treatment: Activated carbon filtration*. Revise Version, University of Nebraska Lincoln, NebGuid 1489.

Clark R. M. (1989). *Granular Activated Carbon: Design, Operation, and Cost*. Lewis Publishers.

Dang, D., Ding, W., Cheng, A., *et al*. (2011). Isotherm equation study of f adsorbed from water solution by Fe2(SO4)3 modified Granular Activated Alumina. Separation Science and Engineering. *Chinese Journal of Chemical Engineering, 19*(4), 581–585.

Davis, J., Robert, L. (2002). *Engineering in emergencies: A practical guide for relief workers* (2nd ed.). Warwickshire, UK: RedR /ITDG Publishing.

Love, O. T., Jr., Eilers, R. G. (1986). Report finds only 50 drinking water plants able to remove organics, groundwater monitor. *Journal - American Water Works Association*, *74*(8).

Mohammadi, A. A., Morovati, M., Najafi Saleh, H., *et al*. (2020). Groundwater quality evaluation for drinking and industrial purposes. A case study in Northeastern Iran. *International Journal of Environmental Analytical Chemistry*, *00*: 1–11.

Phillips, W. J., Shell, G. L. (1969). Pilot plant studies of effluent reclamation. *Water and wastes Engineering, 6*(11): 38–41.

Suif, Z., Che Osmi, S. K., Othman, M., *et al*. (2022). Design of groundwater filter media using activated carbon for emergency purpose. *Proceedings of the 5th International Conference on Sustainable Civil Engineering Structures and Construction Materials, Lecture Notes in Civil Engineering, 215*, 1357–1369.

Tadda, M. A., Ahsan, A., Shitu, A., *et al.* (2016). A review on activated carbon: Process, application and prospects. *Journal of Advanced Civil Engineering Practice and Research*, *2*(1), 7–13.

Thinojah, T., Ketheesan, B. (2022). Iron removal from groundwater using granular activated filters by oxidation coupled with the adsorption process. *Journal of Water and Climate Change*, *13*(5), 1985–1994.

Violante, A., Huang, P. M., Gadd, G. M. (2008). *Biophysico Chemical Processes of Heavy Metals and Metalloids in Soil Environments*. Wiley Interscience, America.

Weber, W. J. Jr. (1972). *Physicochemical Processes for Water Quality Control*. Wiley Interscience, John Wiley and Sons Inc., New York, NY.

Copyright © 2024 by Osmi, S. K. C., *et al.* and HH Publisher. This work is licensed under the Creative Commons Attribution-NonCommercial 4.0 International Lisence (CC-BY-NC4.0)