DEVELOPMENT OF LOW-COST FILTRATION SYSTEM FOR GROUNDWATER IRON REMOVAL APPLICATION

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Bachelor of Civil Engineering (Environmental) with Honours

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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Specially dedicated to
my beloved grandmother, mother, father, sister and brother

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ABSTRACT

Groundwater, also known as subsurface water, has been used in many countries and in various fields including domestic, agricultural, industrial, commercial establishment, and public institutions. The majority of Earth's freshwater is found in icecaps and glaciers which is over 68%, and over 30% is found in groundwater. Iron is commonly found in groundwater in soluble ferric, Fe^{3+} and insoluble ferrous Fe^{2+} forms. Groundwater can be dangerous to the human and environment if the iron content is higher than the maximum allowable value. Iron can cause toxicity in plant, reduce nutrient availability, staining and clogging of the irrigation system. Although 0.1 ppm of iron may cause clogging of the irrigation systems, reduce water flow rate, and reduce the plant growth while above 0.3 ppm of iron can cause discoloration on the plant leaves and staining. Currently, there are several technologies applied for iron removal from groundwater, including Vyredox technologies, oxidation followed by filtration, filter separation media, aeration, and membrane technologies. However, the existing technologies have some limitations for the application in relatively small area farm such as the space requirement and cost consideration. In this study, a low-cost self-fabricated filtration system with the local available materials has been designed and developed. The groundwater samples were collected from Miracle Berry Farm at Malim Nawar, Perak. The iron removal efficiency from groundwater by the filtration system were investigated by analysing the initial and final concentration of iron in groundwater before and after filtration. The iron concentrations were tested using Flame Atomic Absorption Spectrometer (FAAS). The amount of Powdered Activated Carbon (PAC) required for effective iron removal were studied. The other parameters including color, turbidity, and Chemical Oxygen Demand (COD) removal efficiency were investigated. The groundwater filtration flux was studied to ensure the filtration system allows water to pass through in a consistent rate. The groundwater was allowed to flow through the filter system by gravitational force without pressure pump. The cost analysis was performed to evaluate the cost needed for a simple filter system but effective in iron removal. Overall, the iron removal efficiency of the system has achieved 89%, to a level of less than the allowable concentration of iron in water. Color and turbidity values were observed to be reduced after the groundwater passing through the filter system, which were found to be 82% and 95% respectively. COD value was observed to be reduced in a gradually rate and recommendations for improvement in the future study was provided.

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A	surface area of the filter which the water is passing, m^2
C_f	final concentration
C_i	initial concentration
J	Flux, $L/(m^2 \cdot h)$
R	removal efficiency, %
V	volume of water pass through the filter surface, L
Δt	time interval over which the flux is measured, h

COD	Chemical Oxygen Demand
FAAS	Flame Atomic Absorption Spectrometer
FAO	Food and Agricultural Organization
Fe^{2+}	Ferrous iron
Fe^{3+}	Ferric iron
GAC	Granular Activated Carbon
HNO_3	Nitric acid
MAL	Maximum Allowable Limit
MOH	Ministry of Health
PAC	Powdered Activated Carbon
PVC	Polyvinyl Chloride
WHO	World Health Organisation

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CHAPTER 1

INTRODUCTION

1.1 Background

Groundwater, also referred subsurface water, has historically served as a vital resource in numerous countries and across various sectors, encompassing domestic, agricultural, industrial, commercial, and public domains. Throughout antiquity, human societies relied on groundwater for essential daily activities. Communities exercised prudent management of these water resources to sustain their livelihoods and agricultural practices. This ancestral tradition offers valuable insights into the innovative and resourceful approaches adopted by early civilizations in water resource management. However, as the global population burgeons, concerns regarding groundwater pollution become significant, attributed to contaminants originating from human activities. Presently, agricultural activities account for the largest proportion of global groundwater extraction, with approximately 70% allocated to agricultural endeavours, including the cultivation of food, fibres, livestock, and industrial crops (The Nature Conservancy, 2022). In regions characterized by arid and semi-arid climates, groundwater serves as a primary irrigation source, with up to 90% of withdrawals directed towards agricultural irrigation (UNESCO, 2022). Notably, small-scale farmers often harness groundwater systems, thereby realizing cost efficiencies relative to large-scale surface water infrastructures, attributable to reduced operational expenditures.

Groundwater can be extracted from wells and boreholes using submersible pumps or hand pumps to meet small-scale needs. Consequently, it is particularly favoured for agricultural purposes, especially in regions characterized by limited, unreliable, or insufficient water resources. Groundwater represents a valuable resource for agriculture due to its ability to provide a relatively stable and consistent water supply, even during dry seasons and droughts. This reliability renders it an attractive option for farmers seeking to sustain their crops throughout the year. Moreover, groundwater is often less susceptible to pollution compared to surface water sources, as it is shielded by layers of soil and rock.

However, the presence of iron in groundwater poses several challenges in agriculture. While iron is an essential micronutrient for plants, but excessive levels of iron in irrigation water can have adverse effects. Iron concentrations exceeding 0.1 ppm may lead to the clogging of irrigation systems, reduced water flow rates, and impaired plant growth, while concentrations exceeding 0.3 ppm can cause discoloration and staining of plant leaves. Toxicities in plant tissues may occur when iron levels reach 4 ppm or when the pH of the root medium falls below 5.5 (Gladis & Shuai, 2005).

As concerns regarding iron in agriculture continue to increase, researchers have sought solutions to address these challenges. Various methods have been employed to remove iron from groundwater, including physio-chemical and biological approaches. These methods include oxidation followed by precipitation and filtration, filter media separation, Vyredox technology, aeration, and membrane-based removal with ion pretreatment (Khatri, Tyagi, & Rawtani, 2017). Oxidation, precipitation followed by filtration is effective in removing organic irons, it is a simple and low-cost operation, and oxidant used kills the harmful disease-causing bacteria present in water. Filter media separation has a high removal efficiency, fast rate, and no chemicals needed, effective in removing pathogenic microbes and it is an economical method in removing iron from water. Membrane-based removal in combination with pretreatment of ions has the benefit of less retentate volume, minimum labour requirement, and highly selective. Aeration is a treatment that does not need chemicals, has good mixing and high mass transfer rates. Vyredox technology is an in-situ purification of groundwater that removes iron from groundwater before the groundwater is extracted (Hallberg and Martinell, 1976). It has the advantage of the iron free groundwater can be withdrawn from the well. No chemicals are required in this iron removal process. Each method offers distinct advantages in terms of efficiency, cost-effectiveness, and environmental impact.

In this study, a low-cost treatment system for iron removal from groundwater will be developed for agricultural use. Filter media separation, comprising a combination of coarse sand, fine sand, and powdered activated carbon (PAC), will be evaluated as a simple, space-efficient, and cost-effective filtration system fabricated from locally available materials.

1.2 Problem Statements

The presence of iron in groundwater can significantly impact water quality and lead to clogged irrigation systems. While iron itself does not pose health risks to humans, it can impart a reddish or rust-colored appearance and unpleasant odor to water (Filtration and Separation, 2011). Additionally, iron accumulation on irrigation equipment can result in clogged emitters when ferrous ions are exposed to air (Gladis & Shuai, 2005). During irrigation, ferrous ions can be oxidized into insoluble ferric ions, forming solid particles that can clog pipes and irrigation systems. Iron contamination in irrigation systems can adversely affect plants, causing staining, discoloration of leaves, clogging of irrigation systems, and reduced plant growth (Turhadi Turhadi et al., 2019). This presents a significant challenge in agriculture, impacting vegetation growth and nutrient content in plants (Batty and Younger, 2003).

Cost-effectiveness is a crucial consideration in iron removal applications for agriculture, as these systems are intended for long-term use. For example, membrane-based removal combined with ion pretreatment may require low labor but can suffer from membrane scaling and fouling, reducing performance and lifespan while increasing energy consumption and transmembrane pressure (Liao et al., 2018). It requires high cost due to the high energy consumption and after a few cycles of operation, the removal efficiency will be reduced, hence the membrane needs to be replaced. Oxidation and aeration processes also entail significant energy inputs and chemical reagents such as oxygen, chlorine, ozone, and potassium permanganate increasing operational costs. Additionally, it is imperative to account for the costs associated with the disposal of treatment residues and waste arising from iron removal applications.

Space requirements pose another challenge in iron removal applications. Current groundwater treatment methods necessitate various treatment tanks which depending on treatment capacity. Processes such as aeration and oxidation followed by filtration may require larger treatment units than simple cartridge-based filtration systems. Moreover, treatments involving chemical reagents necessitate specialized storage cabinets or dedicated rooms with appropriate safety features. Adequate space must also be allocated for easy access to the treatment system for maintenance and repairs.

In order to aid with these challenges, there is a need for a small footprint, cost-effective, locally sourced, and efficient iron removal filtration system. Such a system aims to ensure optimal plant growth and crop yield while minimizing environmental impacts. Therefore, the purpose of this study is to develop a low-cost iron removal filtration system that requires minimal installation space.

1.3 Aims and Objectives

The objectives of the thesis are shown as following:

i) To fabricate a low-cost treatment system for iron removal in groundwater for agriculture application.
ii) To evaluate the iron removal efficiency of the fabricated system and other characteristic in groundwater.
iii) To optimise the system performance with different amount of powdered activated carbon in removing iron from groundwater.
iv) To analyse the cost of filter system fabrication and compare to the existing technologies.

1.4 Scopes of Study

In this study, a low-cost filtration system will be fabricated using Polyvinyl Chloride (PVC) pipe to remove iron from groundwater for agricultural applications. The system will incorporate filter media, including coarse sand, fine sand, and Powdered Activated Carbon (PAC), arranged within the PVC pipe to specific dimensions. Additionally, a laundry bag will be utilized as a screen for the filter system. The cost of the developed system will be calculated and compared to that of other existing treatment systems. The efficacy of the fabricated system will be assessed through a before-after analysis, wherein the concentration of iron before and after the groundwater passes through the system will be measured. Iron concentration will be determined using a Flame Atomic Absorption Spectrometer (FAAS). Furthermore, common parameters and characteristics of groundwater, such as color, turbidity, and Chemical Oxygen Demand (COD), will be analysed. Turbidity will be assessed using a HI 98703 portable Turbidimeter, while COD and color will be analysed using a HACH DR 3900 spectrophotometer. The optimisation of performance for the fabricated iron removal system in removing iron from groundwater will also be investigated by manipulate the amount of PAC added to the system.

CHAPTER 2

LITERATURE REVIEW

2.1 Groundwater

Groundwater, also known as subsurface water, refers to water stored below the Earth’s surface in soil and porous rock aquifers (Encyclopaedia Britannica, 2023). The majority of Earth’s freshwater is contained within icecaps and glaciers, accounting for over 68%, while groundwater constitutes over 30% on the freshwater portions (Shiklomanov and Rodda, 2004). Groundwater originates from precipitation, surface runoff, and water stored in surface bodies such as lakes and rivers, which infiltrates into the soil and stored underground. It accounts for approximately 33% of total water withdrawals worldwide (Famiglietti, 2014). Notably, 43% of total consumptive water use for irrigation is sourced from groundwater (Siebert et al., 2010). In arid and semi-arid countries, groundwater is utilized for irrigation purposes up to 90% (UNESCO, 2022).

Groundwater serves as a dependable water source, providing a stable and consistent supply even during dry seasons and droughts. It contributes to the sustainability of natural ecosystems and offers economic benefits by facilitating year-round crop cultivation (Ismanto et al., 2022). Moreover, groundwater is less susceptible to pollution compared to surface water sources, as it is shielded by layers of soil and rock. However, groundwater supplies are vulnerable to chemical pollution from activities such as fracking, agricultural chemical usage, leachate from landfills and septic tanks, and other point and nonpoint sources of contamination

(Encyclopaedia Britannica, 2023). Such contaminants can render groundwater unsafe for consumption and daily use, necessitating costly treatment processes.

2.2 Chemical Constituents in Groundwater

Natural fresh groundwater contains dissolved elements, including major ions, minor constituents, trace elements, organic compounds, and dissolved gases (Poeter et al., 2020). Many trace elements are present at lower concentrations, sometimes falling below human ability to detect them using commonly used analysis methods. Iron, for instance, is a naturally occurring minor constituent in groundwater, typically found at concentrations ranging from 0.1 to 5.0 mg/L.

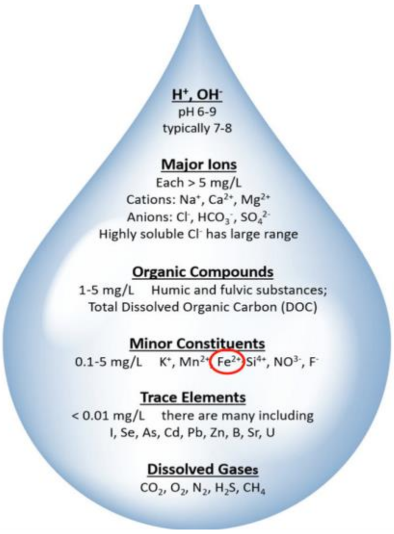


Figure 2.1: Chemical Constituents in Groundwater (Poeter et al., 2020)

2.2.1 Occurrence of Iron in Water

There are three types of iron commonly found in groundwater which are ferric ions (Fe^{3+}), ferrous ions (Fe^{2+}), and bacterial iron. Ferrous ion is the dissolved or soluble form of iron, typically present in groundwater under anaerobic conditions with little to no oxygen. The presence of ferrous ions does not cause discoloration or staining and is not visible in water. However, high concentrations of ferrous ions may result in metallic taste and undesired odors. Ferric ion, on the other hand, is an oxidized and insoluble form of iron that can impart a reddish-orange color to water (Evangelista, 2021). It forms when ferrous ions are exposed to air and react with oxygen under aerobic conditions. Bacterial iron appears as a slimy orange substance floating on the water's surface. Iron bacteria combine iron and oxygen to create deposits of "rust," "bacterial cells," and slimy material that adhere to well pipes, pumps, and plumbing fixtures (Kummer, 2023). According to World Health Organisation (WHO) standards, iron concentrations below 0.3 mg/L are considered unnoticeable, while concentrations ranging from 0.3 to 3.0 mg/L are deemed acceptable in well water. For drinking water standards, the iron concentration must be less than 0.3 mg/L to ensure health and safety (World Health Organization, 2003).

2.3 Groundwater usage

The extensive utilization of groundwater can be attributed to several factors, including ease of access, superior protection from pollution sources, higher water purity compared to surface water, reduced susceptibility to seasonal and perennial changes, widespread distribution over large areas, and lower capital production costs (Thinojah and Ketheesan, 2022). Groundwater supplies remain relatively unaffected by short droughts and are readily available in many regions, making it the preferred water source for areas lacking dependable surface water supplies. It is a more cost-effective option than tap water and boasts greater cleanliness compared to surface water sources.

Groundwater serves various functions, categorized into provisioning services, regulatory services, supporting services, and cultural services (UNESCO, 2022). Provisioning services cater to human needs, encompassing agriculture, industry, and human settlement. Regulatory services denote the capacity of aquifers to regulate the quantity and quality of groundwater systems. Supporting services pertain to groundwater-dependent ecosystems and other environmental features reliant on groundwater. Cultural services are associated with leisure activities, traditions, religion, or spiritual values linked to specific sites (Poeter et al., 2020). Table 2.1 shows the estimation of groundwater extraction per year in 2010 and its uses in selected countries.

Table 2.1: Groundwater Extraction and Uses in Selected Countries (Margat and Van Der Gun, 2013)

Country	Estimated groundwater extraction 2010 (km^3/yr)	Uses by sectors (% of total extraction)		
		Agriculture (Irrigation)	Domestic use	Industry
India	251.00	89	9	2
China	111.95	54	20	26
United States	111.70	71	23	6
Pakistan	64.82	94	6	0
Bangladesh	30.21	86	13	1
Indonesia	14.93	2	93	5
Thailand	10.74	14	60	26
Malaysia	0.59	5	62	33

2.4 Groundwater in Agricultural

Surface water and groundwater serve as sources of irrigation. Groundwater, being a protected subsurface water resource, offers a stable and sustainable supply of high-quality water, particularly during periods of climate change, regional water scarcity, and droughts, thereby ensuring the water requirements for crops (State of Green, 2022). Compared to surface water, groundwater boasts several advantages, including its ability to be stored in aquifers for extended periods, typically being cleaner than surface water in terms of pollutants, being withdrawable near the point of use, and being readily available upon demand, facilitating more timely application (Turner et al., 2004). Groundwater aids farmers in managing drought conditions by acting as a buffer during periods of reduced surface water availability and its resilience to fluctuations in rainfall and surface water availability, rendering it a dependable irrigation water source.

The characteristics of water demand for irrigation encompass factors such as quantity, location, timing, and quality (Turner et al., 2004). Quantity often outweighs quality in importance for irrigation purposes compared to household use, where water quality takes precedence over quantity due to health and safety considerations. Groundwater, extracted through wells, is generally available across various locations, whereas surface water necessitates transportation via piping systems to specific areas, thereby reducing transportation costs, piping system complexity, and labor costs. Additionally, groundwater can be extracted as needed, eliminating the need for storage space required for surface water to meet peak-season demand.

2.5 Effects of Iron in Untreated Groundwater

Iron naturally occurs in groundwater, but high concentrations of iron pose numerous challenges for daily life and industrial operations reliant on groundwater as a water source. As groundwater flows through the soil, iron metal dissolves and can accumulate in the water at high levels (Contamination of groundwater | U.S. Geological Survey, 2018). Elevated iron concentrations in groundwater can stem from human activities such as industrial discharges, urbanization, agricultural practices, groundwater extraction, and improper waste disposal. Additionally, leaks from fuel tanks or spills of toxic chemicals can infiltrate into the ground and seep into groundwater sources. Both soluble and insoluble forms of iron in water can have detrimental effects on agriculture, domestic use, and industrial processes. The effects of iron in untreated groundwater for different fields are shown in Table 2.2.

Table 2.2: Effects of Iron in Untreated Groundwater for Different Sectors

Sectors	Effects	References
Agriculture	Toxicity in plant - leaf discoloration, reduce yield & plant stress	(Turhadi et al., 2019)
	Reduce nutrient availability - interface uptake of other nutrients	(Batty and Younger, 2003)
	Staining on plant leaves, fruits & vegetables	(Rusnak, 2019)
	Clogging irrigation system	(Gladis and Shuai, 2005)
	Microbial growth	(Gu, 2018)
Domestic use	Staining of plumbing fixture or laundry	(Filtration and Separation, 2011)
	Metallic taste and unpleasant odor affect water quality	(Michalakos, 1997)
	Reduce soap and detergent performances	(Libretexts, 2023)
	Clog faucet and showerhead	(Kummer, 2023)
Industry	Clogging and blockage	(Thinojah and Ketheesan, 2022)
	Scaling and fouling	(Liao et al., 2018)
	Equipment corrosion - shorter lifespan of equipment	(Xu et al., 2020)
	Product contamination	(Eufic, 2015)

2.6 Effects of Iron in Agriculture

In agriculture, iron can be absorbed by plant roots during the irrigation process. Excessive uptake of ferrous iron by plants can lead to iron toxicity, particularly when the soil contains high concentrations of ferrous ions. Ferrous ions are absorbed by plant roots and transported via the xylem to the leaves, resulting in an overload of iron in plant tissues. This iron overload can cause tissue damage and disrupt cellular homeostasis. Iron toxicity inhibits cell division and elongation of primary roots, thereby affecting the growth of lateral roots (Aung and Masuda, 2020).

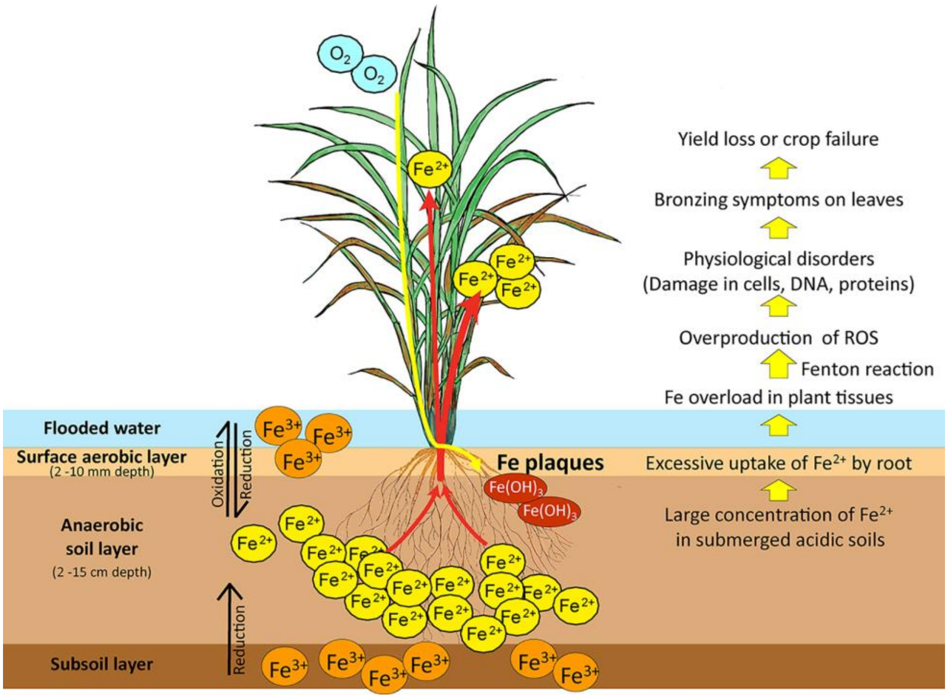


Figure 2.2: Effect of Iron Toxicity in Rice Plants (Aung and Masuda, 2020)

Iron can clog the irrigation system and stain on the piping system and other agricultural appliances. Iron can also affect the water quality and produce a reddish or rush-coloured as shown in Figure 2.3. There is effect of iron staining and clogging on the agricultural appliances including the piping system, irritation system, and the water containers shown in Figure A8, Figure A9, and Figure A10 in Appendix.

Figure 2.3: Reddish or Rush-Coloured Water

2.7 Existing Iron Removal Technologies and Limitations

2.7.1 Existing Iron Removal Technologies

The presence of iron in groundwater can adversely affect human activities and complicate operational processes. Various iron removal technologies have been developed to address this issue, including Vyredox technologies, oxidation followed by filtration, filter media separation, aeration, and membrane-based removal in combination with pretreatment of ions. Each of these iron removal systems offers different efficiencies and advantages in removing iron from groundwater. Table 2.3 and Table 2.4 outline the iron removal efficiency, as well as the advantages and disadvantages of using each method, categorizing them based on their respective strategies for iron removal from groundwater.

2.7.1.1 Vyredox Technologies

The Vyredox method is an in-situ water purification technique designed to achieve a high level of oxidation in the strata surrounding the well, ensuring that water entering the well is free from iron and manganese contaminants (Hallberg and Martinell, 1976). This method effectively prevents the encrustation of pipes used to pump water from the well, a common issue caused by the reaction of iron with oxygen to form ferric ions before the water enters the well. The process involves the utilization of iron-oxidizing bacteria and several aeration wells positioned in a ring around the supply wells. Oxygen-enriched water is introduced into the well, creating an ideal environment for the iron-oxidizing bacteria to facilitate the oxidation of ferrous iron.

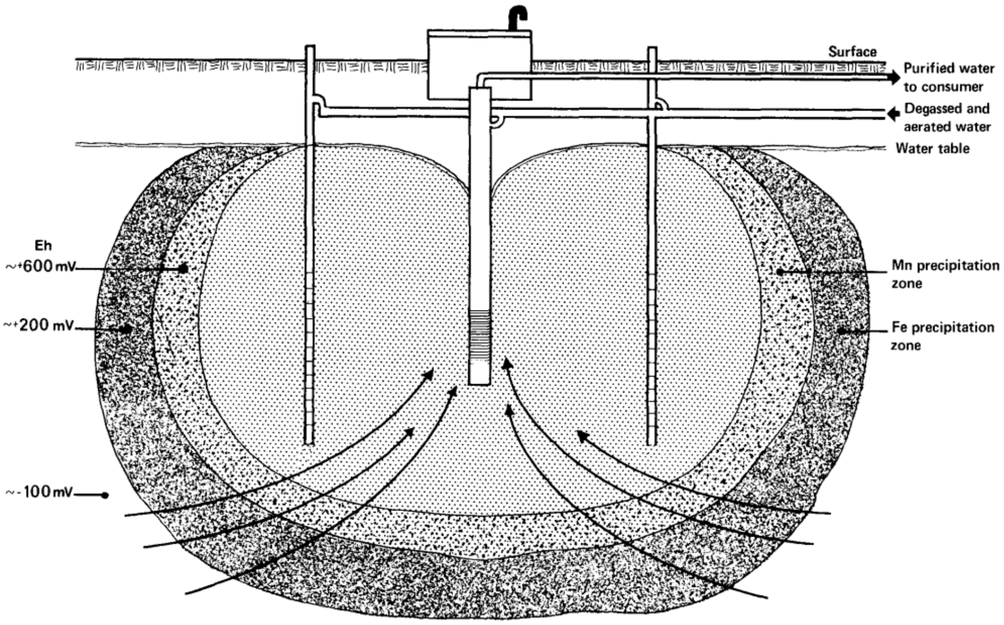


Figure 2.4: Schematic Diagram for In-situ Vyredox Method for Iron and Manganese Treatment (Hallberg and Martinell, 1976)

2.7.1.2 Oxidation Followed by Filtration

Oxidation followed by filtration is a conventional technique used for removing iron from water, involving the oxidation of soluble ferrous iron into the insoluble ferric form present in the water (Khatri, Tyagi, and Rawtani, 2017). In this process, optimal dosages of oxidants such as potassium permanganate, chlorine, ozone, and hydrogen peroxide are typically employed to oxidize the iron in the water. After oxidized, the iron precipitates and can be effectively removed through a simple filtration process. Previous studies have indicated that treatment performance can be enhanced by adding oxidants at optimal dosages, resulting in more efficient removal with shorter oxidation times, particularly at neutral pH values. Additionally, the arrangement of filter media can be optimized for improved removal results, such as by incorporating a green sand layer (Salem, El-Awady, and Amin, 2012).

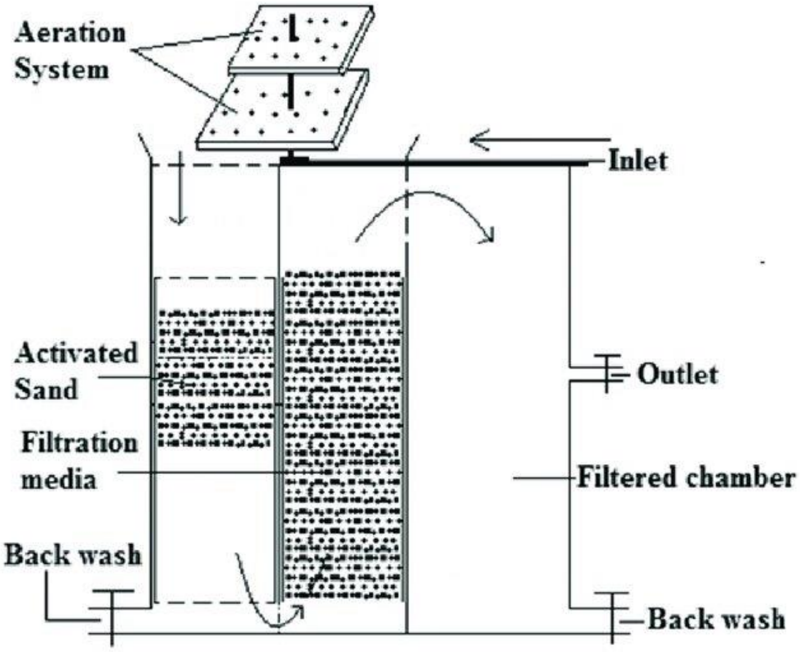


Figure 2.5: Schematic Diagram for Oxidation Followed by Filtration System (Umlong et al., 2022)

2.7.1.3 Filter Separation Media

Filter media separation is a conventional method employed to remove suspended particles such as clay, colloidal and precipitated natural organic substances, and microorganisms from water (Khatri, Tyagi, and Rawtani, 2017). Granular media, including sand, crushed anthracite, and constructed soil filters, are commonly utilized as filter media in this process. Anthracite, in particular, serves as an effective granular filter material that can enhance iron removal efficiency when combined with aeration. Previous studies have demonstrated the effectiveness of a rapid sand filtration-based model, which considers factors such as water inflow conditions, pH levels, initial iron concentrations, kinetics of heterogeneous oxidation, and the characteristics of the filter media (De Vries et al., 2017).

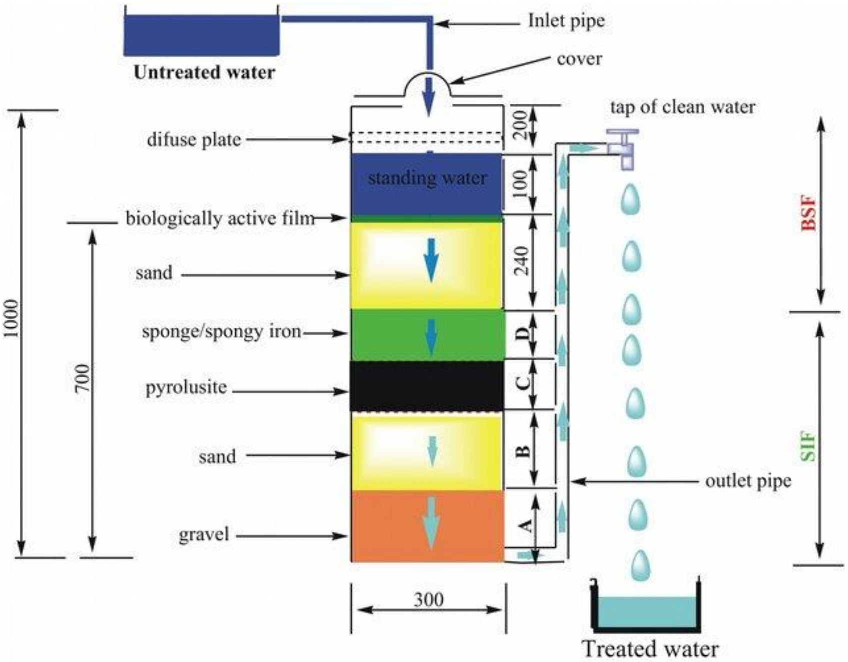


Figure 2.6: Schematic Diagram for Filter Separation Media (Mwakabona et al., 2017)

2.7.1.4 Aeration

Aeration is a conventional water treatment method involves introducing oxygen or oxygen-rich air into the water treatment system to oxidize ferrous iron to ferric iron, leading to the precipitation of iron in water and subsequent removal of metals from the water (Khatri, Tyagi, and Rawtani, 2017). Enhancements in treatment performance can be achieved by incorporating specific microbes into the system, such as utilizing a biofilm of microbes as filter media (Štembal et al., 2005). Additionally, aeration towers have been utilized for iron and manganese removal from groundwater in Egypt (Abdel-Lah et al., 2002).

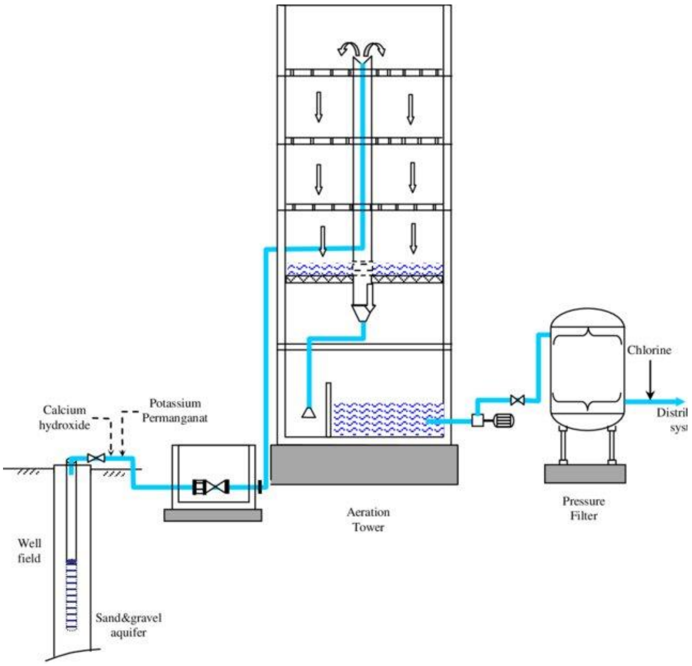


Figure 2.7: Schematic Diagram for Aeration Tower (Abdel-Lah et al., 2002)

2.7.1.5 Membrane-Based Removal in Combination with Pretreatment of Ions

Membrane-based strategies, such as ultrafiltration, microfiltration, and reverse osmosis, have been widely employed for retrieving or removing various metals from wastewater (Khatri, Tyagi, and Rawtani, 2017). Metal ions typically undergo treatment with surfactants and hydrophilic polymers to increase their size, as the pores in membranes for ultrafiltration and microfiltration are larger than the metal ions themselves (Li et al., 2009). The mechanism of iron removal involves the formation of sparingly soluble iron hydroxide particles, which occurs through the oxidation of the metal ion by dissolved oxygen present in the water, even in the absence of chlorine for oxidation purposes (Choo, Lee, and Choi, 2005).

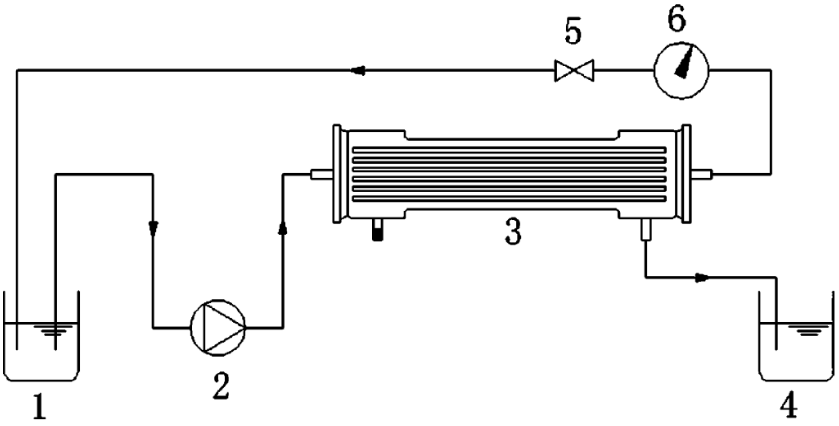


Figure 2.8: Schematic Diagram for Laboratory-Scale Ultrafiltration System (Li et al., 2009)

Table 2.3: Removal Efficiency, Advantages, and Disadvantages of Existing Iron Removal Methods

Technologies	Description	Iron Removal Efficiency (%)	Advantages	Disadvantages	References
Vyredox Technologies	In-situ water purification that allow iron free groundwater to be withdrawn	3.12	No chemical required	High cost Low removal efficiency Risk of blockage	(Osuna *et al.*, 1988)
Oxidation followed by filtration	Oxidation of ferrous ion to ferric ion and removal by filtration process	90-95	Simple and low-cost operation Oxidant used kills the harmful disease-causing bacteria	Chemical residue Cost of energy and chemical Space requirement	(Salem, El-Awady and Amin, 2012)
Filter media separation	Ferric ion separation by layers of filter media	90-98	Cost effective and low maintenance required Fast rate	Limited for ferrous ion removal Back washing is necessity Space requirement	(Khatri, Tyagi and Rawtani, 2017)

(Con't) Table 2.4: Removal Efficiency, Advantages, and Disadvantages of Existing Iron Removal Methods

Aeration	Introduction of air or oxygen into groundwater to convert ferrous ion to ferric ion	40-90	Chemical free Good mixing	High capital investment Space requirement Inefficient oxidation of ferrous ion in the absence of airlift reactor	(Khatri, Tyagi and Rawtani, 2017)
Membrane-based removal in combination with pretreatment of ions	Pretreatment of iron removal and membrane serve as final barrier to remove remaining iron ions	95-98	High efficiency Minimum labor requirement	Membrane scaling and fouling High energy consumption Short life span of membrane	(Liao et al., 2018)

2.7.2 Limitations of Existing Technologies

The primary challenges preventing the adoption of current iron removal systems for farmers, particularly small-scale agricultural operations, revolve mainly around high costs and space requirements. These costs encompass various aspects such as capital investment, equipment procurement, energy consumption, chemical reagents, and maintenance expenses. For instance, the aeration method entails significant capital expenditure due to the specialized equipment required, including aeration tanks, blowers or compressors, diffusers, and control systems, all designed to handle large volumes of water and air while meeting quality and safety standards. Quality equipment often comes at a premium price. Moreover, during operation, aeration systems consume substantial energy to pump air into the water, contributing to higher operational costs compared to methods with lower energy consumption. Similarly, membrane-based removal, when combined with pretreatment of ions, entails costs related to energy and membrane replacement due to fouling and scaling, which diminish membrane lifespan despite its high efficiency in iron removal from groundwater.

Many farms are fully dedicated to agricultural activities across a variety of plant species, leaving little space for specialized iron removal treatments. Space requirements include treatment tanks and dedicated areas for storage, as well as accessibility for maintenance and repair purposes. Treatment tanks commonly used include filtration tanks, aeration tanks, detention tanks, contact chambers, and sludge tanks, each tailored to the specific needs of the treatment system. Methods such as oxidation also necessitate the storage of oxidizing agents, requiring specialized storage cabinets or dedicated rooms with appropriate safety features. Additionally, the pretreatment stage in membrane-based removal, combined with ion pretreatment, can further impact space requirements in the iron removal process. Therefore, adequate space allocation is essential to ensure easy access to the treatment system for maintenance and repair tasks.

2.8 Study on Design of Filter Media Separation

Filter media separation can be designed in a vertical or horizontal direction for the water to flow through. Based on the research, a vertical arrangement that allows water to flow from top to bottom is usually used for better removal performance.

2.8.1 Design of Oxidation Followed by Filtration

In the oxidation followed by filtration process, coupled with the arrangement of the filtration layer and the addition of green sand, impressive results were achieved. Iron removal reached a remarkable 92%, reducing levels to less than 0.1 mg/L, while manganese removal reached up to 96%, bringing concentrations down to less than 0.05 mg/L (Salem, El-Awady, and Amin, 2012). This outcome underscores the efficacy of the vertical arrangement of filtration media in achieving high removal efficiencies for both iron and manganese. The arrangement of the media layers of the filter is shown in Figure 2.4.

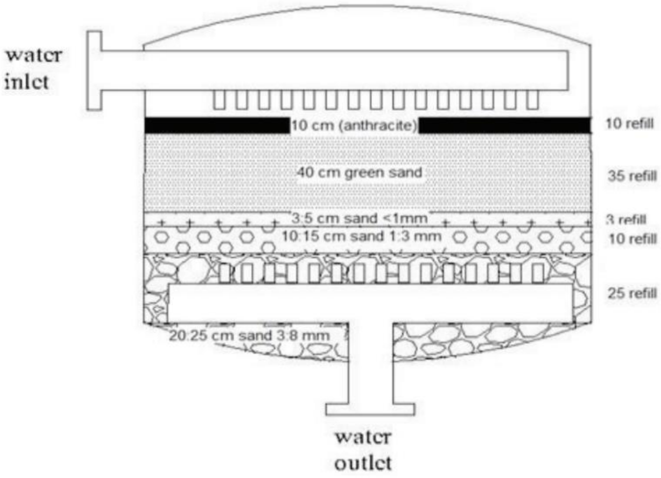


Figure 2.9: Oxidation Followed by Filtration Media Layers (Salem, El-Awady and Amin, 2012)

2.8.2 Design of Granular Filter for Rainwater Treatment

The downward flow filter consisted of a support layer measuring 0.25m, composed of rolled pebbles, followed by a filtration layer consisting of 0.4m of gravel and 0.35m of sand, with granular activated carbon following. This method and arrangement of the filter media successfully removed 13.0% of turbidity, 34.0% of ammoniacal nitrogen, and 10.0% of nitrate from the rainwater (Teixeira and Ghisi, 2019). Figure 2.5 depicts the detailed arrangement of sand in the filter for rainwater treatment.

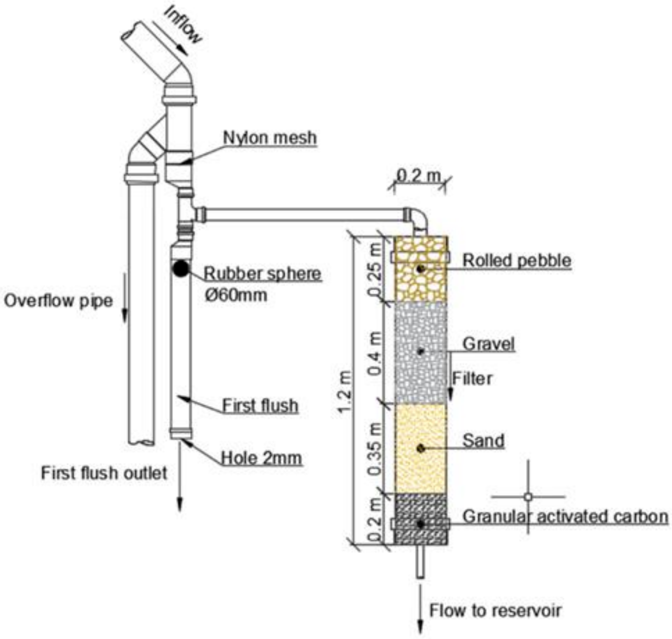


Figure 2.10: Schematic Diagram for Sand Filter Arrangement in rainwater treatment (Teixeira and Ghisi, 2019)

2.8.3 Design of Green Sand Filter

The manganese greensand filter consists of a combination of a sand layer and a 17cm layer of greensand. The preferred direction of flow is from the top to the bottom of the filtration column due to gravity force. However, if there are clay-sized particles present, it is preferable to allow water to flow from the bottom to the top of the filter to prevent the particles from being transported by the water flow (Selim, El-Tawil, and Rostom, 2018).

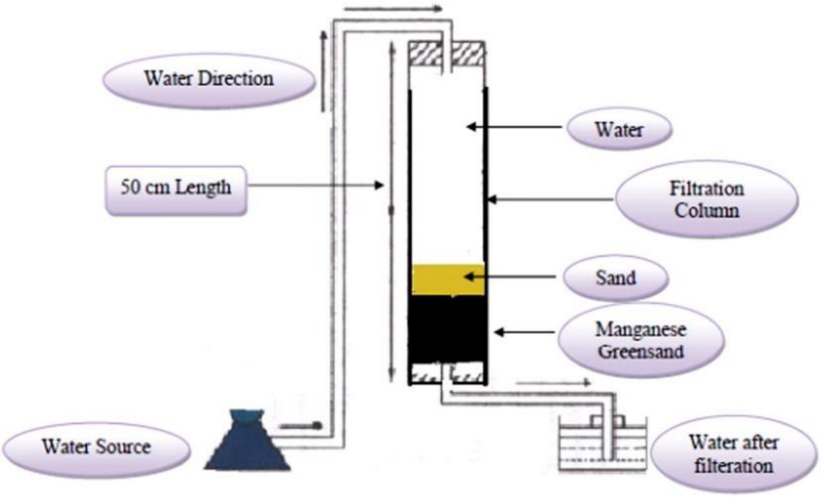


Figure 2.11: Schematic of Green Sand Filter Arrangement (Selim, El-Tawil and Rostom, 2018)

2.9 Study on Granular Activated Carbon (GAC) for Iron Removal

Research has indicated that granular activated carbon (GAC) exhibits a higher removal efficiency compared to Bio-Pac media (BPM) due to the loosely packed nature of BPM within the column and its highest in-situ porosity in comparison to GAC (Thinojah, Ketheesan, and Herath, 2020). To enhance the efficiency of iron removal, increasing the height of the filter media can expand the adsorption sites, leading to improved removal rates.

An economically viable solution for iron removal involves the utilization of activated carbon sourced from natural materials. Activated carbons are extensively used in water treatment due to their cost-effectiveness, simplicity, and rapidity, requiring minimal chemical intervention for iron removal from water (Balaji, Sasikala, & Muthuraman, 2014). GAC, derived from locally available materials such as hardwood charcoal, rice husk, sugarcane bagasse, and coconut shell, offers a cost-effective and highly efficient means of water treatment. These materials are typically accessible at minimal cost or even free of charge. Following drying or heating processes and subsequent cooling, porous products are produced, resulting in GAC with significantly enlarged surface areas and carbon particle adsorption sites. Consequently, GAC demonstrates substantial efficiency in removing iron from water. Table 2.5 presents the iron removal efficiency for various GAC materials, including charcoal, rice husk, sugarcane bagasse, and coconut shell.

Table 2.5: Iron Removal Efficiency for Different GAC Materials

Material Used to Produce GAC	Iron Removal Efficiency (%)	References
Charcoal	90-100	(Siabi, 2003)
Rice Husk	100	(Dalai, Jha and Desai, 2015)
Sugarcane Baggase	93-97	(Balaji, Sasikala and Muthuraman, 2014), (Dalai, Jha and Desai, 2015)
Coconut shell	96-100	(Balaji, Sasikala and Muthuraman, 2014)

2.9.1 Potential of Activated Carbon for Manganese and Iron Removal

Charcoal-derived GAC, favoured for its lower cost and abundant availability, proved highly effective in removing iron ions from water, achieving removal percentages ranging from 90 to 100%. Factors such as the mass of GAC utilized, retention time, and initial iron concentration in the water were observed to influence the efficiency of iron removal (Siabi, 2003). Specifically, as the contact time between iron and GAC increased, a corresponding rise in iron adsorption levels was noted. Moreover, the removal efficiency of heavy metals is contingent upon the initial concentration, with ample adsorption sites available for heavy metal ion adsorption at lower initial ion concentrations (Balaji, Sasikala, and Muthuraman, 2014).

2.9.2 Rice Husk and Sugarcane Bagasse Based Activated Carbon for Iron and Manganese Removal

Activated carbons derived from rice husk and sugarcane bagasse exhibited iron removal efficiencies of up to 100% when subjected to water containing iron. Optimal results were achieved when the filter material was positioned at the center of the soil column (Dalai, Jha and Desai, 2015).

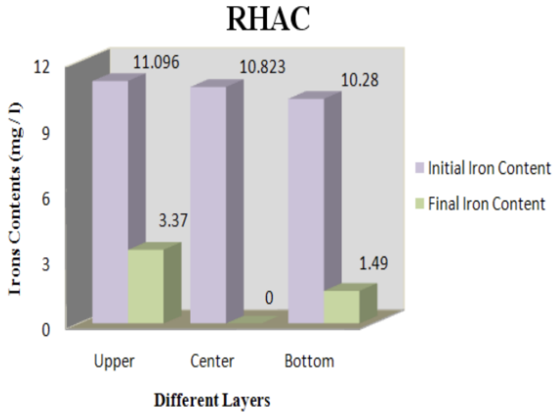


Figure 2.12: Iron Removal in HRAC (Dalai, Jha and Desai, 2015)

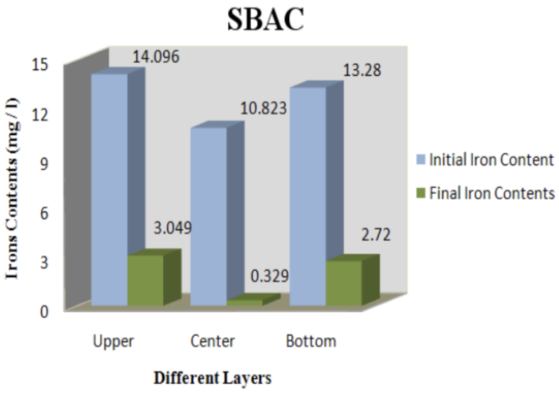


Figure 2.13: Iron Removal in SBAC (Dalai, Jha and Desai, 2015)

2.9.3 Study on The Removal of Iron and Manganese in Groundwater by GAC

Coconut shell-derived activated carbon has shown promising results in the adsorption of iron (Jusoh et al., 2005). This effectiveness can be attributed to the adsorbate's characteristics, including electronegativity and ionic radius, which differ between iron and manganese. Electronegativity, representing an element's ability to attract electrons, influences the adsorption level of metal ions onto activated carbon, with higher electronegativity resulting in increased adsorption (Dastgheib and Rockstraw, 2002). Additionally, iron possesses a smaller ionic radius compared to manganese due to its higher attractive charge in the nucleus on the electron orbital (Jusoh et al., 2005). This smaller ionic radius facilitates the easier penetration of iron into the micropores of activated carbon. Furthermore, coconut coir contains functional groups such as carboxylic, hydroxyl, and lactone, which exhibit a high affinity for metal ions, enhancing the adsorption of iron. The good porosity and high surface area of coconut shell further contribute to its effectiveness in iron adsorption (Balaji, Sasikala, and Muthuraman, 2014).

2.10 Filter Media with Powdered Activated Carbon (PAC)

The filter media is a low-cost system that only requires sand and media bed added into the arrangement. The arrangement will be coarse sand, fine sand and followed by PAC. The recommended coarse sand layer is ranging from 1.0 to 4.0 cm for the roughing filter while fine sand layer is ranging from 0.15 to 0.35 cm for the sand filter (Tepong-Tsindé et al., 2015). Coarse sands are used to screen coarse particles and ferric ions that exist in insoluble form. Fine sands act as the second barrier for the removal of residue ferric ions from the water flow. Besides, PAC is used to adsorb ferrous ions that are soluble in water and cannot be removed by the simple sand filter. Fine particles of PAC have large surface area per unit mass, highly effective for adsorption of small molecules and contaminants, and it provide a large number of active sites for adsorption hence increase adsorption rate of iron from water (WCP Online, 2002). Table 2.6 shows the characteristics of GAC and PAC to remove iron from water.

Table 2.6: Characteristics of GAC versus PAC

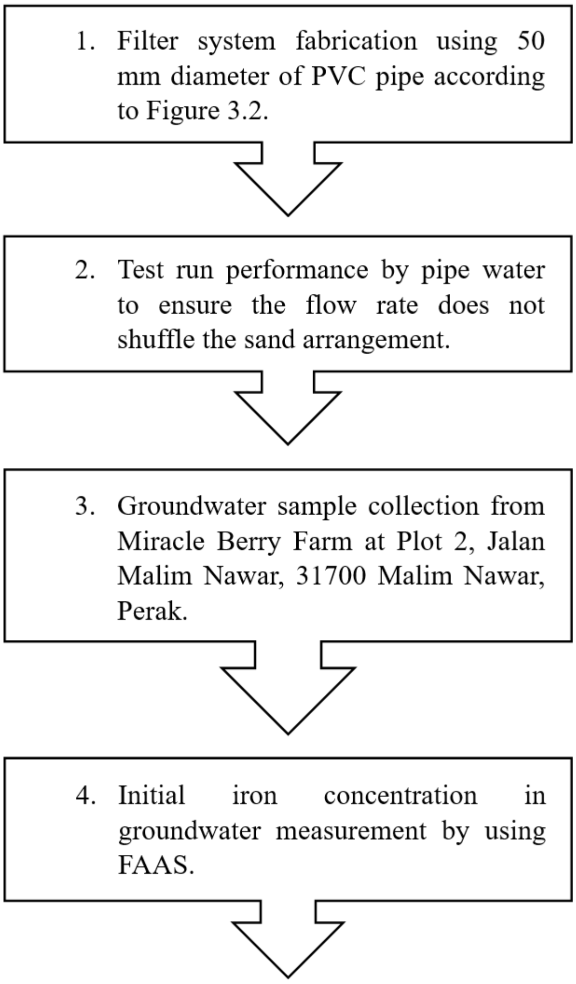
Characteristics	**Types of Activated carbon**	
	Granular	**Powdered**
Particle size	Coarse	Fine (10-100 times smaller than GAC)
Adsorption sites	Small	Large
Adsorption rate	Low	High
Cost	High (Two times of PAC)	Low

Source: WCP Online, 2002.

CHAPTER 3

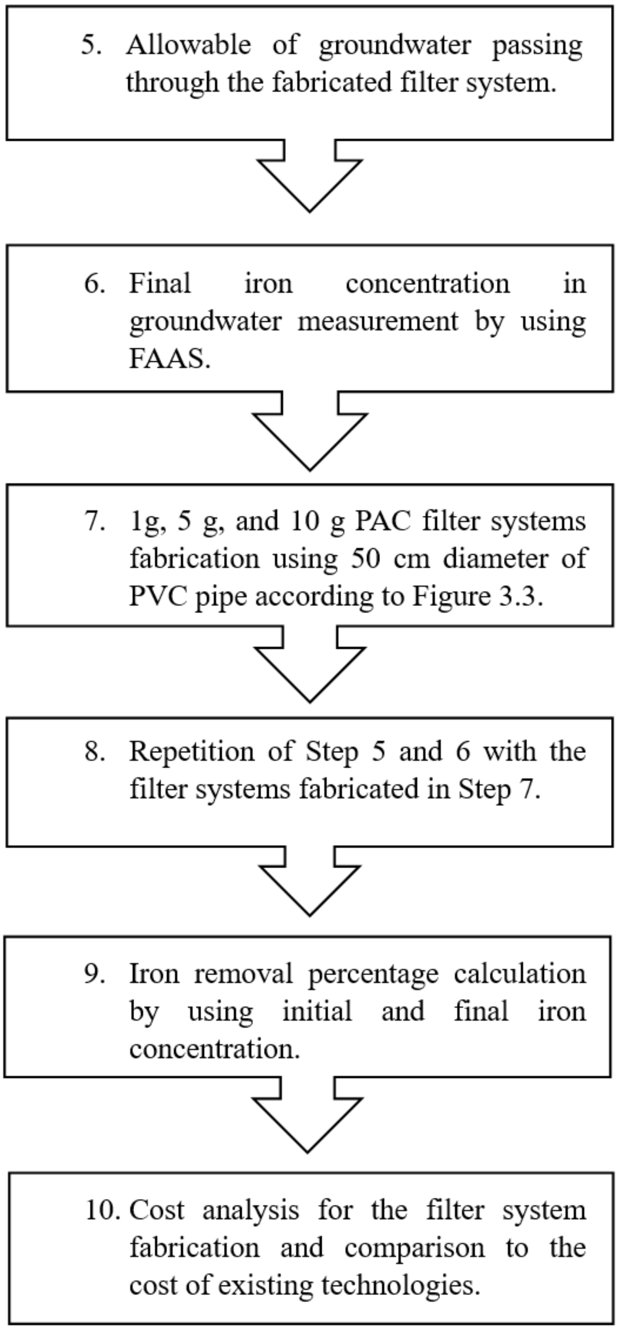
METHODOLOGY

3.1 Overview of Methodology



1. Filter system fabrication using 50 mm diameter of PVC pipe according to Figure 3.2.
2. Test run performance by pipe water to ensure the flow rate does not shuffle the sand arrangement.
3. Groundwater sample collection from Miracle Berry Farm at Plot 2, Jalan Malim Nawar, 31700 Malim Nawar, Perak.
4. Initial iron concentration in groundwater measurement by using FAAS.

Figure 3.1: Flow Chart of The Experiment Methodology



5. Allowable of groundwater passing through the fabricated filter system.
6. Final iron concentration in groundwater measurement by using FAAS.
7. 1g, 5 g, and 10 g PAC filter systems fabrication using 50 cm diameter of PVC pipe according to Figure 3.3.
8. Repetition of Step 5 and 6 with the filter systems fabricated in Step 7.
9. Iron removal percentage calculation by using initial and final iron concentration.
10. Cost analysis for the filter system fabrication and comparison to the cost of existing technologies.

(Con’t) Figure 3.2: Flow Chart of The Experiment Methodology

This research is a preliminary study for iron removal from groundwater sample. The experimental procedures are shown in Figure 3.1. The groundwater was free flow from the top of the filter and there is no pressure applied to the system. After the experiment has been carried out for filter systems with PAC of 0 g, 1 g, 5 g, and 10 g, the iron removal percentage will be calculated.

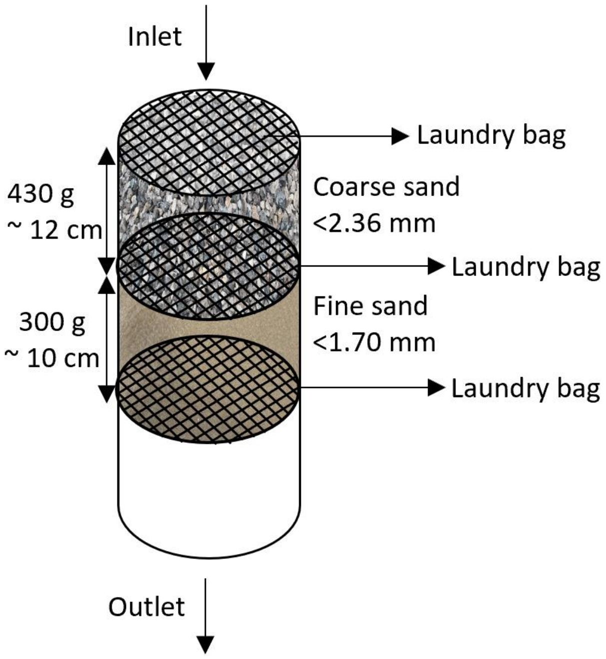


Figure 3.3: Filter System Arrangement without PAC

Figure 3.4: Filter System Arrangement with PAC

3.2 Groundwater Sample Collection

The groundwater is collected from the Miracle Berry Farm at Plot 2, Jalan Malim Nawar, 31700 Malim Nawar, Perak. The sample is stored in a refrigerator under the temperature of 4°C. Some precautionary steps were done for handling with the groundwater sample including labelled the samples clearly and stored samples properly in a clean, chemical resistant containers chemical-resistant containers with tight-fitting lids to prevent contamination and evaporation. The samples were stored in a cool, dark environment away from sources of contamination, direct sunlight, and heat sources to ensures the groundwater does not undergo any biological or chemical reaction and remains in its original condition to allow for accurate and reliable analysis of water quality parameters.

Figure 3.5: Main entrance of Miracle Berry Farm

3.3 Preparation of Filter System

3.3.1 Acquisition of components

The necessary components and materials for constructing the sand filter were procured including PVC pipe, pipe fittings, filter medias (coarse sand, fine sand and PAC), and laundry bag for the media separation.

3.3.2 Fabrication of Filter Body and Filter Bed

The piping as filter body were prepared by cutting the 50 cm diameter PVC pipe into 10 cm and 12 cm lengths. The PVC pipes were then rinsed with tap water to ensure the pipes are free from contaminants. The filter media was poured into the filter system, layer by layer and it is ensured to distributed evenly and uniformly across the filter bed, with a layer of laundry bag to separate the filter media between each other. The volume of coarse sand was 430 g while fine sand is 300 g for the filter systems respectively. The top and bottom of filter systems were covered by a layer of laundry bag respectively to screen out the particulate materials in groundwater.

3.3.3 Final Inspection and Testing

A final inspection was conducted for the filter system to verify that all the filter medias are properly distributed and functioning correctly. The filters were tested for leaks, flow rates, and filtration efficiency using tap water to ensure it can perform well for groundwater filtration. The appropriate flow rate also be observed to avoid the filter media arrangement from shuffling.

3.4 Performance analysis

3.4.1 Filtration Flux Analysis

In the context of fluid dynamics, flux refers to the rate of flow of a fluid, particles, or solutes through a surface perpendicular to the flux vector, per unit area of a surface (Hautala, 2020). Flux is typically expressed in units of volume per unit area per unit time. The experiment took 40 minutes to determine whether the filter system condition was stable and whether its generating flux was consistent and uniform within this period. The groundwater sample filtration flux was analysed by the volume passing through the filter per unit surface area of the filter bed per unit time. Therefore, the groundwater filtration flux will be computed using Equation 3.1.

$$\boldsymbol{J = \frac{V}{A\Delta t}} \tag{3.1}$$

where

J = Flux ($\text{Lm}^{-2}\text{h}^{-1}$)

V = Volume of water pass through the filter surface (L)

A = Surface area of the filter which the water is passing (m^2)

Δt = Time interval over which the flux is measured (h)

3.4.2 Iron Removal Efficiency

The Flame Atomic Absorption Spectrometer (FAAS) at UTAR's Faculty of Science, Block D in Kampar campus was used to measure the concentrations of iron in the groundwater. To ensure the accuracy of the results, all samples underwent acid digestion prior to this analysis to dissolve any contaminants or impurities present in the groundwater samples.

3.4.2.1 Acid Digestion

The Milestone Ethos Up, high performance microwave digestion system was used for acid digestion before the groundwater sample conducted the FAAS analysis. The program EPA 3015A for microwave assisted acid digestion of aqueous samples and extracts was used in this experiment. 22.5 mL of samples were filled into vessels of microwave digestor respectively together with 2.5 mL of concentrated nitric acid (HNO_3). The vessels were then introduced into the rotor bottom plate and fixed with the top rotor plate. After closing the door of microwave digestor, program EPA 3015A was selected and started for the acid digestion. After 2 hours of analysis and cooling, the samples were collected into centrifuge tubes for FAAS analysis.

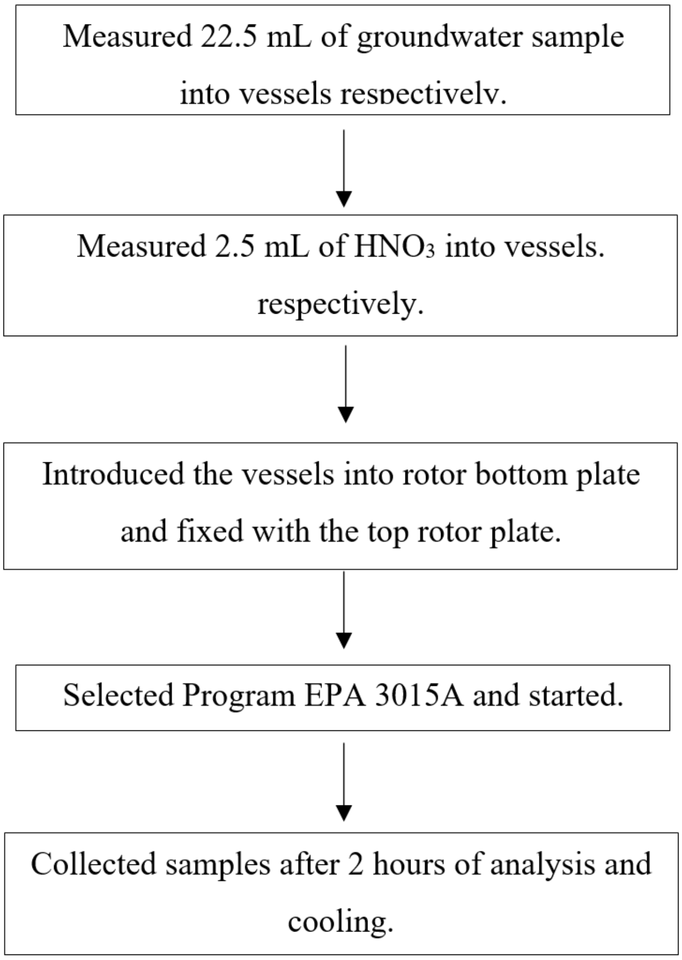


Figure 3.6: Schematic Flow Chart for Acid Digestion of the Samples

3.4.2.2 Flame Atomic Absorption Spectrometer (FAAS)

Blank and standard calibration solutions were prepared before conducting FAAS analysis. The blank solution is 0.5M HNO_3 solution while the existing calibration curve for iron analysis was used. After acid digestion, 5 mL of the groundwater samples were diluted into 50 mL volumetric flasks with 0.5M HNO_3 solution. Samples were diluted to 10 times less than the actual concentrations to make sure they are within the concentration ranges of detection capability of FAAS. It can also help in reducing the matrix effects by the matrix components by minimizing the concentration of the interfering substances to improve the efficiency for the iron concentration testing. Besides, dilution can improve the sensitivity of the analysis by improving the signal-to-noise ratio that permitting a better detection and quantification of the iron concentration. The diluted samples were then filtered into centrifuge tubes using 0.45 um CA syringe filters. The filtered samples were then undergone FAAS analysis to obtain the iron concentrations. The iron concentration analysis involved acquiring multiple readings and calculating the average value. Equation 3.2 was used for the determination of iron removal efficiency.

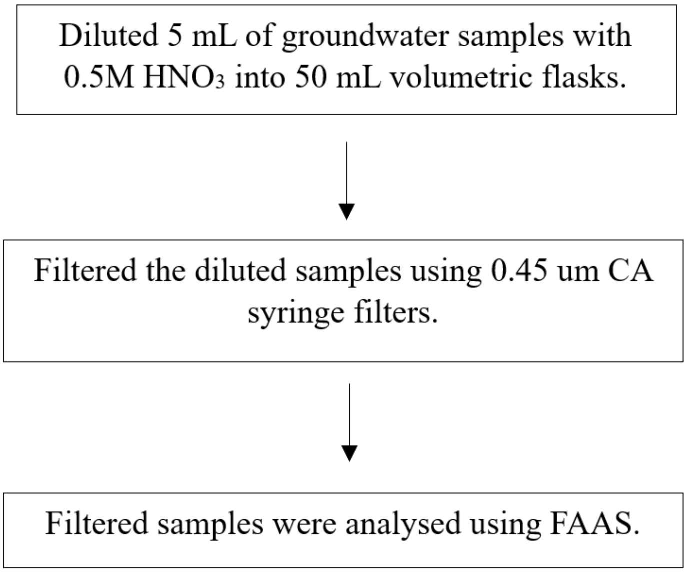


Figure 3.7: Schematic Flow Chart for FAAS Analysis

$$R\ (\%) = \frac{(C_i - C_f)}{C_i} \times 100\% \quad (3.2)$$

where

R = Removal efficiency (%)

C_i = Initial concentration

C_f = Final concentration

3.4.3 Turbidity Removal Efficiency

The rejection efficiency based on turbidity parameters for the groundwater was analysed and calculated. A portable turbidimeter, the HANNA Instrument HI 98703 model was employed to measure turbidity before and after passing through the fabricated filter system. turbidity. To provide precise and reliable measurements of turbidity, calibration is crucial using the provide reference solutions. The groundwater samples were added to the sample cell until the specified line was reached and placed into the turbidimeter for the measurement. To ensure accuracy, the sample cells were cleaned with a laboratory tissue before measurement to ensure the absence of bubbles and fingerprints on the sample cells. Turbidity measurements were recorded in Nephelometric Turbidity Units (NTUs), and an average reading was obtained after multiple measurements were taken. The turbidity rejection efficiency was determined using Equation 3.2.

3.4.4 Color Removal Efficiency

The HACH DR3900 spectrophotometer was utilized to measure color content in the groundwater samples. Following standard procedure, samples were diluted before testing to ensure compatibility with the color range of spectrophotometer. However, the groundwater samples are not required dilution as they fell within the spectrophotometer's defined range. Program 97 on the spectrophotometer was chosen for color measurement. Two empty glass sample cells were filled with 10 ml of each sample and distilled water. To ensure accuracy, the sample cells were cleaned with a laboratory tissue before measurement to ensure the absence of fingerprints on the sample cells. Distilled water served as the blank and was adjusted to zero. Color values were expressed using the American Dye Manufacturers' Institute (ADMI) Color Index. Measurements were repeated to obtain a more precise average reading. Color removal efficiency was calculated using Equation 3.2.

3.4.5 COD Removal Efficiency

In order to perform COD analysis, COD digester and COD analyser are needed. The HACH DRB 200 COD digester was preheated to 150°C before the sample's vials were placed. A blank solution was prepared by pipetted 2 mL of distilled water into a low range COD vial at 45° angle. After that, the samples of groundwater were pipetted into low range COD vials. The vials were rinsed with water and wiped with a clean laboratory tissue. The vials were then inverted gently for a better mixing of the sample with vial and put into the COD reactor for 2-hour heating. Before analysed by the HACH DR3900 Spectrophotometer, the sample vials were cooled at room temperature. Program 430 on the spectrophotometer was chosen for the low range COD measurement. The blank vial was tested to zeroise the value for a absorbance value as a standard for the groundwater samples. The remaining sample vials were tested one by one to determine the COD readings. Multiple COD analysis was carried out to obtain the average reading to improve the accuracy of readings. Equation 3.2 was used to determine the COD removal efficiency.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Groundwater Filtration Flux

In this study, groundwater filtration was conducted passively, relying solely on gravitational force without the application of additional pressure. The volume of groundwater passing through the filter system within specific time intervals, measured in minutes, was carefully collected, recorded, and documented. The groundwater filtration flux, a key parameter, was determined using Equation 3.1. However, during the experiment, flux measurements were conducted and ceased after 40 minutes to assess whether the groundwater filtration flux achieved stability and uniformity over time. Figure 4.1 and Table 4.1 present the filtration flux values obtained with varying amounts of PAC additives, demonstrating stability and consistency in flux values after 40 minutes of filtration time.

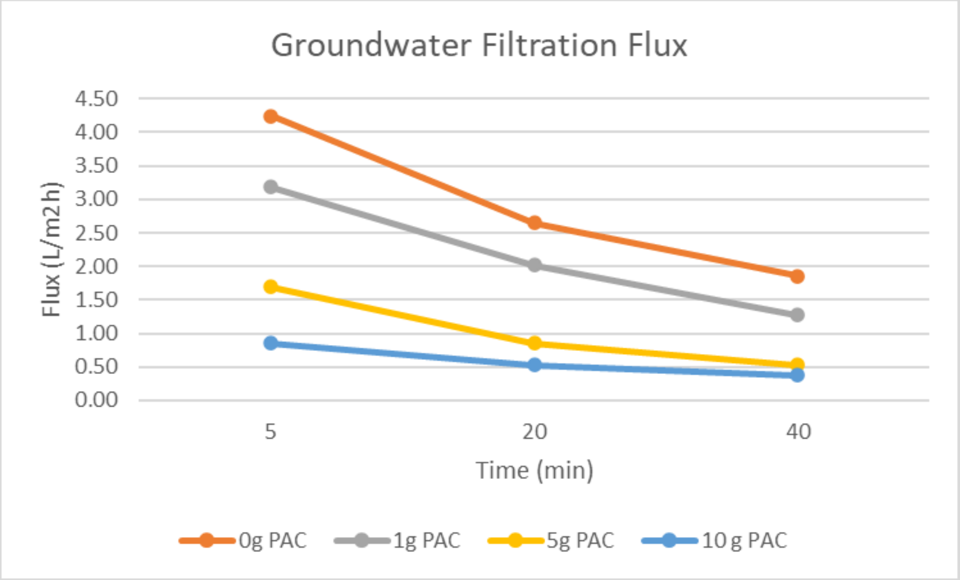


Figure 4.1: Graph of Groundwater Filtration Flux for Different Amount of PAC Against Time

Table 4.1: Groundwater Filtration Flux for Different Amount of PAC

	Groundwater Filtration Flux (L/m^2h)			
Time (min)	**0 g PAC**	**1 g PAC**	**5 g PAC**	**10 g PAC**
5	4.24	3.18	1.70	0.85
20	2.65	2.02	0.85	0.53
40	1.86	1.27	0.53	0.37
Total volume (L)	8.75	6.00	2.50	1.75

The amount of filtrated groundwater for different filters were collected and the filtration flux has shown in Figure 4.1. The results show that the filtration flux is inversely proportional to the amount of PAC used in a filter system. At the first 5 minutes, the highest value of the flux in this research is 4.24 L/m^2h for 0g of PAC used and the lowest value is 0.85 L/ m^2h for 10g of PAC used in the filter system. Among the filter system with PAC, 1 g of PAC filter was obtained the highest value of flux which is 2.65 L/m^2h. The filtration flux gradually decreased until 40 minutes of groundwater filtration time for all the filter systems. The 0 g PAC filter was achieved the highest flux compared to the PAC contained filter systems. Besides, the

1g PAC filter was observed to have the highest value among the filter systems with PAC contained over 40 minutes of time.

There are some reasons for the sand filter to have higher flux value than sand followed by PACs filters. Sands generally have higher hydraulic conductivity compared to PACs and the ability of the porous medium in sands to transmit water is higher than PAC. Besides, sands have larger particle sizes, leading to a larger interconnected pore spaces between the sands which allows water to flow through the filter bed more easily than the filter that contain PAC bed, leading to a higher flux rate for the sand filter. The filter bed with PACs has smaller particle sizes and a smaller interconnected pore size, with high porosity that restrict water flow through it and hence, decrease the filtration flux rate (Utari and Herdiansyah, 2020). Sand filter had higher hydraulic loading than the sand filter with PAC contained, but this can reduce the efficiency of contaminants removals and the filtration performance. Hydraulic loading affects the contact time between groundwater and the filter media, as well as the adsorption capacity for removing contaminants. Hence, it is crucial to control and balance the hydraulic loading with other design parameters including the particle size distribution, filter media depth, and flow rate of groundwater to ensure effective filtration for contaminants removal.

Moreover, the PAC filters utilized in this study featured a deeper filter bed compared to filters without PAC, primarily due to the consistent volume of two sand layers used in each filter, which is 430g for coarse sand and 300g for fine sand. The increased depth of the filter, coupled with the higher amount of PAC, facilitated extended contact time between the water and the filter media, promoting greater adsorption capacity and resulting in a lower flux rate. The adsorption capacity of the PAC filter media enables contaminants to adhere to the surface of PAC particles, impeding water flow and contributing to the reduction in flux rate over time. As contaminants gradually accumulate on the surface of PAC particles, the flux rate gradually diminishes until it reaches a minimum threshold. Typically, when the filter media becomes saturated, all voids are filled with water, and the moisture content equals the porosity of the media (Khaled et al., 2021). Consequently, moisture content primarily influences the downward movement of the solution. Although the groundwater flow through the PAC filter yielded a lower filtration flux compared to the filter without PAC, it was observed that the removal efficiency of contaminants was higher.

The average filtration flux observed in this experiment were found to be lower than other filtration system. In this research, the groundwater was allowed to pass through the filter system by gravitational force without any pressure supplied to the system. Hence, when the system supplied with pressure pump for the groundwater to flow through, there will be a higher filtration flux which allowed the irritation process more efficient.

4.2 Removal of Iron

The groundwater that extracted from the ground undergone microwave digestion and FAAS analysis to determine the initial iron concentration. The initial iron concentration is 14.5 mg/L. The iron concentration in the untreated groundwater is significantly exceeded the Ministry of Health (MOH) allowable level in raw water which is 1.0 mg/L and for drinking water limit is 0.3 mg/L. For the irrigation water use in agricultural, the recommended maximum allowable limit (MAL) by the Food and Agricultural Organization (FAO) for Fe is 5.0 mg/L (Fao.org, 2024). The untreated groundwater undergone filtration process using the simple self-fabricated filters system and the iron concentrations of filtered water were tested again using the FAAS. The results were compared to the initial iron concentration in the untreated groundwater to determine the ability of the filters for iron removal. The comparative removal efficiencies for different periods of time for the untreated groundwater to pass through the filter system were shown in Figure 4.2. A more detailed data for the iron concentration and removal efficiency were shown in Table 4.2.

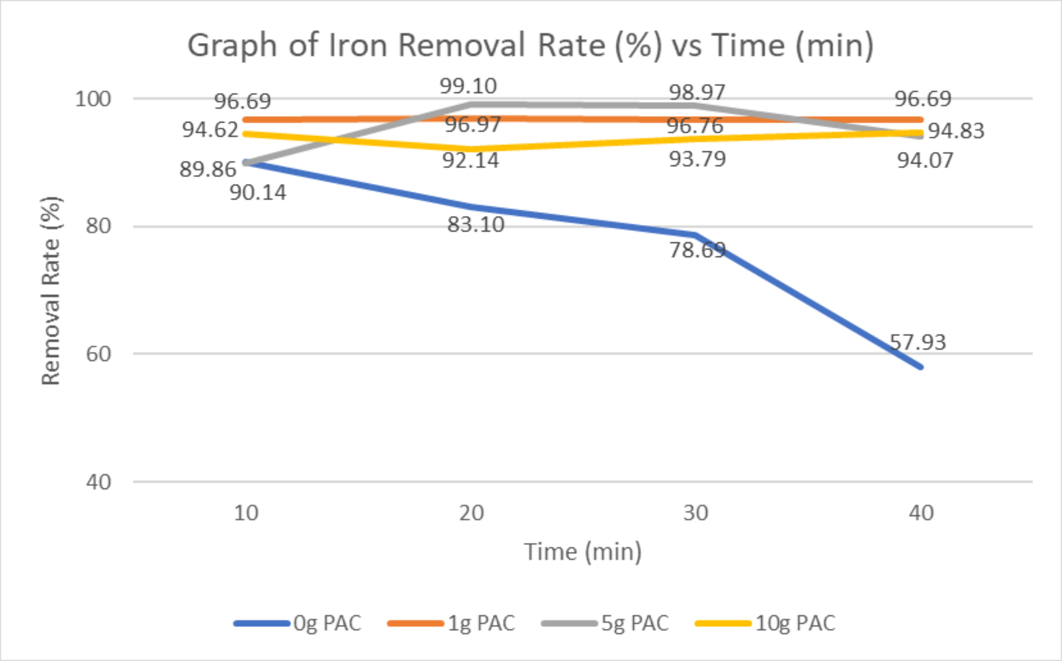


Figure 4.2: Graph Comparison of Iron Removal Rate for Different Amount of PAC Against Time

Table 4.2: Iron Removal Efficiency of Different Amount of PAC for Different Periods of Time

Amount of PAC (g)	Time (min)	Initial Iron Concentration (mg/L)	Final Iron Concentration (mg/L)	Removal Efficiency (%)
0	10	14.5	1.43	90.14
	20		2.45	83.10
	30		3.09	78.69
	40		6.10	57.93
1	10	14.5	0.48	96.69
	20		0.44	96.97
	30		0.47	96.76
	40		0.48	96.69
5	10	14.5	1.47	89.86
	20		0.13	99.10
	30		0.15	98.97
	40		0.86	94.07
10	10	14.5	0.78	94.62
	20		1.14	92.14
	30		0.90	93.79
	40		0.75	94.83

From the results, it is evident that the iron removal rate of the filter system without PAC exhibited a significant change from the beginning to the end of the experimental period. Conversely, for the filter system with PAC beds, the removal efficiency remained stable over time. The filter system without PAC achieved a 90% iron removal efficiency for the groundwater sample within the first 10 minutes of filtration. However, this efficiency gradually declined to 83% within the first 20 minutes and further dropped to approximately 58% after 40 minutes of filtration. In contrast, filter systems with varying amounts of PAC consistently achieved iron removal rates of over 89%. This indicates that even a small amount of PAC was effective in removing iron from groundwater. Additionally, iron removal efficiency can be further enhanced through pretreatment methods such as oxidation by supplying oxygen before the groundwater flows through the filter system. Previous research has demonstrated that pre-oxidation leads to the precipitation of oxidized iron prior to adsorption, thereby increasing the filter efficiency in iron removal (Thinojah and Ketheesan, 2022).

The final iron concentrations were found to be met the allowable value by the Food and Agricultural Organization (FAO) which is 5.0 mg/L. Some of the results for the PAC contained filter systems were observed to be slightly exceeded the allowable limit for raw water, which is 1.0 mg/L, but it was controlled to more stable value which is less than 1.0 mg/L. However, for the filter system without PAC, the results were observed to be increasingly exceeded the allowable value from the first 10 minutes to 40 minutes of the experimental period.

The gradually decreased in iron removal rate over time in a sand filter without PAC filter bed mainly due to the sand filter typically rely on the physical filtration to remove the suspended solid and particulate iron from the groundwater. Therefore, over a period, as the sand filter become saturated with iron particles, the removal capacity diminishes and lead to gradually decreased in the iron removal efficiency. On the other hand, in the sand filter bed followed by PAC filter bed, after the sand filter bed filtered out the particulate iron, the PAC filter bed still able to adsorb the dissolved ferrous ions as well as insoluble ferric ions. Hence, the removal efficiency is not affected over 40 minutes of times as the PAC are not saturated by the iron particles.

Furthermore, sand filters without PAC normally have larger pore sizes compared to the sand filters with PAC filter bed, may allow smaller iron particles to pass through the filter media. This indicated that the sand filter without PAC filter bed has less effective in removing fine particulate iron than the sand filter with PAC filter bed. The higher hydraulic conductivity of sand than PAC will be another reason for the weak iron removal efficiency of filter system without PAC over time. The high hydraulic conductivity of sand allows water to pass through the sand media in a faster rate, results in less contact time of groundwater to the filter media for iron removal. The iron adsorption was observed to increase as contact time of iron with PAC increased (Siabi, 2003). Filtration process can be continued until either the pores of the sand and PAC faces are blocked, or the impermeability of the accumulated solids reaches the practical limits of the system (Bell, 1965).

4.3 Removal of Color

The groundwater that extracted from the ground undergone color analysis using HACH DR 3900 to determine the initial color intensity. The initial color scale is 525 ADMI. After the groundwater samples gone through the filtration system, and undergone filtration flux test, the final color scales were tested for groundwater that filtered through different filter systems with the different PAC amounts. The results were compared to the initial color scale in the untreated groundwater to determine the extent of the filters for color removal. The comparative color removal efficiencies for different periods of time for the untreated groundwater to pass through the filter systems with different PAC amounts were shown in Figure 4.3. A more detailed data for the color scale and removal efficiency were shown in Table 4.3.

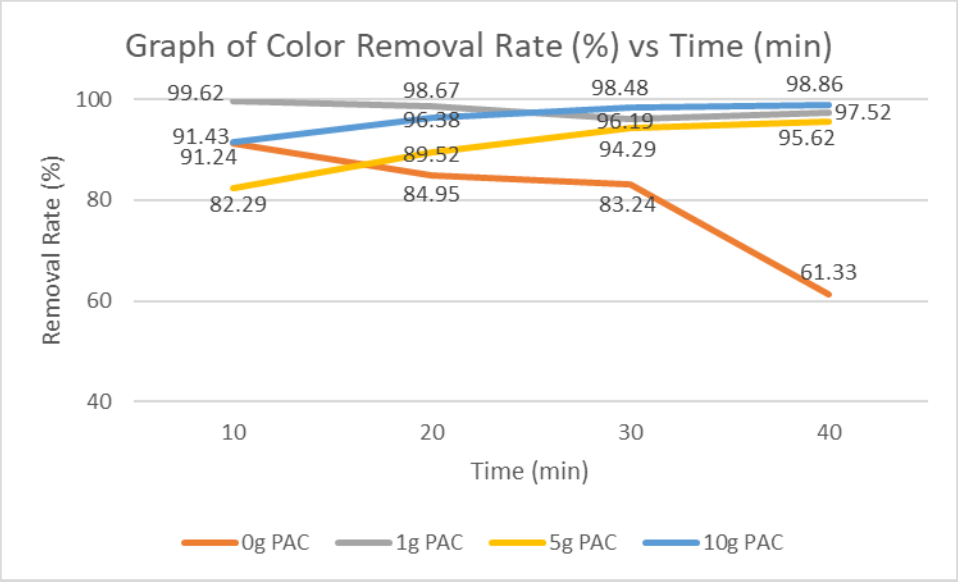


Figure 4.3: Graph Comparison of Color Removal Rate for Different Amount of PAC Against Time

Table 4.3: Color Removal Efficiency of Different Amount of PAC for Different Periods of Time

Amount of PAC (g)	Time (min)	Initial Color (ADMI)	Final Color (ADMI)	Removal rate (%)
0	10	525	46	91.24
	20		79	84.95
	30		88	83.24
	40		203	61.33
1	10	525	2	99.62
	20		7	98.67
	30		20	96.19
	40		13	97.52
5	10	525	93	82.29
	20		55	89.52
	30		30	94.29
	40		23	95.62
10	10	525	45	91.43
	20		19	96.38
	30		8	98.48
	40		6	98.86

Figure 4.2 shows that filter system without PAC have a better removal rate at the starting point and it decreases gradually until 61.33% removal at 40 minutes of filtration. This can be explained by the ability of sand filter to barrier the color to pass through the filter system decreased gradually and it becomes saturated after periods of time. It will be clogged after the sand in the filter system contain high concentration of color-causing compounds. When the sites for filtration are fully saturated and filled, the removal efficiency will be diminished.

For the filter systems that contained PACs in different amounts, the PACs can adsorb color and the results shows that 40 minutes of contact time of groundwater to PACs do not have significant changes to the removal efficiencies. The color can be filtered by sand and followed by PACs to adsorb it although there is only 1g of PACs in the filter system. The removal rates were remained at more than 96% for 1g of PACs, more than 82% for 5g of PACs, and it is higher than 91% for 10g of PACs used in the filter systems.

PAC can remove color by adsorbing color-causing compounds present in the water, which are attracted to and bind with the surface of activated carbon particles. This adsorption process is governed by two intraparticle diffusion mechanisms which are diffusion within the pore volume (pore diffusion) and diffusion along the surface of pores (surface diffusion) (Syafalni et al., 2012). The utilization of PAC media ensures sufficient contact time for impurities to transport from the liquid phase to the pores of the adsorbent, thereby enhancing the removal of color from the water.

4.4 Removal of Turbidity

The groundwater that extracted from the ground undergone turbidity analysis using a portable turbidimeter, model HI 98703 to determine the initial turbidity intensity. The initial turbidity scale is 108 NTU. The turbidity in untreated groundwater samples is acceptable for the MOH Malaysia recommendation of raw water quality, which is 1000 NTU but it is exceeded the drinking maximum acceptable value for drinking water quality standard in Malaysia, which is 5 NTU. After the groundwater samples gone through the filtration system, and undergone filtration flux test, the final turbidity values were tested for groundwater that filtered through different filter systems with the different PAC amounts. The results were compared to the initial turbidity scale in the untreated groundwater to determine the extent of the filters for turbidity removal from the groundwater samples. The comparative removal efficiencies for different periods of time for the untreated groundwater to pass through the filter systems with different PAC amounts were shown in Figure 4.4. A more detailed data for the turbidity value and removal efficiency were shown in Table 4.4.

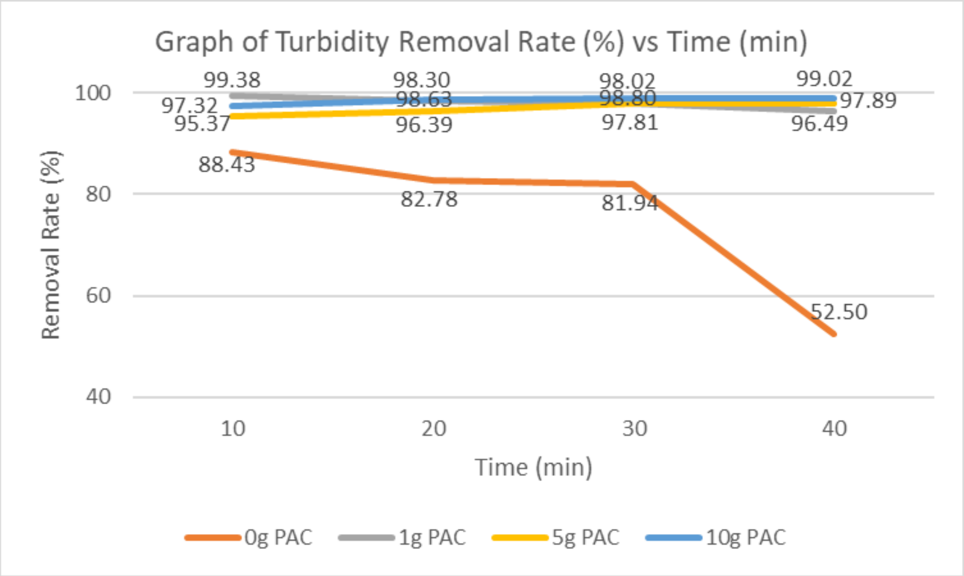


Figure 4.4: Graph Comparison of Turbidity Removal Rate for Different Amount of PAC Against Time

Table 4.4: Turbidity Removal Efficiency of Different Amount of PAC for Different Periods of Time

Amount of PAC (g)	Time (min)	Initial Turbidity (NTU)	Final Turbidity (NTU)	Removal rate (%)
0	10	108	12.5	88.43
	20		18.6	82.78
	30		19.5	81.94
	40		51.3	52.50
1	10	108	0.67	99.38
	20		1.84	98.30
	30		2.14	98.02
	40		3.79	96.49
5	10	108	5.00	95.37
	20		3.90	96.39
	30		2.36	97.81
	40		2.28	97.89
10	10	108	2.89	97.32
	20		1.48	98.63
	30		1.30	98.80
	40		1.06	99.02

Figure 4.3 demonstrates that the 0g of PAC in filter media had the lowest turbidity removal efficiency with a beginning removal rate of 88.43% and dropped to 52.50% after 40 minutes of filtration, while the filter media with PAC produced significantly higher turbidity removal efficiency, ranging from 95.37% to 99.38%. These findings demonstrated that the filter with PAC can effectively reduce turbidity in groundwater. According to the drinking water standard, the filter system with PAC media achieved the acceptable value of turbidity in drinking water, which is less than 5 NTU while for the filter system without PAC media, the turbidity after filtration were exceeded the allowable value shown in Figure 4.4.

The sand filter without PAC becomes saturated with particles and other contaminants which reduce the removal capacity of turbidity from the groundwater while PAC can adsorb the additional contaminants and particles that will affect the turbidity of the groundwater. As the large pore sizes in the sands allow smaller particles to pass through the filter media, the sand filter has less effective at removing fine particulate matter, which lead to a lower removal rate of turbidity compared to the filter consists of PAC filter media. Besides, oxidation and removal of iron from groundwater sample can lead to the presence of iron oxides in the sand filter bed which contribute to solid particle accumulation over time, and it will further reduce the turbidity removal rates.

4.5 Chemical Oxygen Demand

The groundwater that extracted from the ground undergone COD analysis using HACH DR 3900 device to determine the initial COD in the groundwater. The initial COD value is 20 mg/L. The COD in untreated groundwater samples is beyond the acceptable value for the MOH Malaysia recommendation of raw water quality, which is 10 mg/L. After the groundwater samples gone through the filtration system, and undergone filtration flux test, the final COD values were tested for groundwater that filtered through different filter systems with the different PAC amounts. The results were compared to the initial COD values in the untreated groundwater to determine the extent of the filters for COD removal from the groundwater samples. The comparative COD removal efficiencies for different periods of time for the untreated groundwater to pass through the filter systems with different PAC amounts were shown in Figure 4.5. A more detailed data for the COD values and removal efficiency were shown in Table 4.5.

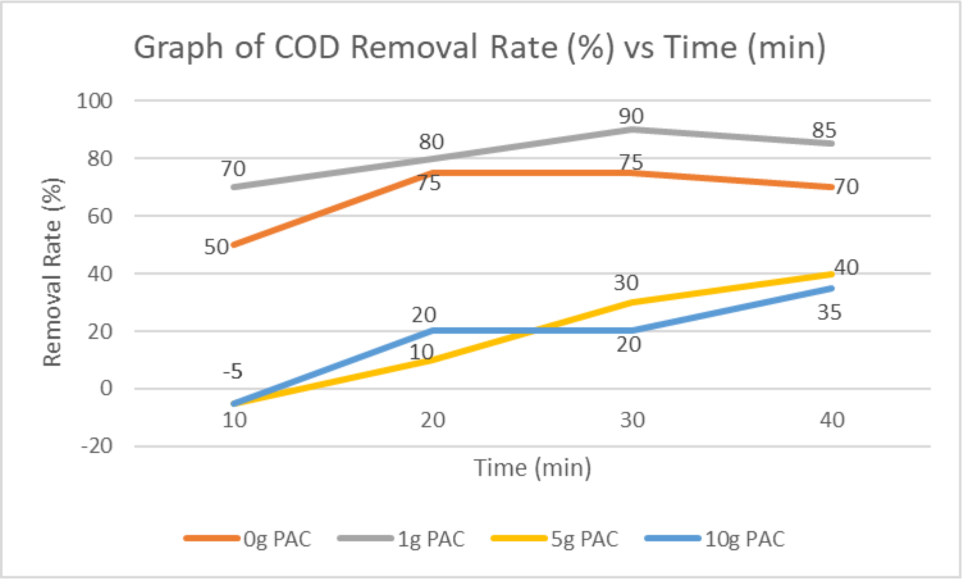


Figure 4.5: Graph Comparison of COD Removal Rate for Different Amount of PAC Against Time

Table 4.5: COD Removal Efficiency of Different Amount of PAC for Different Periods of Time

Amount of PAC (g)	Time (min)	Initial COD (mg/L)	Final COD (mg/L)	Removal rate (%)
0	10	20	10	50
	20		5	75
	30		5	75
	40		6	70
1	10	20	6	70
	20		4	80
	30		2	90
	40		3	85
5	10	20	21	-5
	20		18	10
	30		14	30
	40		12	40
10	10	20	21	-5
	20		16	20
	30		16	20
	40		13	35

The COD measurement is conducted to quantify the oxygen required for the oxidation of both organic and inorganic substances present in the water sample (Saad et al., 2016). It can be observed that the lesser amount of PAC has higher efficiency for the COD removal. For the filter system without PAC, the removal efficiency was ranging from 50% to 75%. These results highlight the substantial impact of varying PAC amounts on the COD removal efficiency. The more amount of PAC used in the filter system, the more unstable the removal efficiency of the COD from groundwater samples. For 5g of PAC used in the study, the results were ranging from -5% to 40% of removal rates while 10g of PAC used ranging from -5% to 35% of removal rates.

There are several potential factors contributing to the observed variations in COD levels during the filtration process, including the oxidation of inorganic compounds, the concentration of refractory organic matter, and the adsorption of organic material by activated carbon. The presence of inorganic compounds in groundwater renders them susceptible to oxidation during the COD test. This oxidative process, occurring as groundwater passes through the filtration system, can elevate the final COD values in the samples (Utari and Herdiansyah, 2020). Additionally, the filtration process may concentrate refractory organic matter, characterized by its resistance to biodegradation, thereby augmenting the overall COD concentration (Novak et al., 1989). Furthermore, the incorporation of PAC into the filtration process facilitates the adsorption of organic material present in the groundwater sample onto the carbon particles. Consequently, when small PAC particles are flushed out from the filter system, they may contribute to an increase in the COD concentration in the water. Moreover, it is plausible that PAC may harbour impurities or contaminants, which could also contribute to elevated COD levels post-filtration. Notably, initial results indicate a negative COD removal within the first 10 minutes, suggesting a transient phase wherein contaminants may be released from the filter system, subsequently leading to an enhancement in COD removal efficiency beyond this initial period.

In this research, the PAC demonstrates an incrementally stable performance in terms of COD removal capability, it is believed that PAC has potential efficacy in long-term applications. However, it's noteworthy that the experiment was conducted over a relatively short duration of 40 minutes, limiting the ability to assess the sustained consistency of COD removal beyond this timeframe. Therefore, extension the experimental time for the sustained study of the COD removal by PAC filter system is necessary.

4.6 Cost Analysis

To evaluate the economic feasibility of employing a self-fabricated PAC filter system for groundwater treatment, a detailed cost analysis was conducted. This study investigated the costs associated with materials including sand, PAC, PVC pipe, pipe fitting, and the laundry bag used for each filter. The laundry bag can be replaced by other materials such as old clothes or old fabrics that have been discarded in households. The costs were then compared against those accessible iron removal technologies that currently available in the market. An assessment of 10 g PAC filter system was selected for the analysis. Table 4.6 shows the cost of the iron removal technologies available in the market. Table 4.7 shows the cost analysis for a fabricated filter system.

Table 4.6: Cost for Technologies Available in Iron Removal

Technology	Cost (RM)	Reference
Fiberglass oxidation chamber iron removal system 75L	1,146.51	Aquascience.net, 2024
Birm iron filter tank oxygen chamber system 9” x 48”	3 905,07	AAJJO, 2015

Table 4.7: Cost Analysis for 10 g PAC Fabricated Filter System

Materials	**Market Price**	**Cost of a filter (RM)**
Sand	RM 1.00 / kg	0.73
PAC	RM 72.00 / 500 g	1.44
PVC Pipe (50 mm D)	RM 5.70 / m	1.71
Pipe Fitting	RM 1.60 / pcs	4.80
Laundry Bag	RM 3.10 / pcs	3.10
Total		**11.78**

According to the cost analysis, the self-fabricated filter system for iron removal was cost RM 11.78 for 10 g PAC contained filter system that extremely different from the cost for the technologies available in market including the fiberglass oxidation chamber iron removal system with a volume of 75 L and birm iron filter tank oxygen chamber system for 9” x 48” volume. The costs are more than hundred times the simple fabricated filter system. Furthermore, the existing available technologies can be observed that have a large volume and required a specific space allocation for groundwater treatment. Hence, they are not suitable for a relatively small area of farm to be implementing the technologies due to the space constraints.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In the present study, a low-cost and simple treatment system utilizing local materials was successfully fabricated for the removal of iron from groundwater intended for agricultural application. The materials employed included PVC pipe, pipe fittings, sand, powdered activated carbon (PAC), and a laundry bag. Furthermore, the second objective was accomplished by analyzing the iron removal efficiency of the fabricated system alongside other parameters, such as color, turbidity, and chemical oxygen demand (COD) in groundwater. The system demonstrated promising outcomes in iron removal through the application of the PAC filtration system. Results indicated that the quantity of PAC within the filter system did not significantly affect iron removal efficiency. Even with a minimal amount of PAC in the sand media, the system exhibited a removal efficiency of over 89% for all configurations containing PAC. This study revealed that varying amounts of PAC within the filter system yielded similar removal efficiencies. Additionally, various performance parameters, including color, turbidity, and COD removal, were assessed, with PAC contributing to improved filter performance across these parameters. The PAC-containing filter system effectively removed color and turbidity from groundwater samples at efficiencies exceeding 82% and 95%, respectively. It was observed that COD have progressively stable condition in removing COD from the groundwater samples. Moreover, system performance was optimized by adjusting the PAC quantity from 0 g to 1 g, 5 g, and 10 g. It was demonstrated that while the iron removal efficiency decreased significantly over time for the filter system without

PAC, systems incorporating PAC exhibited stable trend of removal efficiency with the addition of varying PAC quantities. This underscores the effectiveness of the self-fabricated PAC filtration system in removing iron from groundwater. Last but not least, a cost analysis was conducted for the fabrication of the iron removal filtration system, revealing a total cost of RM 11.78 for a 10 g PAC-containing filter system. This cost was then compared to that of market-available technologies, demonstrating that the fabricated filtration system is significantly more cost-effective than existing alternatives.

5.2 Recommendations

Considering the extensive scope for further advancements in self-fabricated PAC filtration system studies, it is essential to acknowledge and integrate specific recommendations into future research endeavours. These suggestions include:

i. Experimental duration should be extended to ensure robust results and assess the frequency at which PAC replacement is necessary based on the volume of groundwater processed through the system. This prolonged duration is particularly crucial for accurately evaluating the efficiency of COD removal.

ii. The conditions and characteristics of the sand used in the filtration system should be explored to obtain more precise outcomes, considering the potential presence of contaminants within the sand itself.

iii. The characteristics of the PAC utilized in the filtration process should be investigated as variations in PAC composition may influence experimental outcomes. Understanding these characteristics is vital for optimizing the filtration system's performance.

iv. The optimal quantity of PAC required to achieve maximum effectiveness in removing iron and other contaminants from groundwater should be obtained.

This investigation will contribute to enhancing the efficiency and cost-effectiveness of the filtration system.

By addressing these recommendations in future research endeavours, advancements in the development and optimization of self-fabricated PAC filtration systems can be realized, ultimately contributing to improved water treatment technologies for agricultural applications.

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APPENDICES

APPENDIX A: Figures

Figure A1: Flame Atomic Absorption Spectrometer

Figure A2: Milestone Ethos Up Microwave Digestor

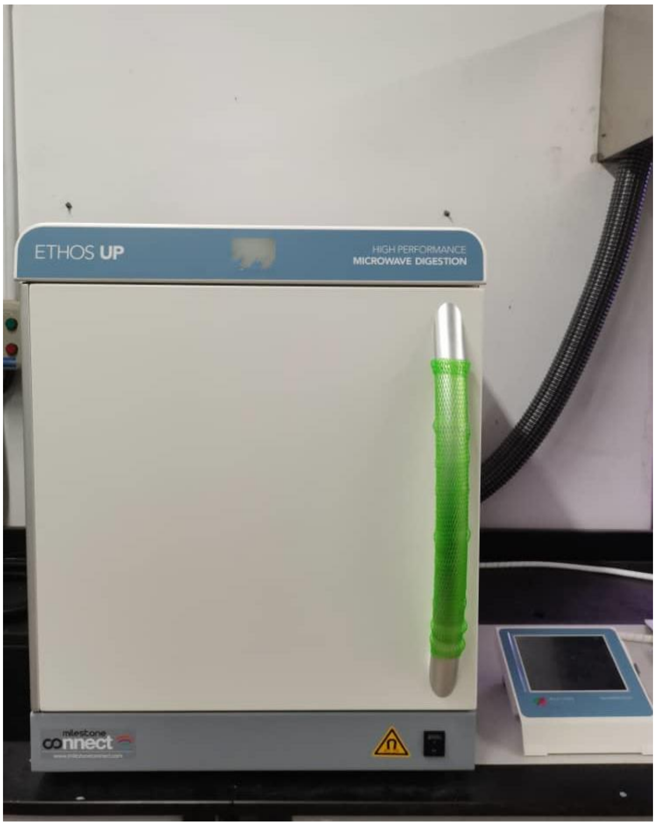


Figure A3: HANNA Instrument HI 98703 Portable Turbidimeter

Figure A4: HACH DR 3900 UV-Vis Spectrophotometer

Figure A5: Sieve Analysis Vibrating Machine

Figure A6: Filter System Fabrication

Figure A7: Fabricated Filter System

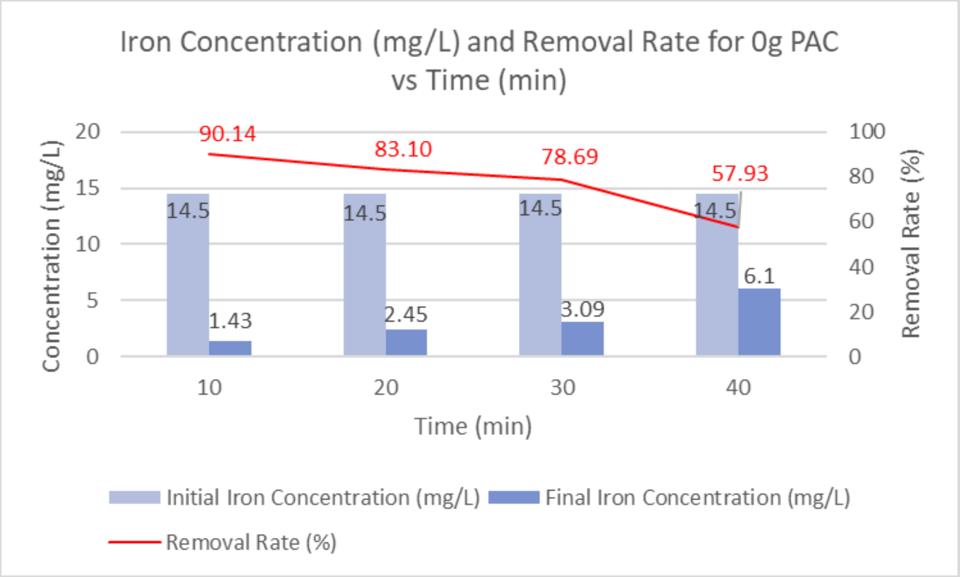
Figure A8: Iron Staining and Clogging of Irrigation System in Miracle Berry Farm

Figure A9: Iron Staining and Clogging of Irrigation System in Miracle Berry Farm

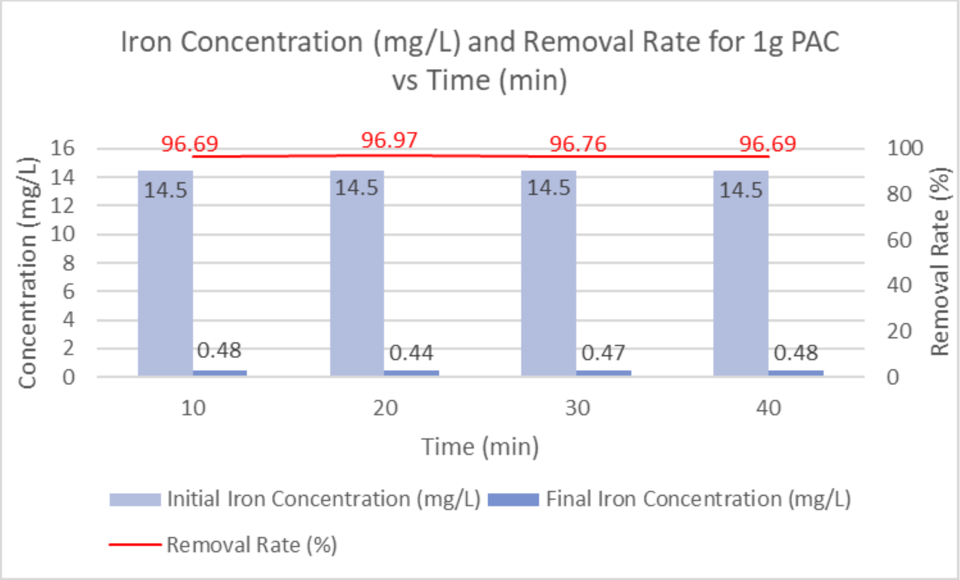
Figure A10: Iron Staining on the Agricultural Appliance

APPENDIX B: Graphs

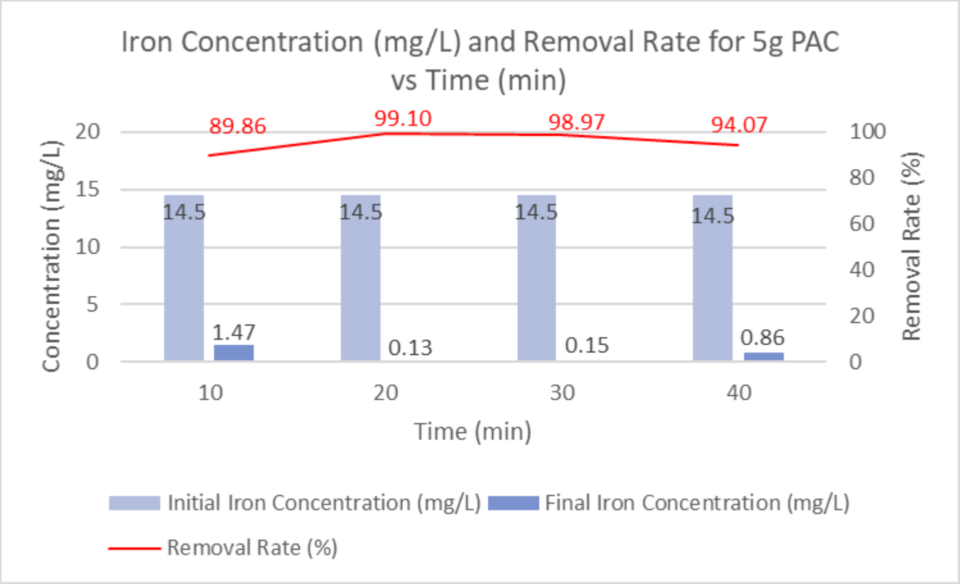
Graph B1: Iron Concentration and Removal Efficiency for 0 g PAC over Time



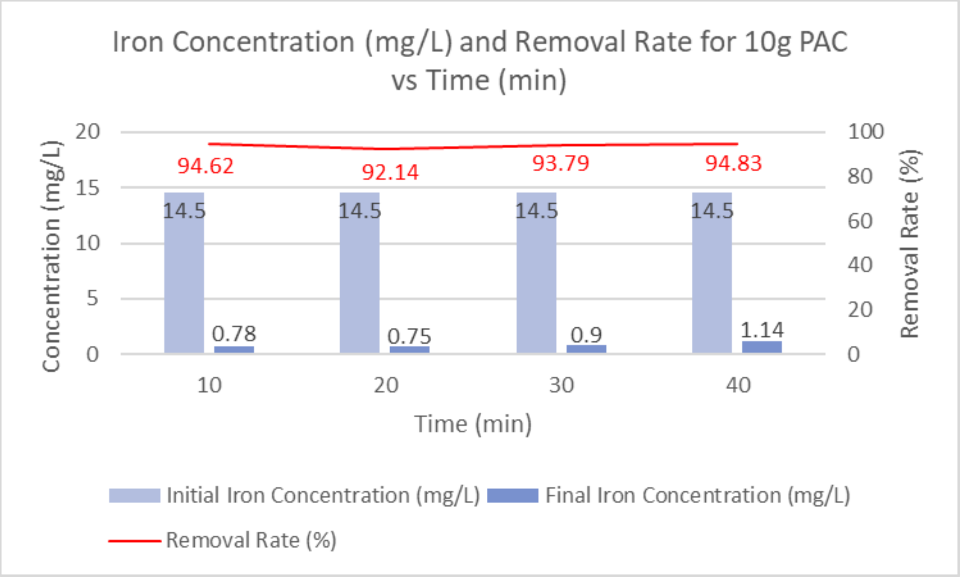
Graph B2: Iron Concentration and Removal Efficiency for 1 g PAC over Time



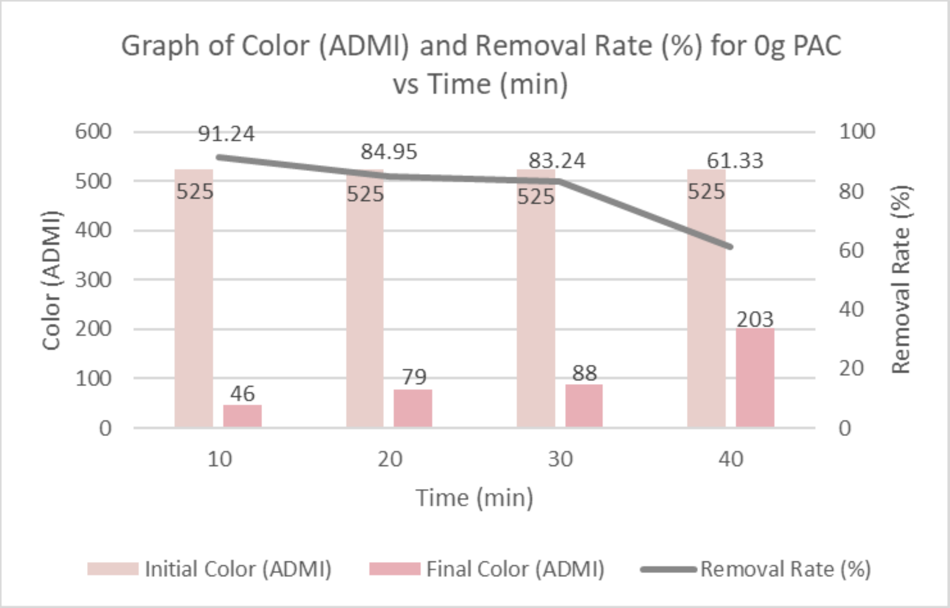
Graph B3: Iron Concentration and Removal Efficiency for 5 g PAC over Time



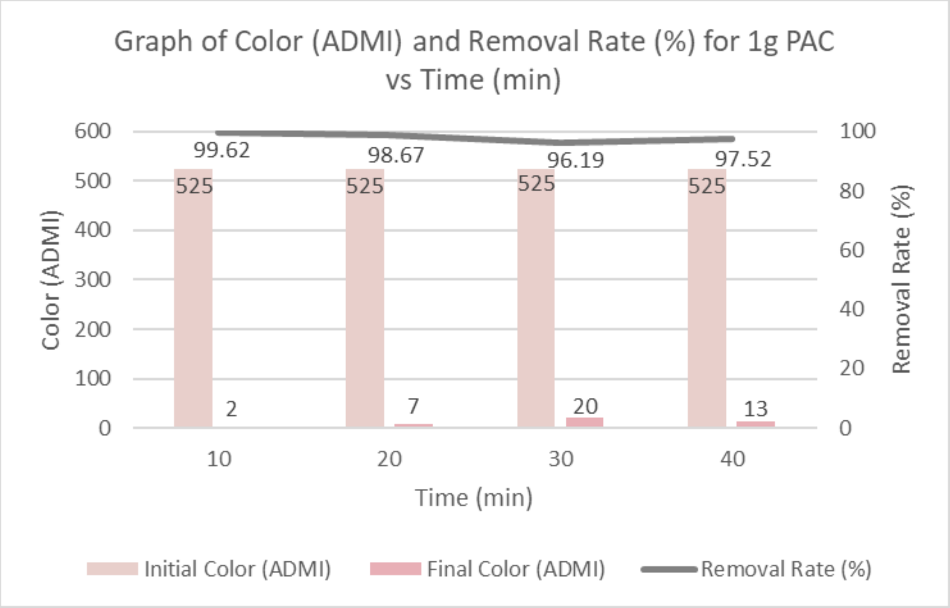
Graph B4: Iron Concentration and Removal Efficiency for 10 g PAC over Time



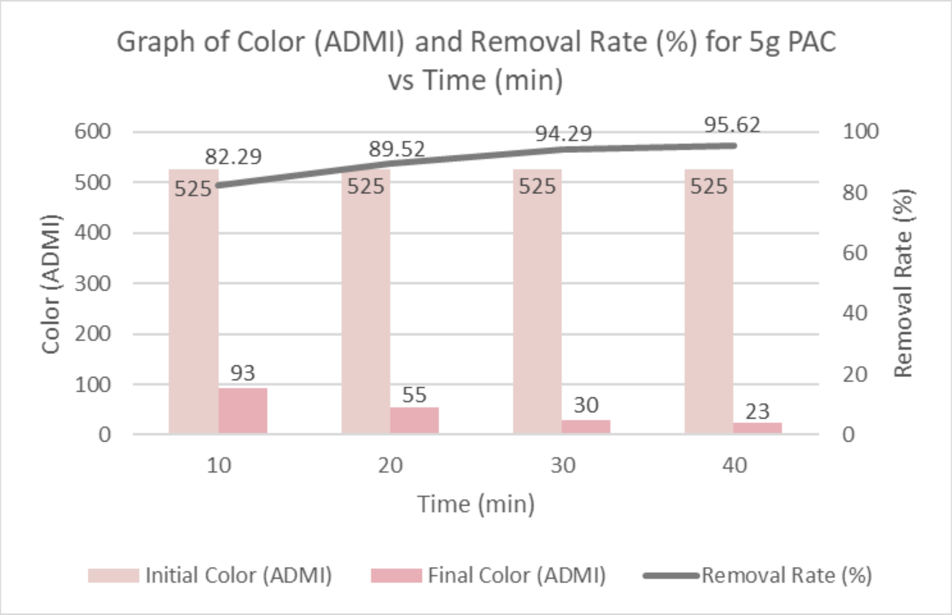
Graph B5: Color and Removal Efficiency for 0 g PAC over Time



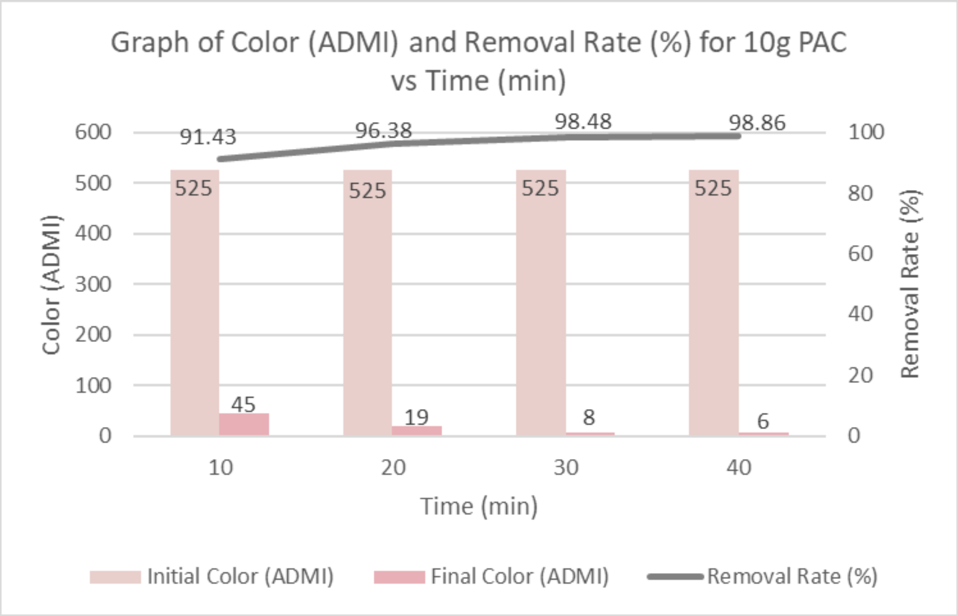
Graph B6: Color and Removal Efficiency for 1 g PAC over Time



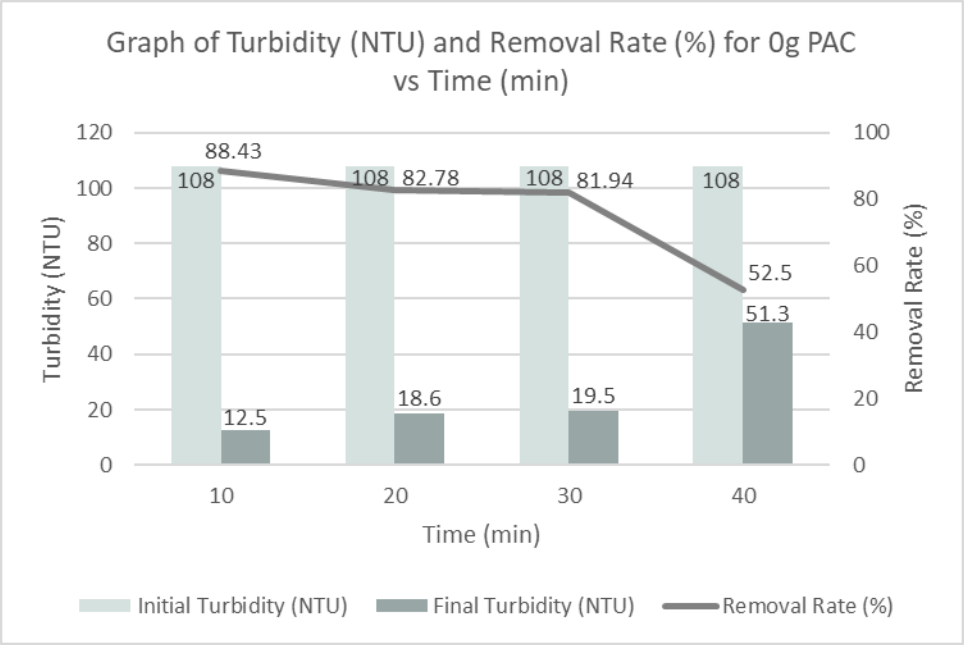
Graph B7: Color and Removal Efficiency for 5 g PAC over Time



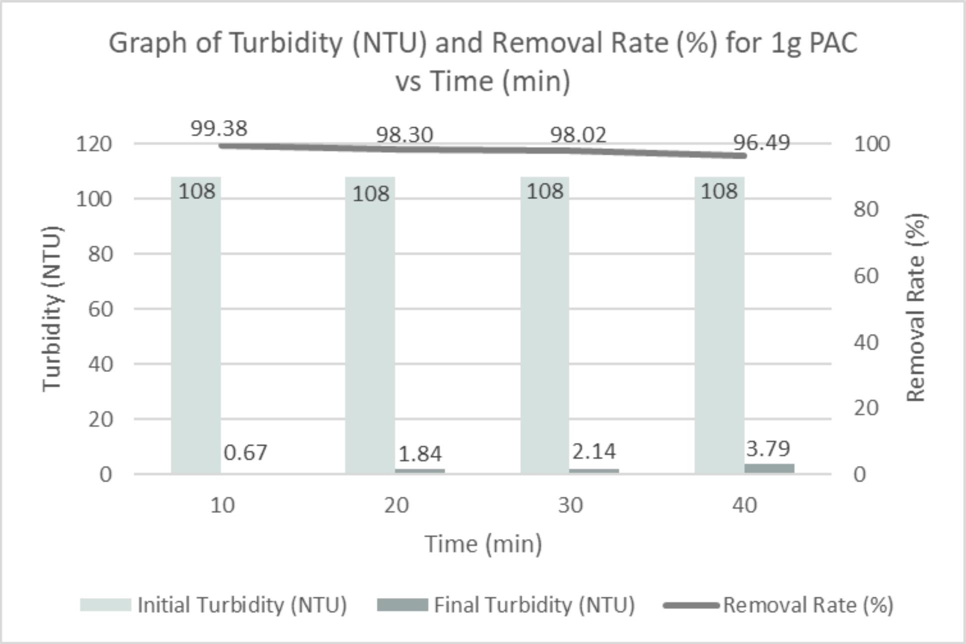
Graph B8: Color and Removal Efficiency for 10 g PAC over Time



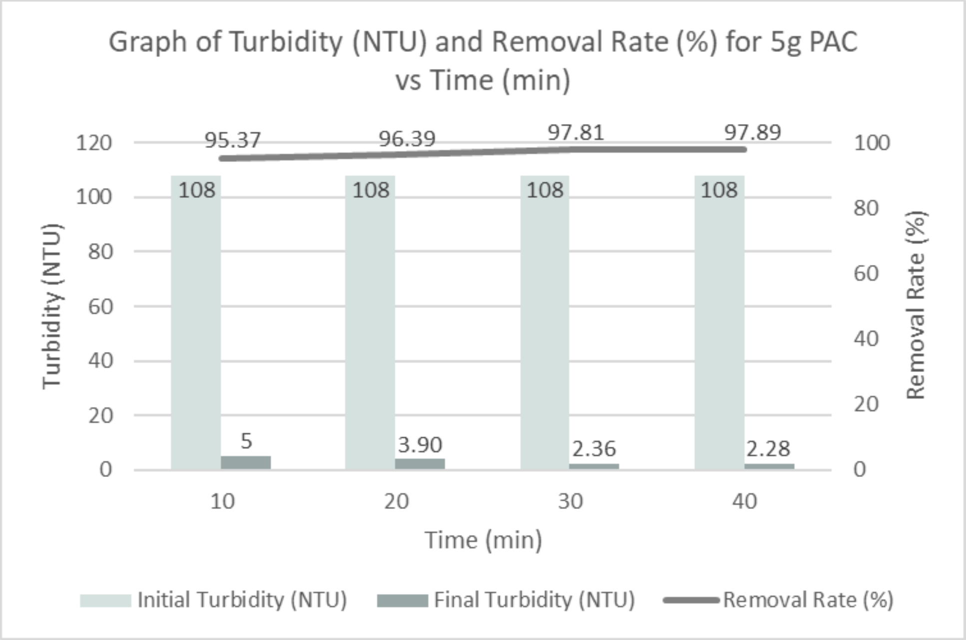
Graph B9: Turbidity and Removal Efficiency for 0 g PAC over Time



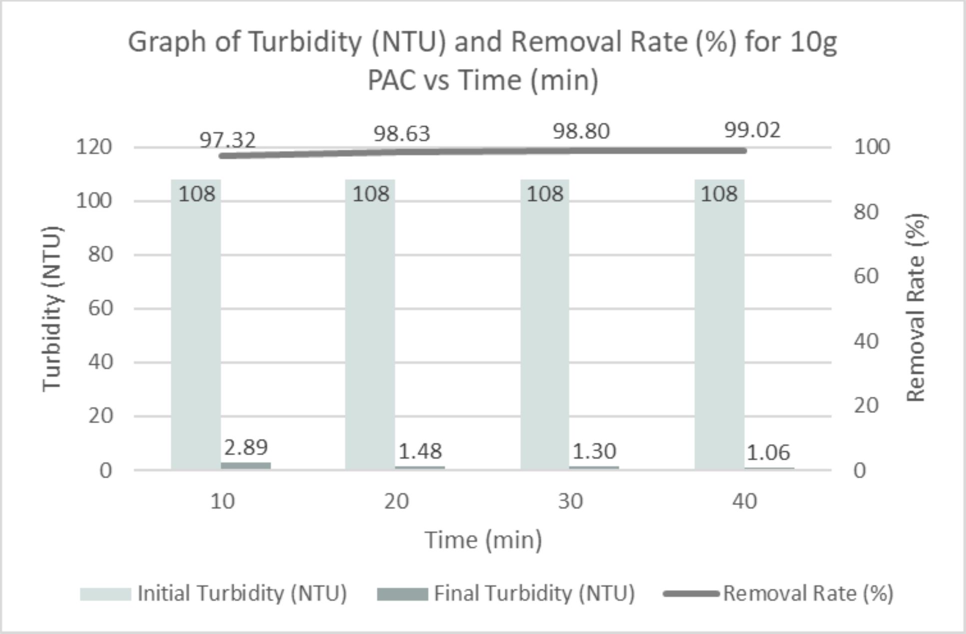
Graph B10: Turbidity and Removal Efficiency for 1 g PAC over Time



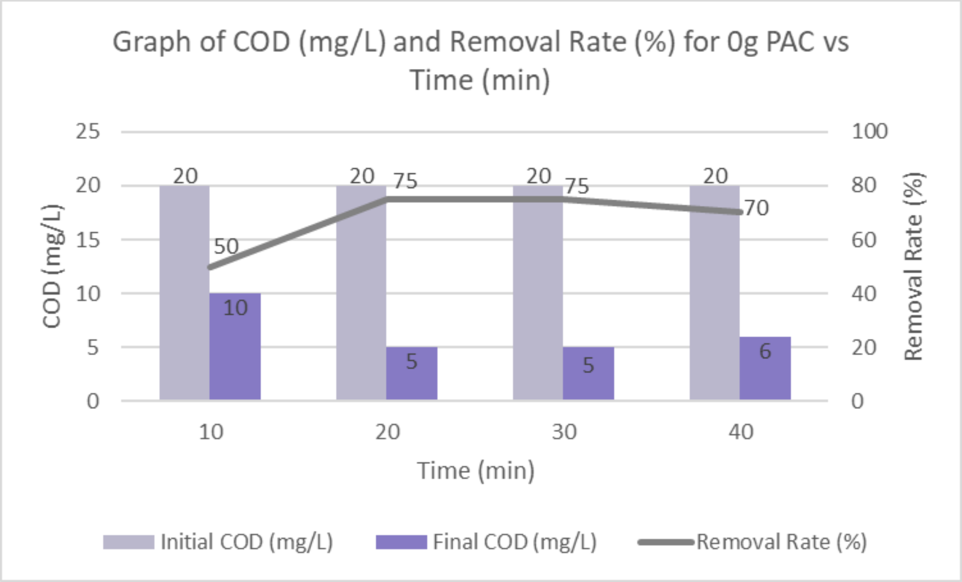
Graph B11: Turbidity and Removal Efficiency for 5 g PAC over Time



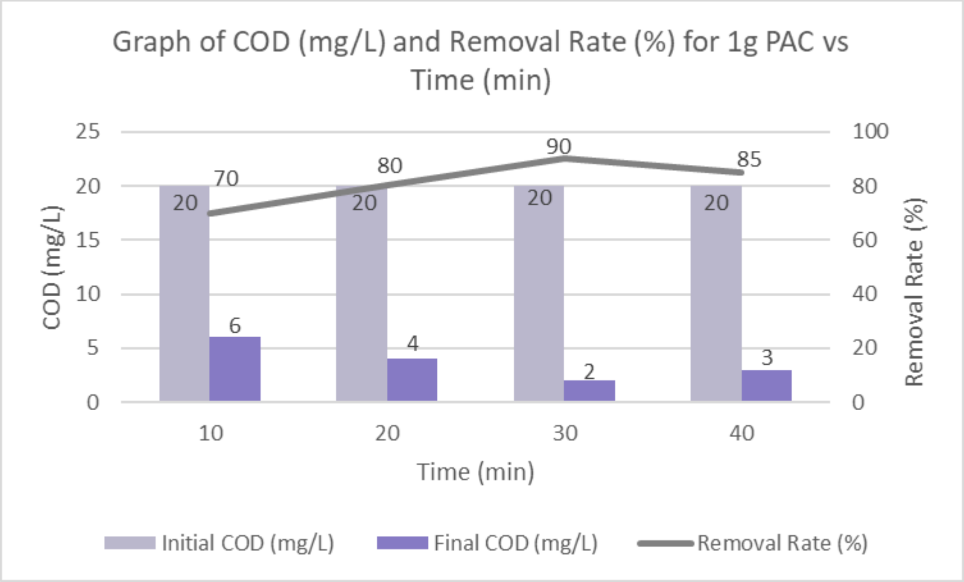
Graph B12: Turbidity and Removal Efficiency for 10 g PAC over Time



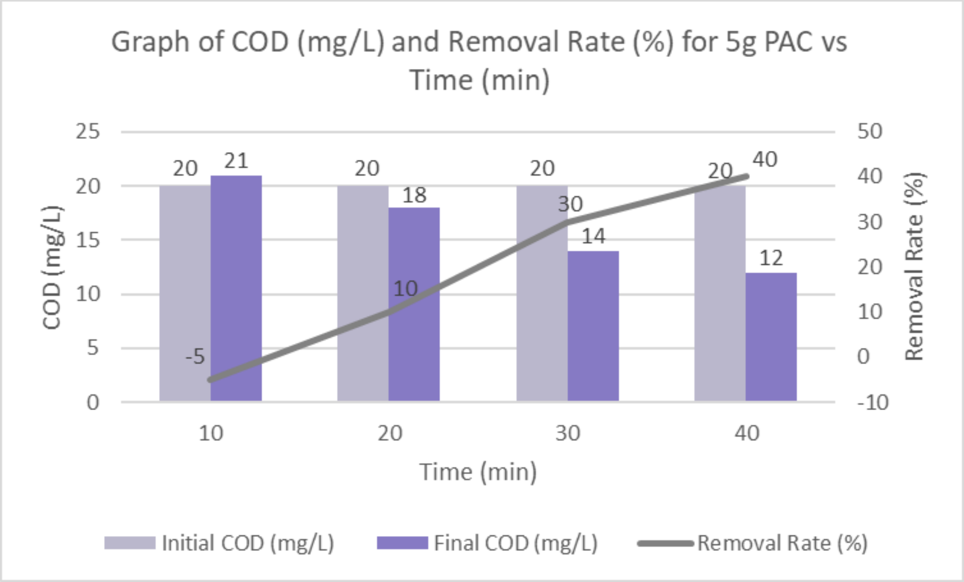
Graph B13: COD Concentration and Removal Efficiency for 0 g PAC over Time



Graph B14: COD Concentration and Removal Efficiency for 1 g PAC over Time



Graph B15: COD Concentration and Removal Efficiency for 5 g PAC over Time



Graph B16: COD Concentration and Removal Efficiency for 10 g PAC over Time