TREATING NUST DOMESTIC WASTEWATER USING DECENTRALIZED WASTEWATER TREATMENT SYSTEM

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A FINAL YEAR PROJECT (FYP) REPORT SUBMITTED TO THE NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF ENGINEERING IN ENVIRONMENTAL ENGINEERING

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APPROVAL SHEET

This is to certify that the contents and forms of thesis titled as "Treating NUST Domestic Wastewater using Decentralized Wastewater Treatment System" is the original work of author(s) and has been carried out under my direct supervision. I also certify that the thesis has been prepared under my supervision according to the prescribed format and I endorse its evaluation for the award of Bachelor of Engineering in Environmental Engineering Degree through the official procedures of the Institute.

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ABSTRACT

Water security is a growing challenge for Pakistan as increased population growth, rapid urbanization and industrial development has increased the volumes of wastewater generated manifold. This is mainly because of improper water resource management in Pakistan. With more than 75% of Pakistan's population residing in less dense semi-urban and rural areas, centralized wastewater treatment is not an option. In this regard, low cost, anaerobic, gravity-based and minimal energy-driven lab-scale plant of Decentralized Wastewater Treatment System (DWTS) was designed under this study. DWTS consisted of Storage Tank (ST), Anaerobic Baffled Reactor (ABR), Anaerobic Filter (AF) and Membrane Filter (MF) to treat real domestic wastewater of NUST. In order to evaluate the treatment performance for full scale DWTS, ABR and AF, combined system was operated at HRT of 24 hours with the use of locally available Polyvinyl Chloride (PVC) filter media and Granular Activated Carbon (GAC) filter media from coconut shell in different phases of the project. The system was inoculated with the combination of 70% of acclimatized sludge (COD:300 mg/L) and 30% of wetland's sludge prior to system operation. The comparison between PVC media of two different lengths i.e. 20 mm and 25 mm revealed that PVC media of 20 mm length was more efficient because of its enhanced surface area with 61% removal of COD as compared to PVC media of 25 mm length with 52.5% removal of COD. However, in the next phase, the optimized PVC media length i.e. 20 mm was compared with the treatment performance of GAC, which revealed that GAC was even more efficient than PVC media of 20 mm length. The COD levels of NUST domestic wastewater using GAC filter media were reduced by 72% i.e. average COD of treated effluent was found to be 97 mg/L, significantly lower than the National Environmental Quality Standards (NEQS) (PAK-EPA, 2000) of 150 mg/L. Moreover, TSS, TKN and TP, were also reduced by 86.7%, 25.7% and 66% respectively, using the most optimum filter media i.e., GAC.

ACKNOWLEDGEMENTS

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ABBREVIATIONS

ABR: Anaerobic Baffled Reactor

AF: Anaerobic Filter

BCM: Billion Cubic Meters

BOD: Biochemical Oxygen Demand

COD: Chemical Oxygen Demand

DWTS: Decentralized Wastewater Treatment System

GAC: Granular Activated Carbon

GDP: Gross Domestic Product

HRT: Hydraulic Retention Time

MF: Membrane Filtration

NEQS: National Environmental Quality Standards

ORP: Oxidation Reduction Potential

SDG: Sustainable Development Goals

SRT: Solids Retention Time

ST: Storage Tank

TKN: Total Kjeldahl Nitrogen

TSS: Total Suspended Solids

PVC: Polyvinyl Chloride

WFMF: Woven Fiber Micro Filtration

WHO: World Health Organization

WSP: Water and Sanitation Program

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CHAPTER 1

INTRODUCTION

1.1 Background

Water is of utmost importance to all forms of life on the planet Earth. It plays a vital role in the socio-economic development around the globe. As in the past 250 years, world's population grew exponentially and so did the demand on water resources, world's freshwater resources are depleting. Urbanization, industrialization and intense agricultural practices around the globe have laid an extreme burden on both; the quality and quantity of water resources. As there has been a shift in peoples' patterns of consumption and production worldwide, it led to the contamination of waterbodies to a great extent (Gutterer et al., 2009).

Almost 80% of the water consumed for domestic purposes ends as wastewater. This wastewater, in most of the cases, is discharged directly into the surface water bodies such as lakes and rivers, leading towards their deteriorated water quality (Renuka et al., 2016). The toxic compounds, released from urban areas as well as from industries enter water streams and worsen their quality, resulting in adverse health impacts to human lives.

According to World Health Organization (WHO), approximately 2.5 billion people in developing countries still do not have proper sanitation facilities which result in demise of more than 15 million people each year (World Health Statistics, 2013). Out of 17 Sustainable Development Goals (SDGs) set by the United Nations General Assembly in 2015, SDG 6.2 and 6.3 focus on treatment of wastewater, increased water recycling and safe reuse globally.

In Pakistan, the water availability has reduced from 1,299 m^3 per capita in 1996-1997 to about 1,100 m^3 per capita in 2006. This decrease has been further projected to less than 700 m^3 per capita at the end of 2025 (Murtaza et al., 2012). Water and sanitation agencies of Pakistan has been emphasizing on water quantity rather than water quality in order to meet increasing demands of water. However, the concerned authorities must shift their attention towards increased treatment technologies, equipment and trained staff for treating wastewater.

To treat wastewater, trend has shifted from aerobic treatment to anaerobic treatment, hence, removing the misconception that anaerobic systems have poor removal efficiencies. The major disadvantage of aerobic treatment is that it yields bulk amount of sludge which can cause process failures and must be properly treated before disposal. Aerobic systems consume considerable amount of energy mainly due to their aeration requirements while energy is a major issue in Pakistan.

1.2 Magnitude of Problem

According to statistics of 2006, Pakistan bore a loss of Rs. 343.7 billion per year due to improper sanitation which is equivalent to 3.9% of Pakistan's Gross Domestic Product (GDP) according to a report published by Water and Sanitation Program (WSP) in the year 2012. This number comprises of cost related to premature deaths, reduced productivity loss due to various illnesses and cost required for treatment and recovery. This total loss due to poor sanitation facilities in Pakistan is approximately seven times higher than the national health budget of Pakistan (WSP Report, 2012).

Due to rapid population growth in Pakistan, the situation is intensifying with each passing day. It has been estimated that in Pakistan, about 30% of all illnesses and 40% of all mortalities are due to waterborne diseases (Daud et al., 2017). Among all waterborne diseases, diarrhea takes number one position and is a major cause of death among infants of Pakistan. Another study shows that every fifth citizen of Pakistan suffers from a disease caused by ingesting contaminated water (Kahlown et al., 2006).

1.3 Problem Statement

The annual generation of wastewater in Pakistan is about 4.43 billion cubic meters (BCM) out of which 3.06 BCM is municipal and 1.37 BCM is from industries. The annual effluent potential of fifteen main cities of Pakistan is over 2.47 BCM (PCRWR, 2006).

Many rural areas of Pakistan do not have proper systems for the collection of domestic wastewaters due to which the wastewater flows in their streets and trickles down to groundwater reservoirs. The water supply networks are also not monitored regularly which may lead to percolation of wastewater to groundwater, resulting in various types of diseases.

The sanitation requirements of such areas could not be addressed by a centralized approach to sanitation because of large infrastructure investment associated with the extensive technology. However, there is a growing need to adopt a decentralized approach to sanitation i.e. on-site sanitation systems to address the problem.

A variety of on-site wastewater treatment technologies are available worldwide, however, selecting the most feasible option requires detailed analysis of cost, design, operation, maintenance, topographical constraints, availability of trained personnel and equipment associated with the treatment technology. Decentralized Wastewater Treatment System (DWTS) is an on-site sanitation system that treats wastewater, both black and grey water, mostly at community scale, or even larger scale.

1.4 Objectives

1. Comparison of treatment performance of locally available Polyvinyl Chloride (PVC) filter media of two different lengths i.e. 20 mm and 25 mm having same diameter of 15 mm, treating real domestic wastewater.
2. Treatment of real domestic wastewater using Granular Activated Carbon (GAC) as filter media.

1.5 Scope of the Study

In order to achieve the said objectives, the study was conducted on a lab-scale plant in two phases. First phase dealt with the comparison of treatment performance of locally available PVC media of two different lengths and the second phase was concerned with the use of GAC as filter media for treating NUST domestic wastewater. However, before the analysis of treatment performance of each of the chosen media, the setup was inoculated with 70% of acclimatized sludge (COD 300 mg/L) and 30% of the wetland's sludge. After acclimatization phase, each filter media was studied for a period of 3 to 4 weeks.

CHAPTER 2

LITERATURE REVIEW

2.1 Domestic Wastewater Disposal Problems

Pollution is the introduction of unwanted and harmful substances present in the natural systems that have detrimental effects on our ecosystems. Domestic wastewater is highly polluted with organics which if disposed untreated, causes several significant impacts on the environment. Firstly, organics are a source of food for both pathogenic and non-pathogenic microorganisms present in the water, which they use along with oxygen as a source of energy for growth. This results in oxygen depletion. Secondly, domestic wastewater has two essential nutrients, nitrogen and phosphorus, needed for plant growth. Algae present in the water take-up the nutrients and grow rapidly, covering the surface of the water. As they spread over the surface, sunlight, that is vital for photosynthesis of aquatic plants gets blocked. Consequently, those plants die and are decomposed by bacteria through an oxygen using process. Excess oxygen consumption by the algal population and bacterial decomposition challenges the survival of other living creatures present in the water bodies. This process is described as eutrophication. Additionally, nitrogen exists in other forms that pose a risk such as ammonia gas, which is fatal to fish and nitrite, which can be poisonous to humans. Hence, to avoid negative outcomes related to the disposal of wastewater, it is treated to remove a wide range of chemicals either to a quantity in which they are harmless or a less harmful form, within limits as specified in the National Environmental Quality Standards (NEQS) (Gutterer et al., 2009).

2.2 Domestic Wastewater Composition

Domestic wastewater contains about 99.9% of water and only 0.1% of solids. Out of 0.1% solids, 30% are inorganic solids and 70% are organic solids including fats, carbohydrates and proteins. Typical concentration ranges for different pollutants of raw domestic wastewater are given below:

Table 1: Typical Range of Pollutants for Raw Domestic Wastewater

Sr. No.	Parameter	Concentration (mg/L)
1	**Chemical Oxygen Demand (COD)**	250-1000
2	**Biochemical Oxygen Demand (BOD)**	100-400
3	**Total Suspended Solids (TSS)**	100-350
4	**Total Phosphorus (TP)**	4-15
5	**Total Nitrogen**	20-100

Source: Dionisi (2017)

2.3 Comparison of Aerobic and Anaerobic Treatment of Domestic Wastewater

In biological processes of wastewater treatment, microbes are responsible for degradation and breakdown of different organic pollutants with the help of nutrient uptake. The microbes use the organics as a food source, converting a portion of the carbon matter into new biomass and the remainder of the carbon into carbon dioxide. The CO_2 thus, produced is released as a gas and the biomass produced is removed by liquid-solid separation, leaving the wastewater free from the original organic matter. If oxygen is used by microbes for conversion, the process is called as aerobic digestion and if no oxygen is involved, the process is termed as anaerobic digestion (Grady et al., 2011).

Aerobic treatment of wastewater, although offers advantage of less odor problems due to non-production of hydrogen sulfide and methane gas but have several disadvantages which take over its advantage. Constant aeration and mixing are required by suspended growth cultures; hence, oxygenation is energy intensive process, thereby, increasing the overall cost associated with the process. The Solids Retention Time (SRT) is quite low for aerobic processes as biosolids frequently generated need to be disposed of properly and regularly.

On the other hand, anaerobic processes do not have requirement for aeration and mixing. Therefore, these minimal energy-driven processes are favored upon aerobic processes. Also, SRT is quite high as lesser amount of sludge is produced by anaerobes. This makes anaerobic processes less expensive and simple in operation as compared to aerobic processes (Youcai, 2018).

2.4 Wastewater Management Strategies

2.4.1 Centralized Wastewater Treatment

Typically, in urban areas, industrial and municipal wastewater are collectively carried through large sewage systems to a common treatment plant. This centralized approach demands high, investment and operational cost, thereby, is an expensive sanitation solution (Santiago-Díaz et al., 2019). Centralized wastewater management consists of a single collection network of sewers that branches out to houses, industrial facilities, commercial and recreational places, transporting the collected wastewater to an off-site treatment plant which is distant from the point of wastewater generation. Hence, it is also known as an off-site management system (Hophmayer-Tokich, 2006).

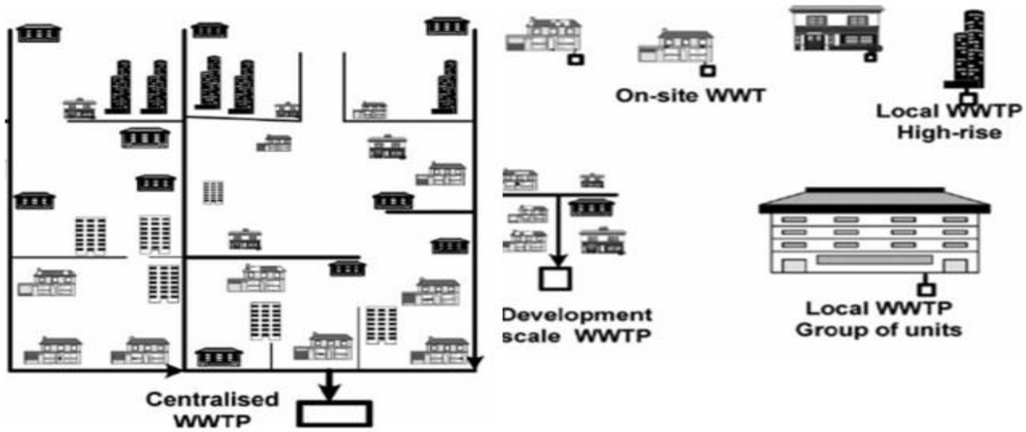

Figure 1: Centralized Wastewater Treatment System (Left) vs. Decentralized Wastewater Treatment System (Right)

2.4.2 Decentralized Wastewater Treatment

In Decentralized Wastewater Treatment System (DWTS), the treatment plant is near the source of origin of wastewater, so it does not require a wide network of sewer lines for the collection and transportation of wastewater. Hence, it is simple in operation than centralized treatment. DWTS is also known as on-site management of wastewater (Leitao et al., 2005).

Typically, a DWTS consists of:

I. ***Primary Treatment:*** Biodigesters, sedimentation ponds, sedimentation tanks or septic tanks
II. ***Secondary Treatment:*** Anaerobic baffled reactor or anaerobic filter
III. ***Tertiary Treatment:*** Constructed wetlands or membrane filtration (Gutterer et al., 2009).

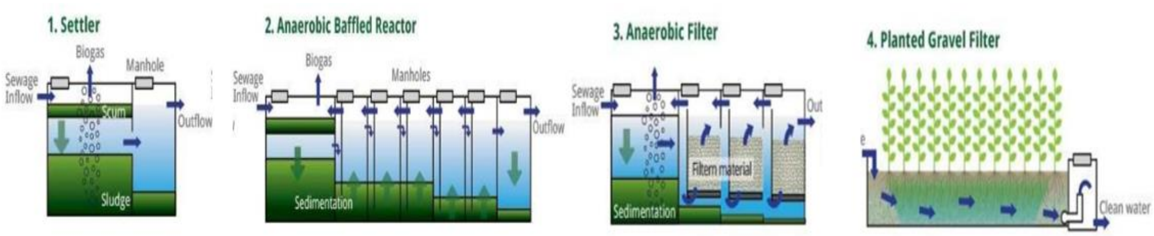

Figure 2: Primary, Secondary and Tertiary Treatment Units of DWTS

2.5 Components of Decentralized Wastewater Treatment Systems

2.5.1 Septic Tank

The treatment done through septic tanks is most commonly used DWTS approach throughout the world, especially in rural or isolated areas. Septic tank is a simple unit that operates as both; a settling tank and a sludge digester. However, septic tanks have low efficiencies ranging between

30-50%, depending on the settling efficiencies and the nature of the wastewater (Hahn & Figueroa, 2015).

2.5.2 Anaerobic Baffled Reactor (ABR)

The integrated use of anaerobic primary and secondary treatment has proved effective to remove biological colloids and maximize the production of methane gas, a by-product of anaerobic digestion. Anaerobic Baffled Reactor (ABR) is a compartmentalized digester with a series of alternating baffles in each compartment. The wastewater is pumped through each compartment, where it flows from the inlet, passing over the baffles to the outlet (Bwapwa, 2012). Several communities of microorganisms are formed in each compartment of ABR. The type of microbial community in any compartment depends on the amount and kind of substrate present, along with the temperature and pH of the wastewater. In the initial compartments with higher substrate concentrations, acidogenic bacteria grow, whereas, methanogenic bacteria are abundant in the later compartments (Barber & Stuckey, 1999). Additionally, anaerobic digestion that takes place in ABR does not remove nutrients from the wastewater. Hence, the effluent of ABR is suitable for horticulture (Bwapwa, 2012).

2.5.3 Anaerobic Filter (AF)

Anaerobic Filters (AF) are reactors or digesters that comprise of a series of filtration chambers. The filter medium has microorganisms growing on it, which degrades the organics in the wastewater as it passes through, thereby filtering it. AF is preferred over ABR to treat domestic wastewater due to its higher organic loading removal efficiencies. According to a research, AF yields noticeably higher removal efficiencies than conventional septic tanks for the parameters such as, TSS, COD, BOD and thermos-tolerant coliforms. Therefore, AF is a more effective alternative in the treatment of black water, especially in rural areas and developing countries (Sharma and Kazmi, 2015).

2.6 Research Work Examples

1. Renuka et al. (2016) studied *“Performance Evaluation of Paneled Anaerobic Baffle-cum-Filter Reactor (PABFR) in Treating Municipal Wastewater.”* The reactor consisted of five chambers in total; first three chambers were up-flow anaerobic baffled chambers, separated by hanging baffles, followed by two anaerobic filter chambers. The last two chambers were filled with plastic pall rings as filter media to treat municipal wastewater and the total working volume of PABFR was 100 liters.

Results:

PABFR was optimized at an HRT of 8 hours with removal efficiencies as; COD 90%, BOD 91% and TSS 95%.

2. Saad (2019) studied *"BOD and COD Reduction from Domestic Wastewater using Sedimentation, Aeration, Activated Sludge, Sand Filter and Activated Carbon."* Massive COD and BOD reduction were found when domestic wastewater passed through a series of treatment processes. These processes included screening and equalization as preliminary treatment, followed by sedimentation, coagulation and flocculation as primary treatment. Activated sludge process was used as secondary treatment and sand filter along with activated carbon was used as tertiary treatment. Lastly, disinfection was achieved by chlorination.

   Results:

   COD and BOD reduction were found to be 92.17 and 96.66% respectively.

2.7 Work Done At IESE

1. Komal et al. (2014) studied *"Anaerobic Baffled Reactor (ABR) coupled with Anaerobic Peat Filter (APF) for On-site Domestic Wastewater Treatment."*

   Results:

   COD removal efficiencies in ABR-APF were 90, 89 and 80% at HRT of 48, 36 and 24 hours respectively. Highest removal efficiency was found at HRT of 48 hours. However, optimized HRT was 36 hours, with lesser volumes of wastewater required and being more economical at the same time.

2. Javed et al. (2017) studied *"Designing and Optimization of Anaerobic Filter for Secondary Treatment in Decentralized Wastewater Treatment System (DWTS)."*

   Results:

   COD removal efficiencies for different media at a fixed HRT of 36 hours were; stone 89%, crushed glass 94% and PET bottle caps 83%.

3. Khan (2019) studied *"Decentralized Wastewater Treatment System (DWTS) for Medium Strength Domestic Wastewater",* showing minor differences in COD removal among PVC media of different lengths.

   Results:

   The most optimum PVC media length was found to be 20 mm as PVC media of 15 mm was subjected to media structure distortion, despite of its larger surface area. Combined

ABR and AF system was optimized at an HRT of 24 hours with 86% removal in influent's COD.

2.8 Selection of Media

The factors which are responsible for selecting the media are:

- Favors biofilm growth
- High porosity leading to high adsorption capacity
- Regeneration ability to reduce the solid waste handling and disposal problems associated with it.

Keeping in view the afore mentioned factors, we selected two media; Polyvinyl Chloride (PVC) and Granular Activated Carbon (GAC). PVC pipes were cut into two lengths i.e. 20 mm and 25 mm to be used in different phases. Their diameter was same as 15 mm. GAC, made from a green raw material i.e. coconut shell was imported from Thailand. GAC's iodine number was 1200 and surface area was 1,100 m^2/g.

CHAPTER 3

MATERIALS AND METHODS

3.1 Lab-Scale Experimental Setup

In order to treat NUST domestic wastewater, a combination of Anaerobic Baffled Reactor (ABR) and Anaerobic Filter (AF) was used. The setup was further equipped with Membrane Filter (MF) in later stages of project to enhance removal efficiencies of analyzed parameters. However, due to pandemic COVID-19, the MF unit could not be operated.

The system was designed at an HRT of 24 hours and a flow rate of 1.75 liters per hour, which was maintained by using a peristaltic pump.

The lab scale-prototype for decentralized treatment of NUST domestic wastewater is explained as follows.

3.1.1 Anaerobic Baffled Reactor (ABR) Design

The Anaerobic Baffled Reactor (ABR) was made up of acrylic sheets of 6 mm thickness. There were total 6 compartments in ABR with each compartment having its own sampling port of 6 mm diameter to check performance efficiency at each compartment level. These compartments were constructed using baffles (top-down and bottom-up) to provide a better contact between substrate and biosolids, also these compartments were provided with 6 mm diameter valve at the top to collect gas from each compartment individually. ABR had total volume of 23 liters with working volume of 21 liters. The remaining volume was utilized in freeboard at its top.

3.1.2 Anaerobic Filter (AF) Design

The Anaerobic Filter (AF) was also fabricated from 6 mm thick acrylic sheets having a total depth of 35.5 cm with 30.5 cm solely as filter media depth. To prevent media fluidization, a mesh with pore size of 12 mm was installed at the bottom of media bed and 2.54 cm above AF reactor bed. Similarly, another mesh with pore size of 6 mm was installed at the top of the media bed, just below the effluent line to prevent escaping of sludge into the effluent line. AF had total volume of 16.5 liters with working volume of 15.33 liters.

3.1.3 Membrane Module

The Membrane Tank (M-Tank) was fabricated from HDPE (High Density Polyethylene) having 1 cm thickness, 15 cm length and 18 cm width. There were two ports at the top to collect permeate. The membrane was pasted on front and back side of the module using CLEAR glue. A Woven Fiber Micro Filtration Membrane (WFMF) with nominal pore size of 1-3 μm was used for the purpose. The surface area of membrane was 0.044 m^2 and operational flux was maintained at 6 LMH (Liters per Minute per Hour) with the help of a peristaltic pump.

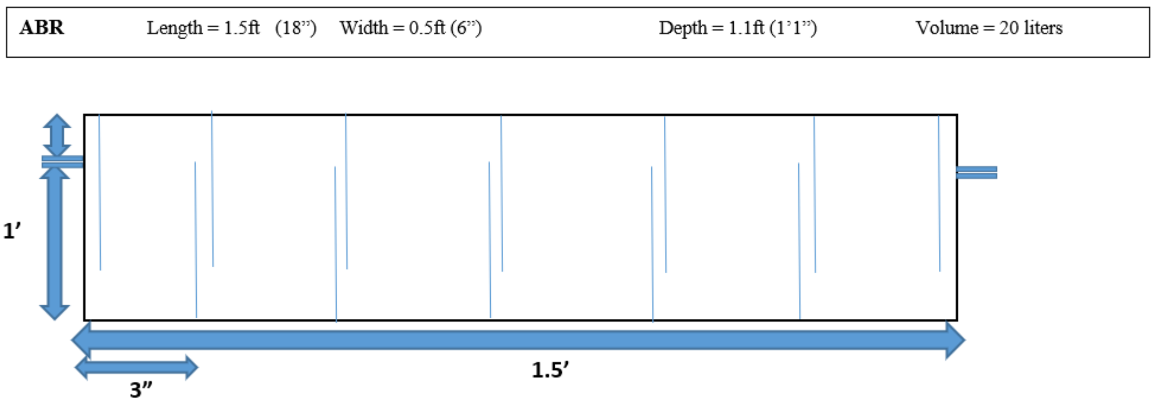

Figure 3: ABR Design Specifications

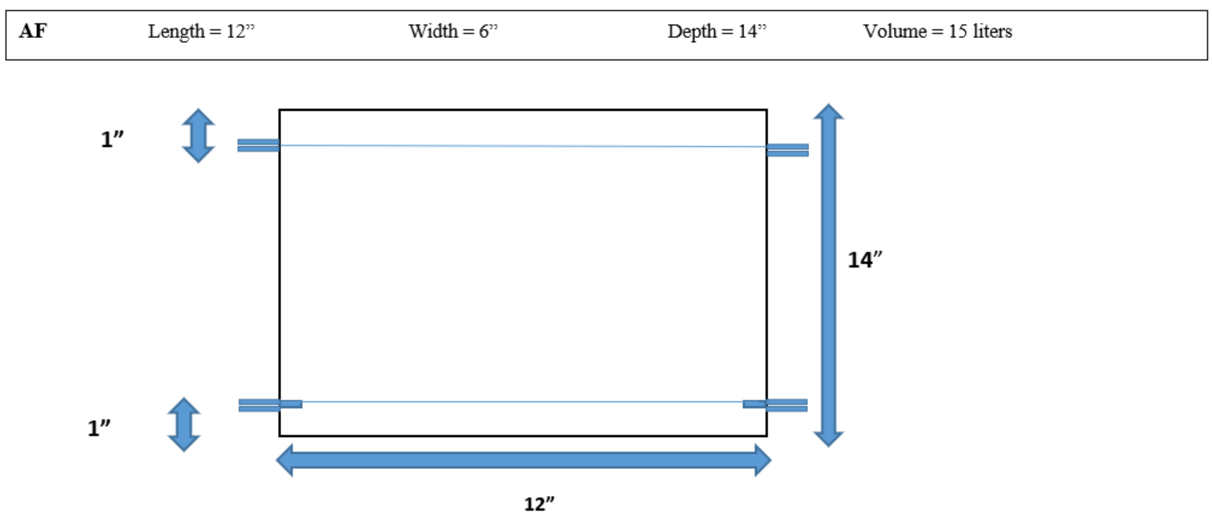

Figure 4: AF Design Specifications

Table 2: Membrane Specifications

Membrane Specifications	
Pore Size	1-3 μm
Operational Flux	6 LMH
Max Allowed TMP	200 mbar
Surface Area	0.044 m^2
Configuration	2 sheets per module (back and front)

3.2 Seed Sludge Preparation

As limited time was given for conducting research, hence, seed sludge inoculation was extremely important and useful.

70% of pre-prepared sludge, used in an ongoing research of IESE was mixed with 30% of wetlands sludge. This mixture was acclimatized to a COD of 300 mg/L. However, till the time taken for our project setup installation, the prepared sludge was stored in a closed tank and was given the following feed every day; 300 mg/L of glucose for providing carbon, hydrogen and oxygen, 50 mg/L of sodium bicarbonate in order to maintain its pH, 113 mg/L of ammonium chloride for providing nitrogen, 62 mg/L of potassium dihydrogen phosphate for providing phosphorus. This feed was selected and provided to acclimatize sludge according to real domestic wastewater strength.

3.3 Process Flow

NUST domestic wastewater goes into Membrane Bioreactor plant (MBR) installed near ISRA apartments NUST. This treated wastewater is then used for horticulture purposes. In order to run our setup, we connected one of the inlets to MBR plant to our setup, in a room adjacent to MBR plant. The inlet pipe entered in a 100-liter storage tank. From there, the wastewater was pumped to ABR through peristaltic pump (Longer Precision Measuring instrument BT 300-2J, China). The wastewater in ABR flowed through different compartments and finally entered AF. Inside the AF, wastewater moved against gravity, encountering biofilm developed onto filter media and finally got collected from permeate tank.

3.3.1 Troubleshooting

a) As our study was being conducted on real domestic wastewater, the inflows fluctuated a bit and there was frequent clogging of inlet and outlet pipes. However, the pipes were frequently backwashed to ensure constant flow through the setup. Flowrate was daily checked to ensure that HRT was kept constant.

b) Due to availability of abundant sunlight at selected project site and nutrients in wastewater, we encountered algal growth after few weeks of project setup. Hence, to combat this, we covered ABR and AF units with opaque sheets to mimic actual DWTS conditions which are installed underground.

c) We were able to install the membrane successfully but could not reach to its optimization of relaxation to filtration mode due to pandemic COVID-19 crisis.

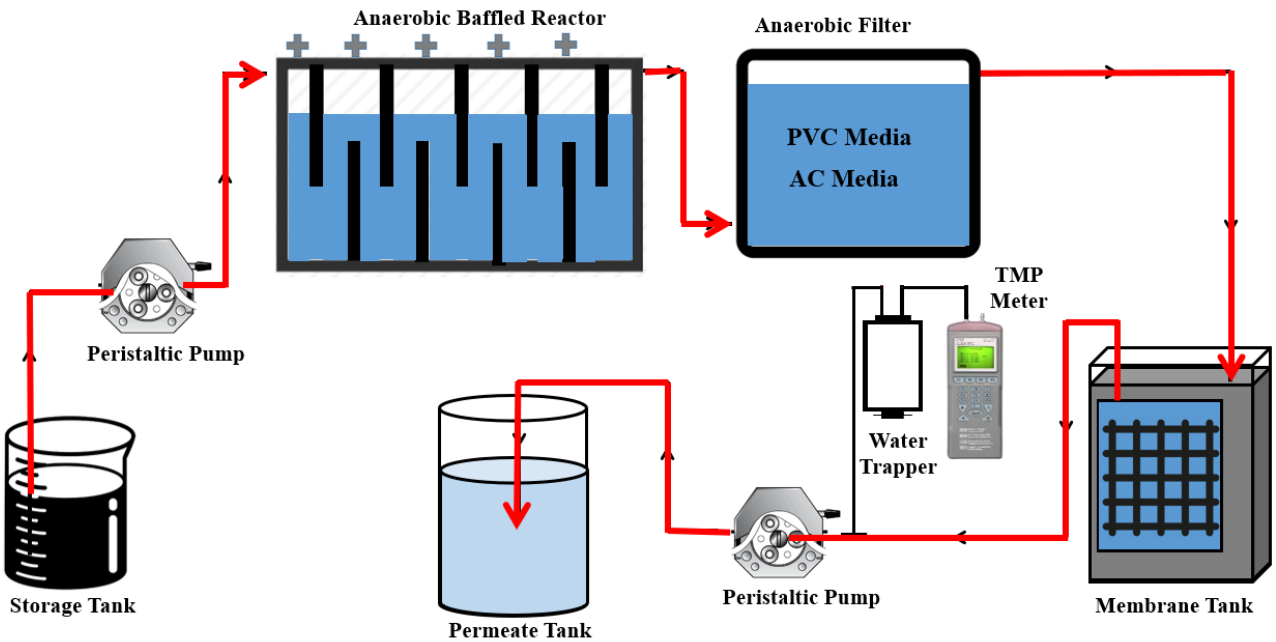

Figure 5: Process Flow Diagram

3.4 Analysis of Wastewater Parameters

Following table shows the wastewater parameters that were analyzed throughout the research, along with the equipment used for those parameters' laboratory test.

Table 3: Wastewater Parameters Analyzed and Equipment Used

S. No.	***Test***	***Method***	***Equipment Used***
1	***pH***	Electrometric Method	pH Meter
2	***Oxidation-Reduction Potential (ORP) (mV)***	Electrometric Method	ORP Meter
3	***Chemical Oxygen Demand (COD) (mg/L)***	Closed-Reflux Method	COD Thermo-reactor
4	***Total Phosphorus (TP) (mg/L)***	Colorimetric/ Spectrophotometric Method	UV/Vis Spectrophotometer
5	***Total Kjeldahl Nitrogen (TKN) (mg/L)***	Distillation Method	Automatic TKN Analyzer
6	***Total Suspended Solids (TSS) (mg/L)***	Gravimetric Method	Whatman Filter Papers, Oven, Graduated Cylinder, Filtration Assembly, China Dishes, Desiccator, Analytical Balance
7	***Temperature*** $(°C)$	Electrometric Method	Mercury Thermometer

3.4.1 Total Suspended Solids (TSS)

Procedure:

1. Take clean china dishes and oven dry them in a preheated oven at 105 degrees Centigrade for 15 minutes.
2. Take Whatman filter papers (1.5 microns) and oven dry them at 130 degrees Centigrade for 20-30 minutes.
3. Weight these pre-heated filter papers.
4. Set the filtration assembly. Take about 50 ml of sample and pass through filter paper with the help of vacuum pump.
5. Let these filter paper dry in oven for 1 hour at 105 degrees Centigrade. Find out the final weight of filter papers.

$$\textit{TSS (mg/L)} = \frac{Final\ Wt. - Initial\ Wt. \times 1000}{Volume\ of\ Sample}$$

3.4.2 Total Phosphorus (TP)

There are three major forms of phosphorus that exist in wastewater bodies; Orthophosphates, Polyphosphates (Ortho and Poly are collectively termed as Inorganic Phosphates) and Organic Phosphorus. These different forms of phosphorus originate in wastewater from different sources such as agricultural runoffs or from human discharges.

Procedure:

1. Take 50 ml of each of your samples in different beakers.
2. Pipette out 2 ml of Ammonium Persulfate and add in each of the beaker. Rinse pipette after use.
3. Pipette out 1 ml of Sulfuric Acid and add in each of the beaker.
4. Set the beakers on hot plates till volume is reduced to half in each of the beaker.
5. Dilute these samples with distilled water till 50 ml volume is reached.
6. Add 1 to 2 drops of phenolphthalein in each of the beaker.
7. Add 0.1 M of Sodium Hydroxide in each of the beaker.
8. Take out 10 ml of the sample from each of the beaker and discard the rest of the sample. Add 2 ml of Vanadate Molybdate in each of the 10 ml of sample. Prepare blank with 10 ml of distilled water and 2 ml of Vanadate Molybdate for zeroing the spectrophotometer. Spectrophotometer was pre-programmed to wavelength of 470 nm. Reaction time of 5

minutes was given by turning on the timer of spectrophotometer. Phosphate concentration was calculated using the calibration curve.

3.4.3 Total Kjeldahl Nitrogen (TKN)

Nitrogen exists in 4 different forms in wastewater bodies. These are Organic Nitrogen, Ammonia Nitrogen, Nitrates and Nitrites. Nitrates & Nitrites collectively are known as Inorganic Nitrogen whereas Organic and Ammonia nitrogen together are known as Kjeldahl Nitrogen.

Procedure:

1. Take about 20 ml of sample with the help of measuring cylinder and add it into the vials of digestion apparatus.
2. Add 3 g of Potassium Sulfate in it.
3. Add 0.1 g of Copper Sulfate in it.
4. Add 7 ml of concentrated Sulfuric Acid in it.
5. Let the digestion process take place for 3 hours.
6. After digestion, let all the vials cool down to room temperature by resting for 40 minutes at least.
7. Now run the distillation process. Color of solution changes to colorless after distillation step.
8. Titrate against 0.02 N of Sulfuric Acid solution till end point is reached i.e. light pink colored solution.

$$\textbf{TKN (mg/ L)} = \frac{\textit{Volume of Sulfuric Acid Used} \times 0.02 \times 14 \times 1000}{\textit{Volume of Sample}}$$

3.4.4 Chemical Oxygen Demand (COD)

COD is a measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as Ammonia and Nitrite. The fact that COD is always greater than BOD is because that during COD test all the organic matter is converted into H2O and CO2 regardless of the bacterial assimilation of the readily biodegradable matter. The COD values will be much higher if the feed contains more biologically resistible matter.

Procedure:

1. COD determination method is called as “Closed Reflux Method.”
2. In COD vials, take 2.5 ml of your sample as well as blank in one of them.

3. With the help of pipette, take about 1.5 ml of Potassium Dichromate and add in each of the vial.
4. With the help of pipette, take about 3.5 ml of concentrated Sulfuric Acid and add in each of the vial.
5. Rinse pipette with distilled water after each step.
6. Invert the vials for 3 to 4 times to ensure uniform mixing of contents.
7. Set the vials for 2 hours for digestion at 150 degrees Centigrade.
8. Let them cool down for some time at room temperature.
9. Titrate each of the vial against FAS after adding 2 to 3 drops of Ferroin indicator till the end point is reached i.e. reddish-brownish color.

$$\textbf{COD (mg/L)} = \frac{(Vol.of\ FAS\ used\ for\ Blank - Vol.of\ FAS\ used\ for\ Sample) \times Normality\ of\ FAS \times 8000}{Volume\ of\ Sample}$$

3.4.5 Power of Hydrogen (pH)

pH values range from 0 to 14 on a pH scale, with 7 being a neutral point. Aqueous solutions at 25°C are termed to be acidic if their pH is less than 7 with 0 being the most acidic and aqueous solutions at 25°C are termed to be basic if their pH value is above 7 with 14 being most basic.

There are 2 main parts of a pH meter:

a) A hydrogen ion-sensitive glass electrode which measures the difference in the hydrogen ions concentration between the inside and outside of the bulb.
b) A reference electrode whose output is independent to the hydrogen ions concentration in the solution of interest.

Before start measuring pH of samples, we must calibrate it by adopting following procedure. pH meter is calibrated using buffer solutions of pH 4, 7 and 10. Firstly, dip the probe in buffer solution of pH 7 and enter CAL on pH meter. Wait for the value to be stabilized and then rinse the probe with distilled water. Repeat this step with buffer solutions of pH 4 and 10, a slope will be displayed on pH meter each time. Once calibration procedure is completed, pH meter is ready for measurements.

Procedure:

1. Turn on the pH meter and dip the probe in sample of interest and press MEAS.
2. Stir the probe gently in sample and wait for the readings to be stabilized.
3. After noting the reading, rinse the probe with distilled water.

3.4.6 Oxidation Reduction Potential (ORP)

ORP is the potentiometric measurement of all the oxidized and reduced species present in water bodies. The main idea behind measuring ORP is the concentration of dissolved oxygen present in water. Higher values of ORP indicate higher amount of oxygen in the sample and negative values of ORP indicate absence of oxygen in sample. A good anaerobic system will thus have an ORP range of -300 to -450 mV

ORP is measured directly using an ORP meter or a pH meter with ORP electrode. The ORP probe consists of two electrodes; A Reference Electrode consisting of Silver or Silver Chloride sand A Sensing Electrode made up of noble elements like Gold or Platinum which are resistant to chemical oxidations. For measuring ORP of sample, the probe is dipped into sample solution and is stirred gently. Readings are displayed on meter. Note the reading once it gets stabilized.

3.4.7 Temperature

Temperature is a significant factor which determines the rate of anaerobic activity of bacteria. The effective temperature range for anaerobes to function properly is from 20 to 30 degrees Centigrade. We measured the natural temperature fluctuations using Mercury thermometer. Mostly, DWTS around the world are constructed underground, hence, not having much temperature fluctuations and change in microbial activity.

3.5 Acclimatization Phase

In each compartment of ABR, 20% of its volume was filled with prepared sludge and the setup was left undisturbed for 60 hours (Renuka et al., 2016). We initially compared the performance efficiency of PVC media of two different lengths. Based upon the results discussed in Chapter 4, the optimum PVC media length was further compared with performance efficiency of GAC. Each media in AF was given an acclimatization period of 10 days before starting to conduct tests on it.

3.6 Optimization Phase

The laboratory test for each of the selected media continued for a period of 3 to 4 weeks to investigate the trends of removal and finding out the most optimum filter media among PVC 20 mm, PVC 25 mm and GAC.

Figure 6: PVC Filter Media

Figure 7: GAC Filter Media

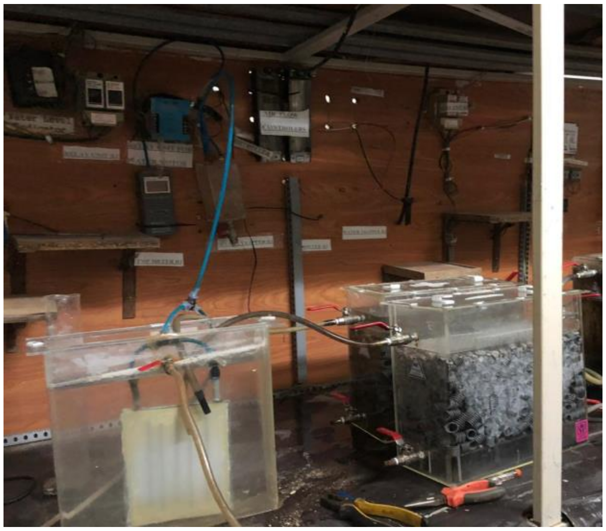

Figure 9: DWTS Installation

Figure 8: DWTS Commissioned

Figure 10: Covered ABR and AF Units

CHAPTER 4

RESULTS AND DISCUSSION

In phase-1 of laboratory testing, for first three weeks, we used PVC media of 25 mm length as filter media. This was followed by PVC media of 20 mm length for next four weeks. Previous research had already proved that PVC media of 20 mm length was more efficient as compared to PVC media of 25 mm length for synthetic wastewater. However, we confirmed our results using real domestic wastewater of NUST. The phase-2 of laboratory testing was concerned with GAC as filter media for four consecutive weeks. The removal efficiencies for each of the analyzed parameter, using different AF media are discussed below.

4.1 Phase 1- PVC Media

4.1.1 Total Suspended Solids (TSS) Removal

Total suspended solids concentration was quite low in the influent since we used NUST domestic wastewater which had already been passed from bar screens. During first three weeks of laboratory testing, while using PVC media of 25 mm length, TSS in influent remained between 90-100 mg/L with an average value of 93.3 mg/L. This value was lesser than NEQS of TSS i.e. 200 mg/L. However, this concentration was progressively decreased as wastewater passed through different compartments of ABR and finally through AF. Treated wastewater had TSS between 20-22 mg/L with an average value of 21 mg/L and removal efficiency of 77.5%.

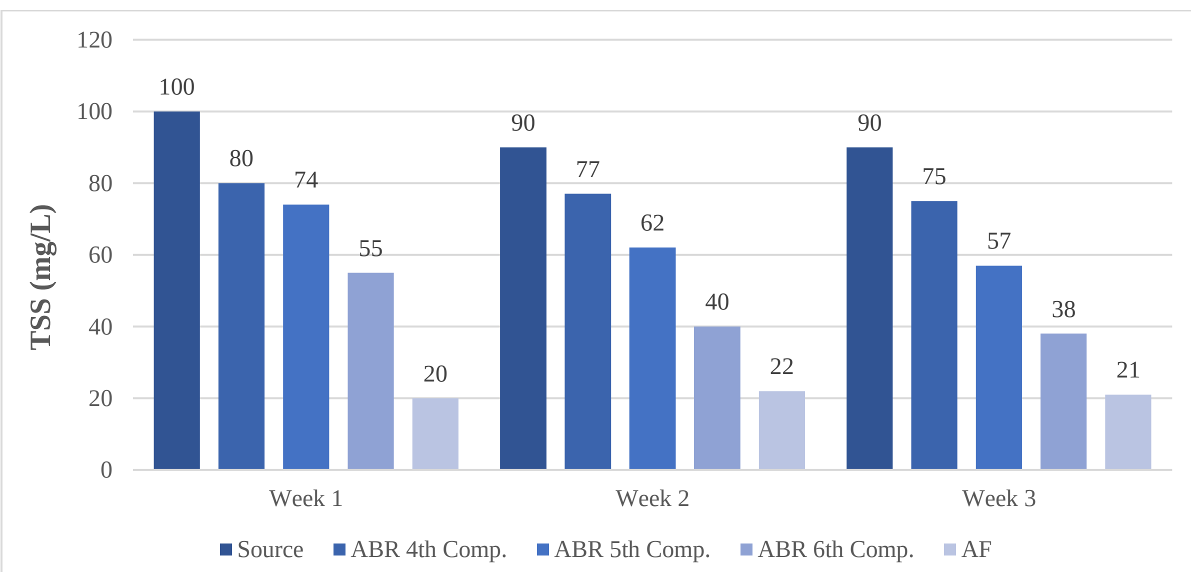

Figure 11: TSS Removal using PVC Media 25 mm

For the next four weeks of testing, while using PVC media of 20 mm length, TSS concentration of influent varied from 90-93 mg/L with an average value of 92 mg/L. Again, the concentration was lesser than NEQS of 200 mg/L. However, after treatment, the effluent had TSS varied from 18-20 mg/L with an average value of 19 mg/L and removal efficiency of 79.3%.

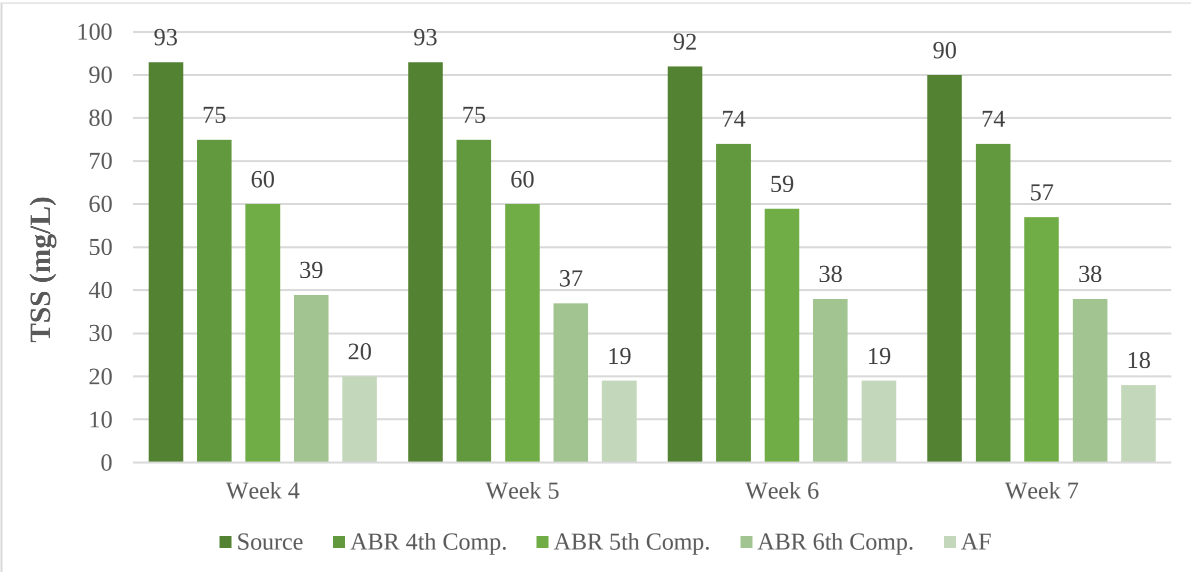

Figure 12: TSS Removal using PVC Media 20 mm

Hence, the enhanced removal of 79.3% showed that PVC media of 20 mm length was more effective than PVC media of 25 mm length.

4.1.2 Total Phosphorus (TP) Removal

While using PVC media of 25 mm length for first three weeks, TP concertation of influent ranged from 16-17 mg/L with an average value of 16.3 mg/L and after treatment in ABR and AF, TP of effluent was decreased to about 9-10 mg/L with an average value of 9.24 mg/L and removal efficiency of 43.3%.

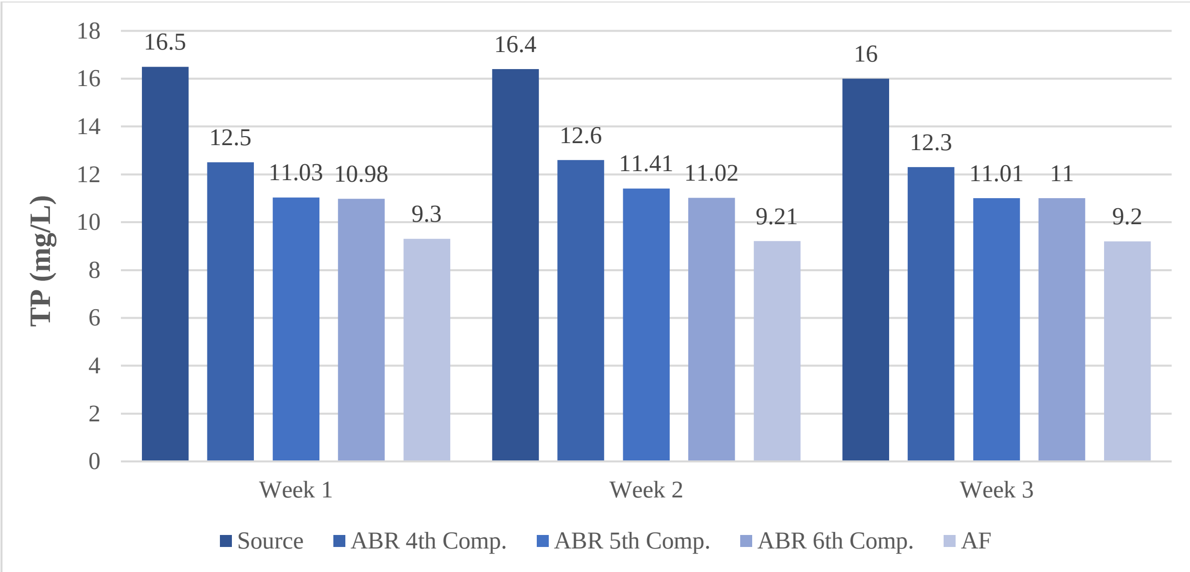

Figure 13: TP Removal using PVC Media 25 mm

While using PVC media of 20 mm length, for next four weeks, influent's TP varied from 14-16 mg/L with an average value of 14.6 mg/L and after treatment, TP values were lowered down to 5-6 mg/L with an average value of 5.8 mg/L and removal efficiency of 60.3%.

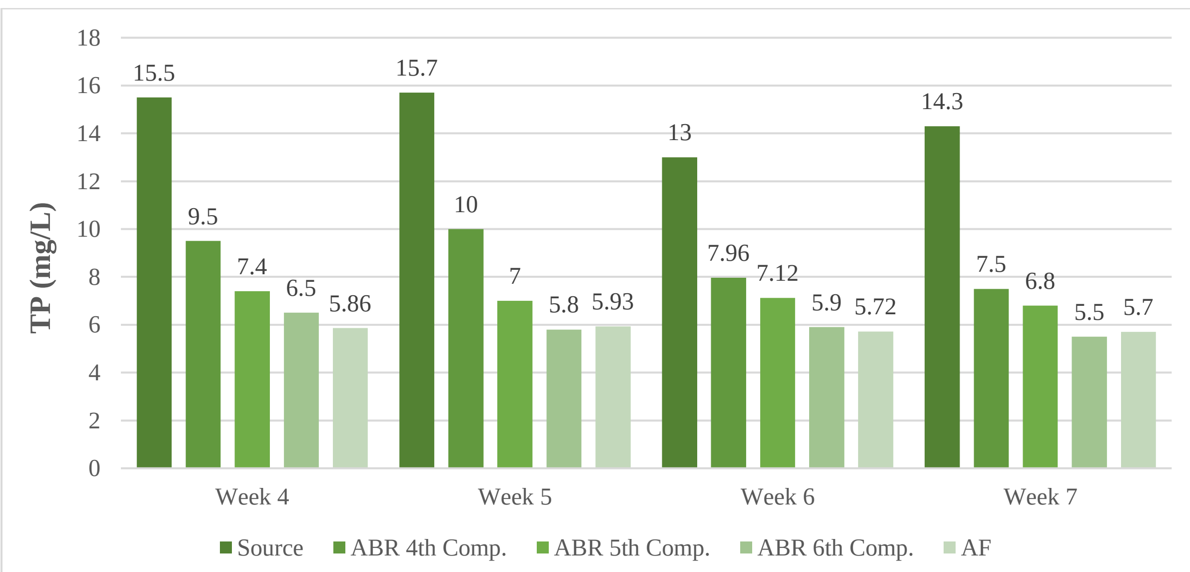

Figure 14: TP Removal using PVC Media 20 mm

This showed that PVC media of 20 mm length was more effective for TP removal as compared to PVC media of 25 mm length.

4.1.3 Total Kjeldahl Nitrogen (TKN) Removal

We preferred Total Kjeldahl Nitrogen (TKN) determination over ammonium nitrogen since mostly the domestic wastewater is organic in nature. NEQS for ammonium nitrogen is 40 mg/L, however, if TKN international standards of USEPA 30 mg/L are being met, it meets nitrogen standards too. While using PVC media of 25 mm length in first three weeks of laboratory testing, influent's TKN ranged from 38-40 mg/L with an average value of 38.5 mg/L. After treating real domestic wastewater through ABR and AF, TKN values were decreased to a range of 31-33 mg/L with an average value of 32 mg/L and removal efficiency of 16.9%.

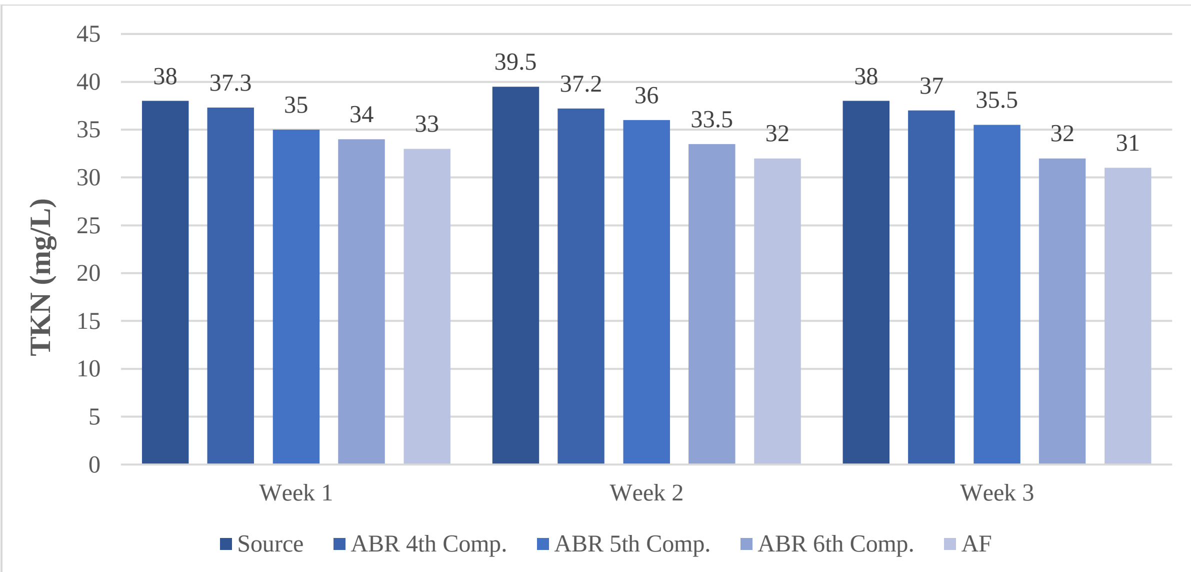

Figure 15: TKN Removal using PVC Media 25 mm

While using PVC media of 20 mm length for next four weeks, influent's TKN varied from 36-38 mg/L, with an average value of 36.5 mg/L (below NEQS of ammonium nitrogen) and after treatment, these values were decreased to about 28-29 mg/L with an average value of 29.1 mg/L, and removal efficiency of 20.3%. As biological removal of nitrogen involves aerobic nitrification for conversion of ammonium nitrogen into nitrites and nitrates by nitrifiers, which require at least 4 mg/L of dissolved oxygen, hence, the wastewater treatment under study being anaerobic in nature, did not account for high removal efficiency for dissolved nitrogen.

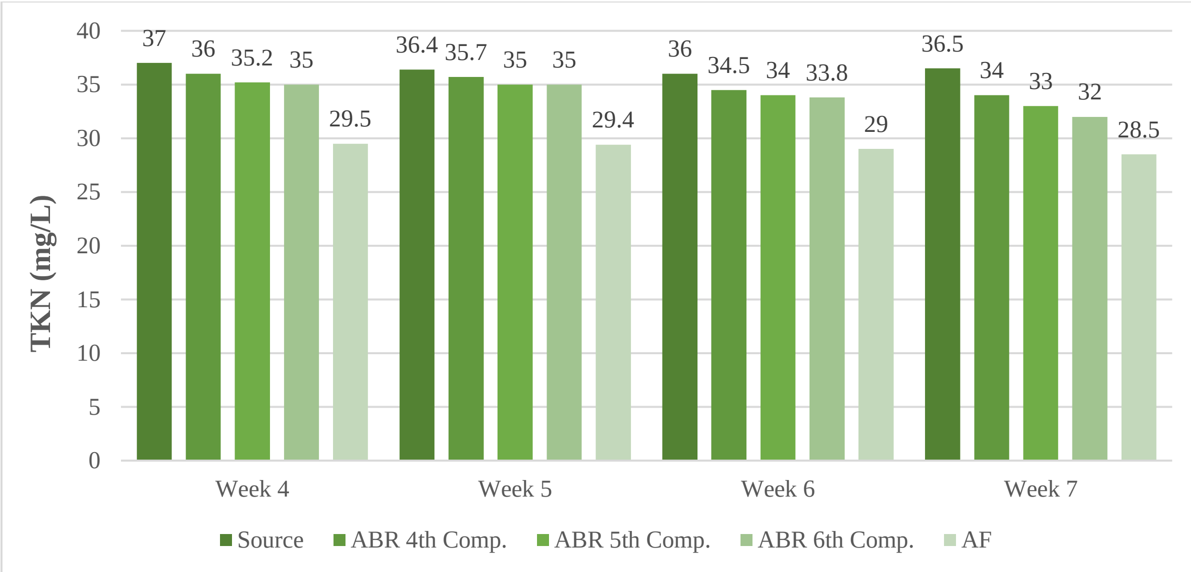

Figure 16: TKN Removal using PVC Media 20 mm

A slight increase in removal efficiency was observed using PVC media of 20 mm length, again concluding that PVC media of 20 mm was more effective than PVC media of 25 mm length.

4.1.4 Chemical Oxygen Demand (COD) Removal

This parameter significantly influenced the selection of optimum PVC media length. While using PVC media of 25 mm length in first three weeks of laboratory testing, influent's COD ranged from 283-285 mg/L with an average value of 284 mg/L. This marked NUST domestic wastewater as a medium strength wastewater. However, after treating it, COD values were lowered down to 134-136 mg/L with an average value of 135 mg/L and removal efficiency of 52.5%**.**

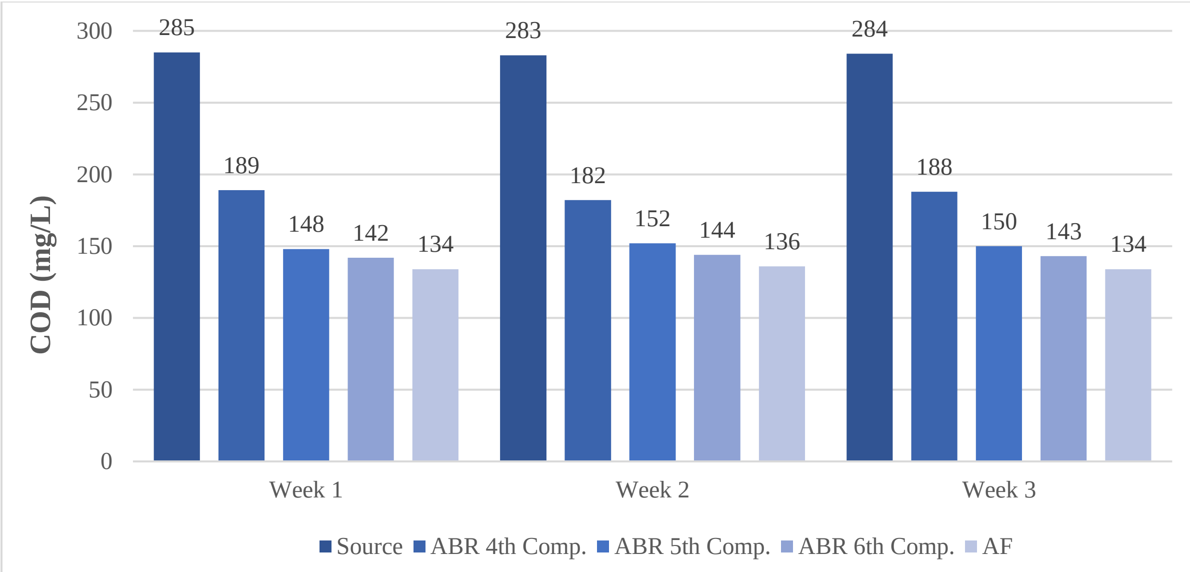

Figure 17: COD Removal using PVC Media 25 mm

For next four weeks of testing, while using PVC media of 20 mm length, influent's COD ranged from 275-278 mg/L with an average value of 277.5 mg/L and after treating it in ABR's different compartments and AF having PVC media of 20 mm length, COD levels were dropped to a range of 100-120 mg/L with an average value of 107.7 mg/L and removal efficiency of 61%.

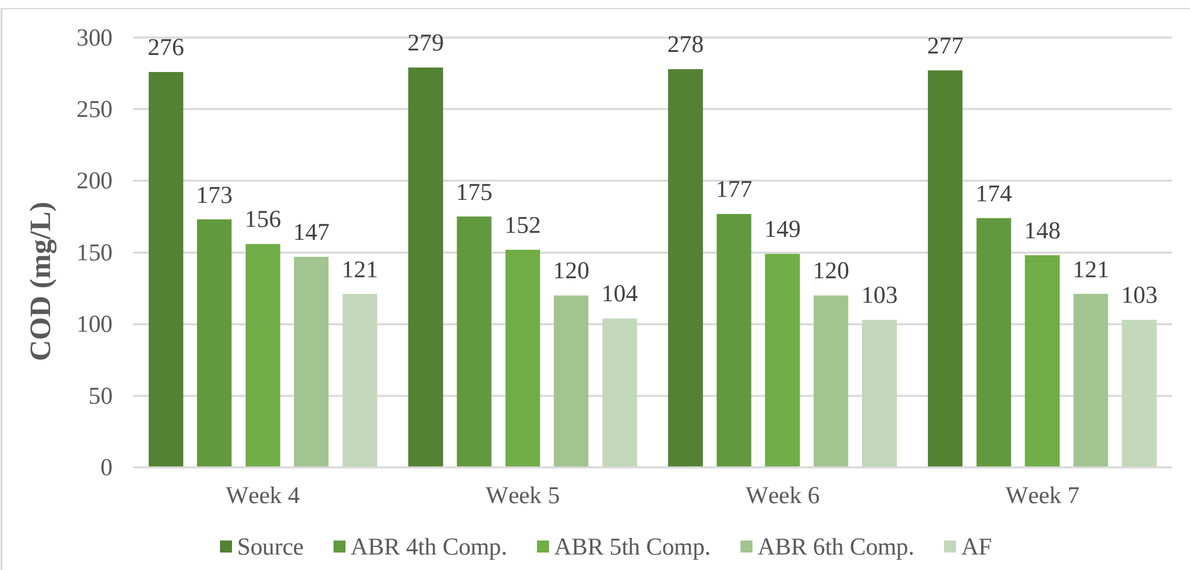

Figure 18: COD Removal using PVC Media 20 mm

This confirmed that PVC media of 20 mm length was optimum for treating real domestic wastewater as it lowered down COD within safe limits of NEQS.

4.1.5 Power of Hydrogen (pH)

In biological treatment of wastewater, pH must be maintained at a specific level for optimum microbial activity. The effective pH range for methanogens is from 6.5 to 7.5. During the project, pH of treated wastewater using PVC media remained within the safe range specified by NEQS i.e. from 6 to 9.

Average pH of effluent using PVC media of 25 mm length was 7.37.

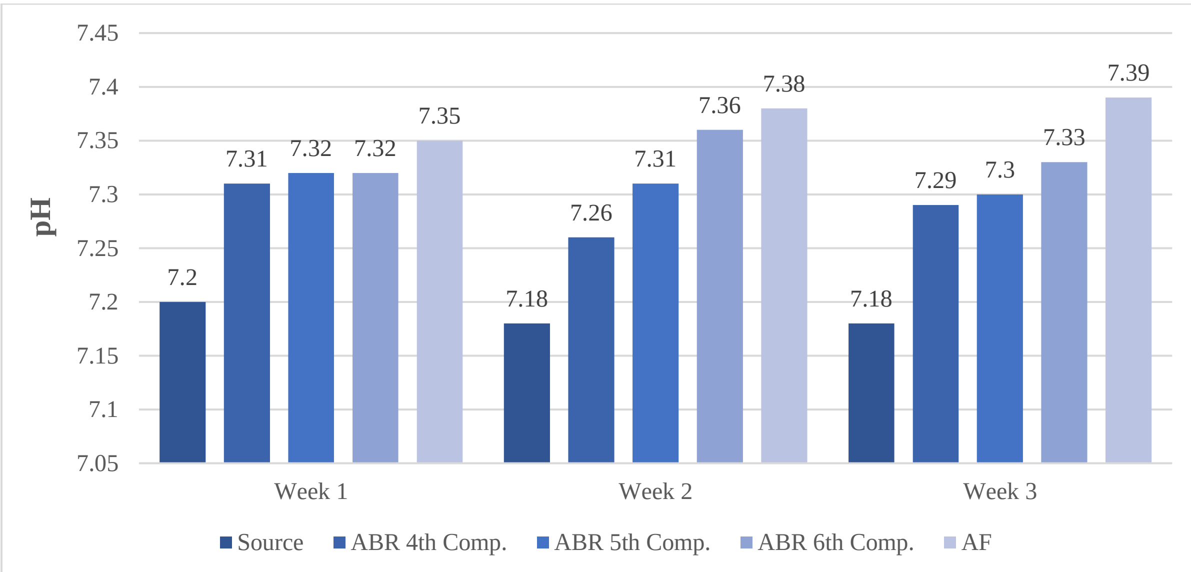

Figure 19: pH using PVC Media 25 mm

Average pH of effluent using PVC media of 20 mm length was 7.36.

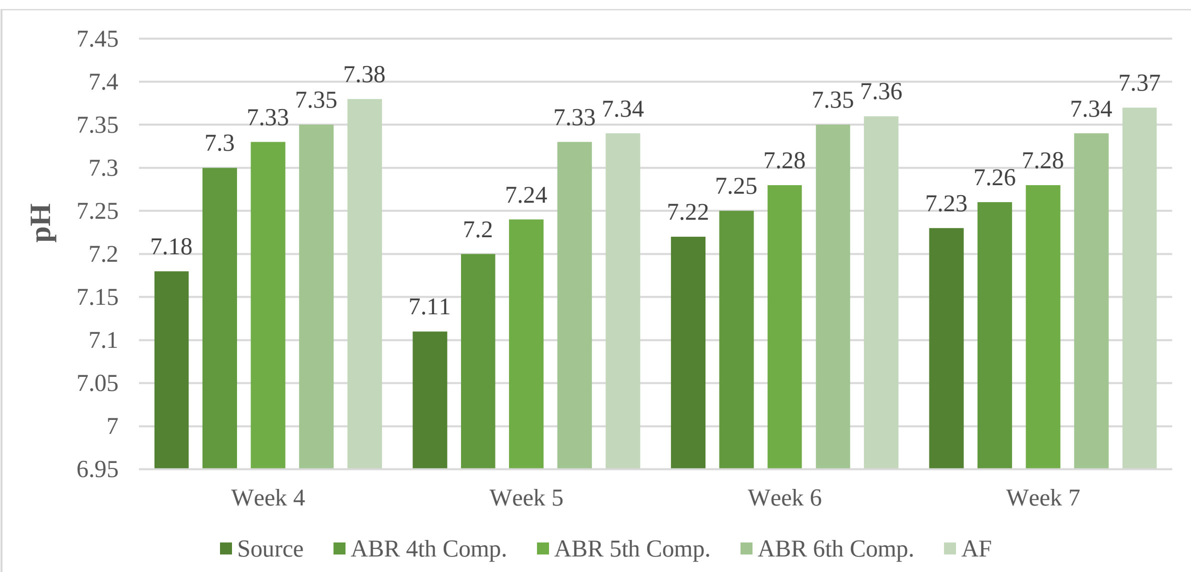

Figure 20: pH using PVC Media 20 mm

4.1.6 Oxidation Reduction Potential (ORP)

A good anaerobic system has an ORP range of -300 to -450 mV. As we used acclimatized anaerobic sludge for ABR, its ORP was initially recorded as -90 mV and was further decreased to -293 mV, showing anaerobic conditions. For AF, it started from 20 mV, showing aerobic conditions but became anaerobic with the passage of time.

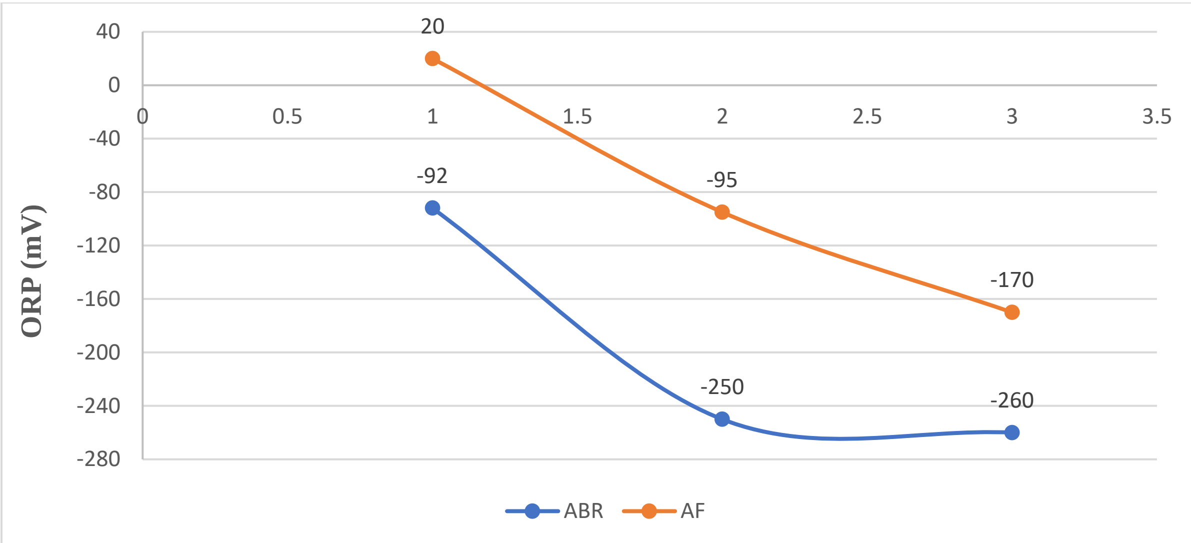

Figure 21: ORP using PVC Media 25 mm

When we replaced PVC media of 25 mm length with PVC media of 20 mm length in AF, conditions became aerobic for AF as shown in the graph, ORP increased to 25 mV. However, with the passage of time, anaerobic conditions prevailed and ORP gradually dropped to -264 mV. For ABR, conditions continued in anaerobic phase with no change in anaerobic condition.

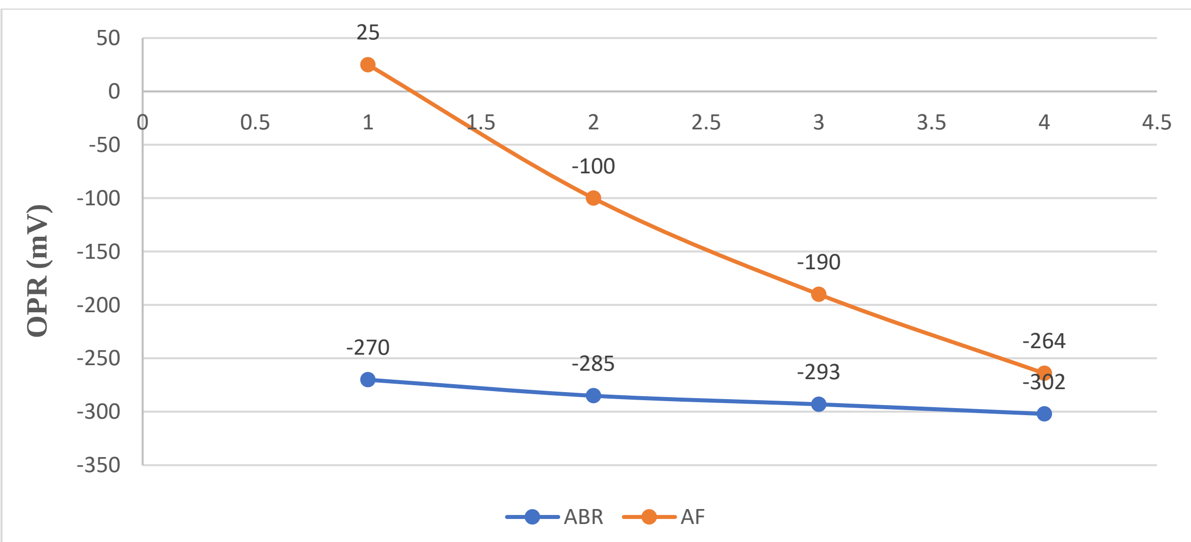

Figure 22: ORP using PVC Media 20 mm

4.1.7 Temperature

Temperature throughout the treatment process varied from 12 to 16ºC, not showing much fluctuations as the setup was placed in a covered area. Hence, this was one of the operational parameters and not considered for the performance.

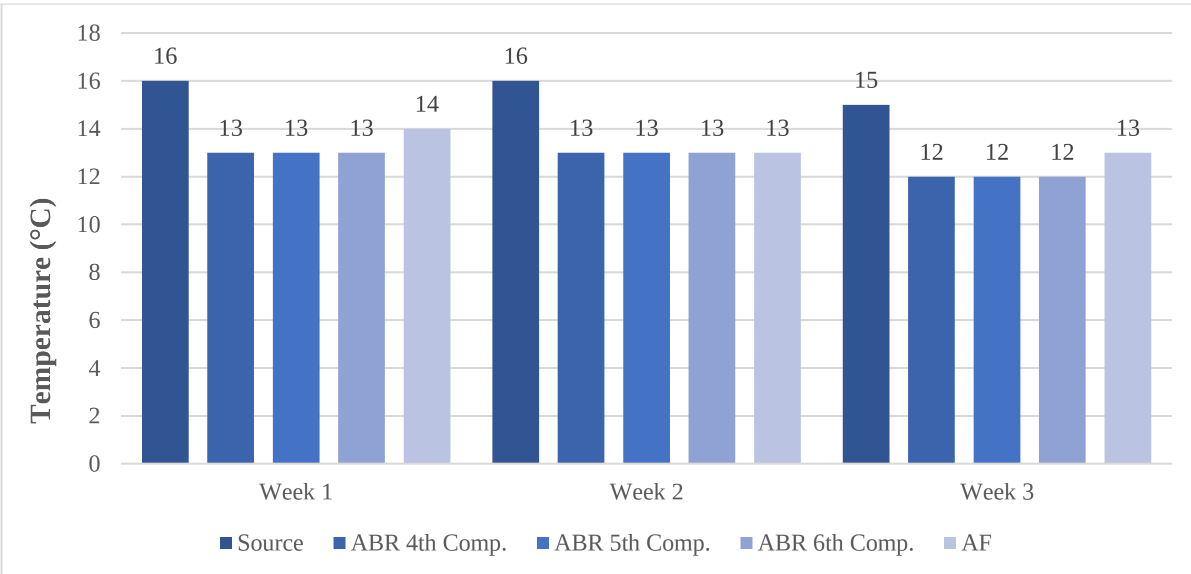

Figure 23: Temperature using PVC Media 25 mm

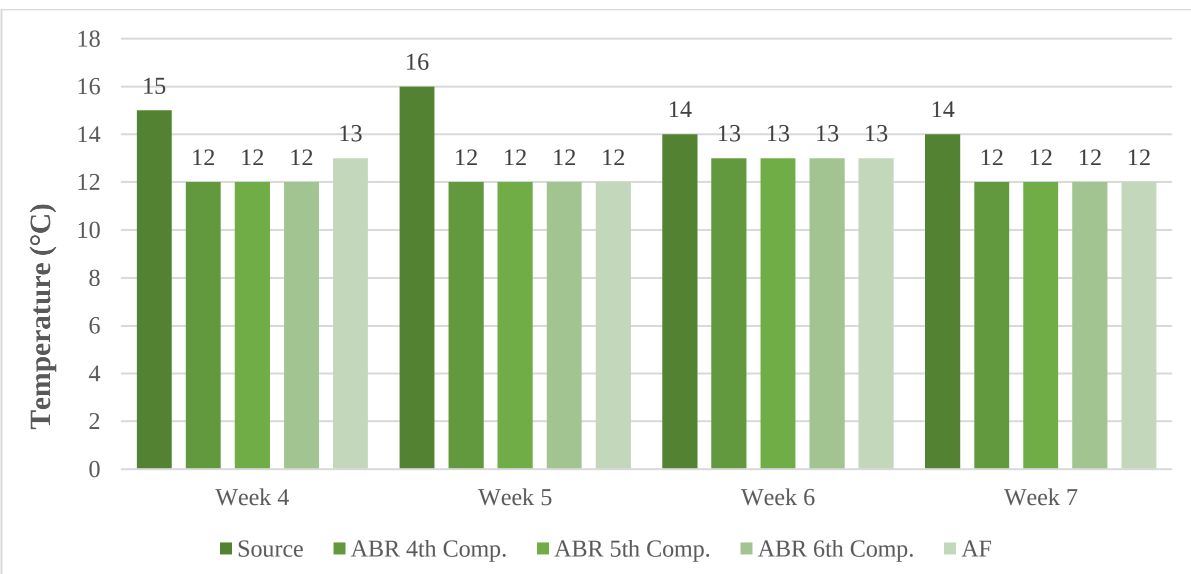

Figure 24: Temperature using PVC Media 20 mm

4.2 Phase 2- GAC Media

4.2.1 Total Suspended Solids (TSS) Removal

TSS values for influent ranged from 95-100 mg/L with an average value of 98 mg/L. However, after treatment through ABR and GAC in AF, TSS values were dropped to 12-14 mg/L with an average value of 13 mg/L and removal efficiency of 86.7%.

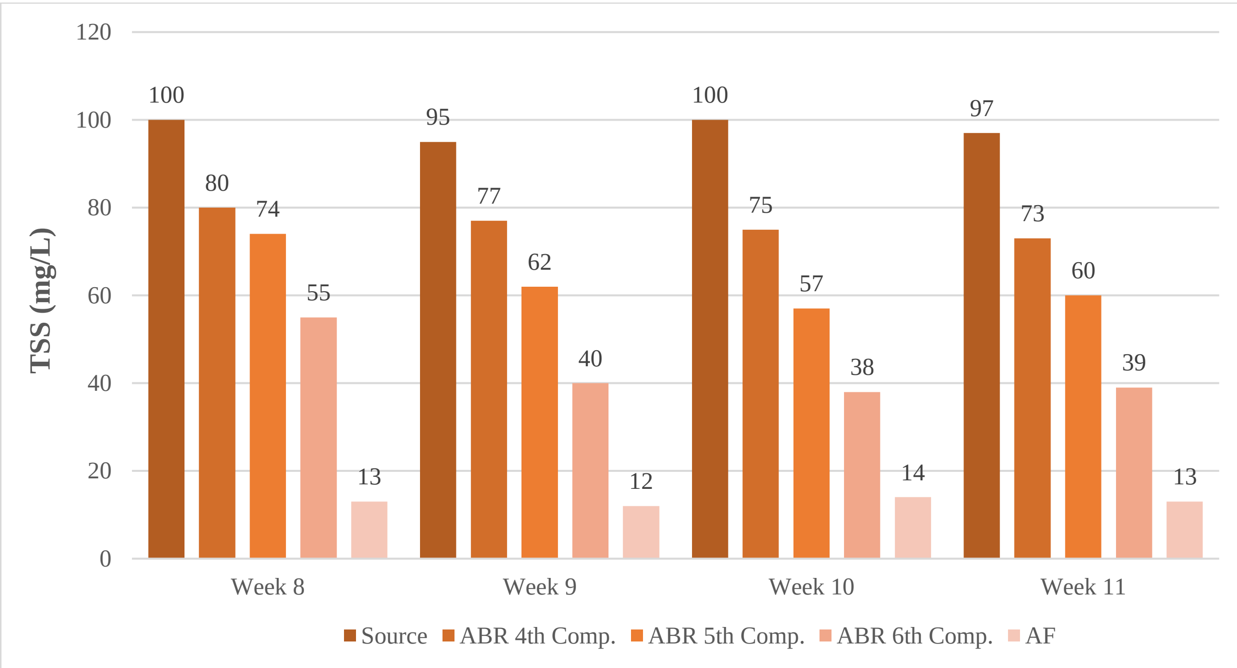

Figure 25: TSS Removal using GAC Media

4.2.2 Total Phosphorus (TP) Removal

TP values for influent ranged from 15-17 mg/L with an average value of 16 mg/L. However, after treatment through ABR and GAC in AF, TP values were dropped to 5-6 mg/L with an average value of 5.4 mg/L and removal efficiency of 66%.

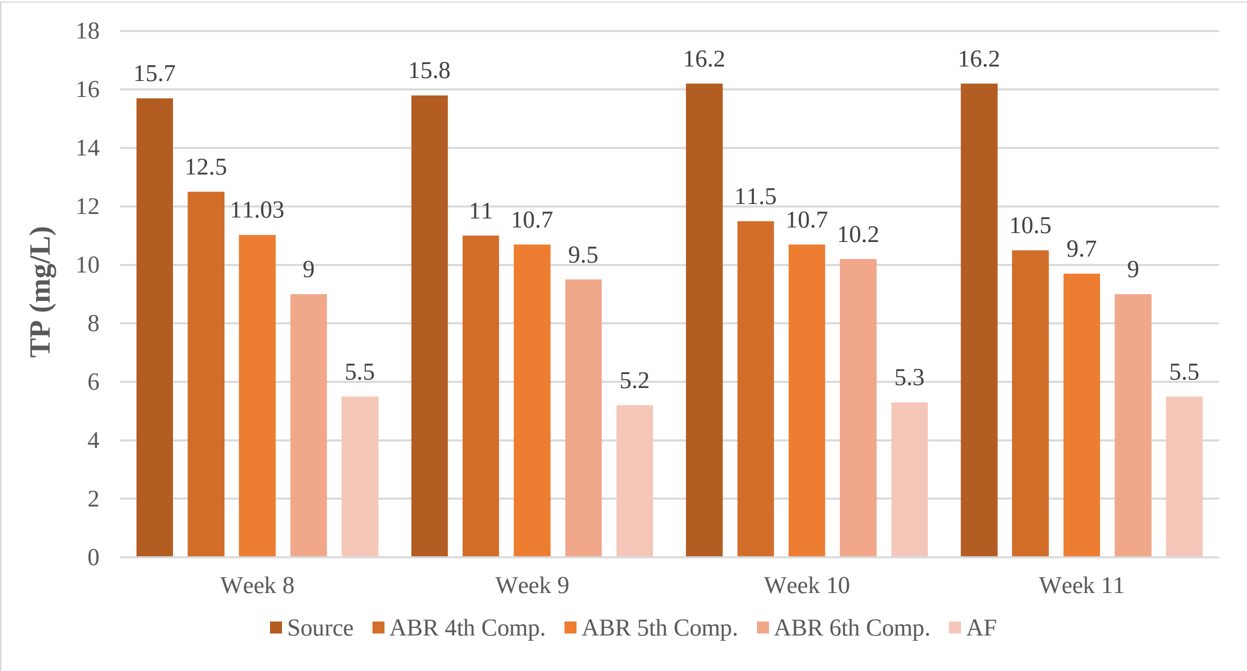

Figure 26: TP Removal using GAC Media

4.2.3 Total Kjeldahl Nitrogen (TKN) Removal

TKN values for influent ranged from 37-40 mg/L with an average value of 38 mg/L. However, after treatment through ABR and GAC in AF, TKN values were dropped to 28-29 mg/L with an average value of 28.5 mg/L and removal efficiency of 25.7%. The enhanced removal efficiency using GAC accounted for its high adsorption capacity for dissolved organic nitrogen.

Although, the physical adsorption capacity of GAC degrades with time, as the filter media becomes exhausted, however, biofilm-based degradation for dissolved organics and particulate matter improves.

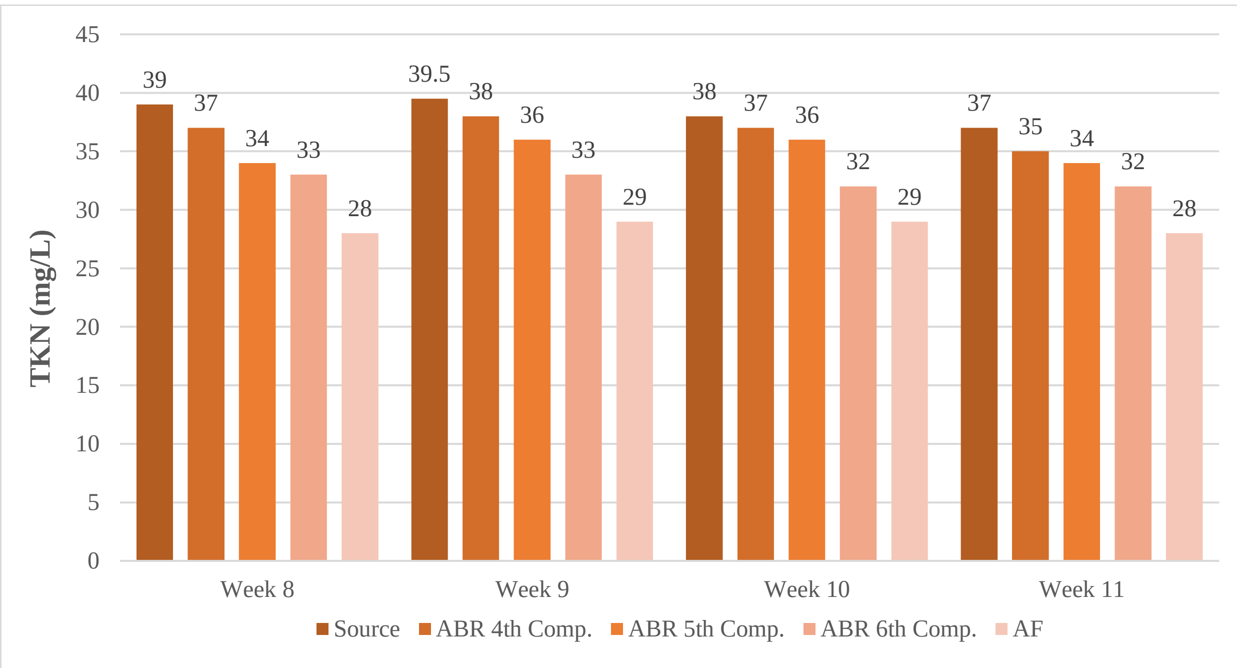

Figure 27: TKN Removal using GAC Media

4.2.4 Chemical Oxygen Demand (COD) Removal

COD values for influent ranged from 335-350 mg/L with an average value of 343 mg/L. However, after treatment through ABR and GAC in AF, COD values were dropped to 95-98 mg/L with an average value of 97 mg/L and removal efficiency of 72%. This led to another conclusion that GAC was even more better filter media than PVC media of 20 mm length which showed removal of 61%.

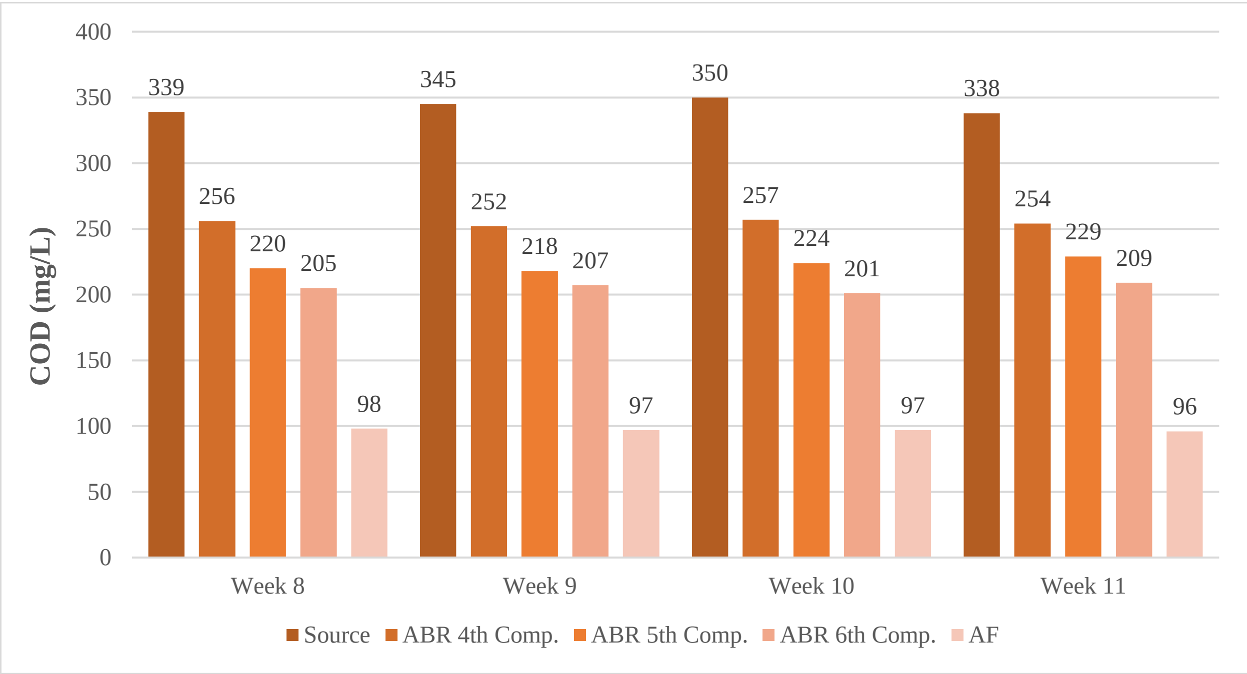

Figure 28: COD Removal using GAC Media

4.2.5 Power of Hydrogen (pH)

Treated effluent had an average pH of 7.43 which was within the safe range of NEQS i.e. from 6 to 9.

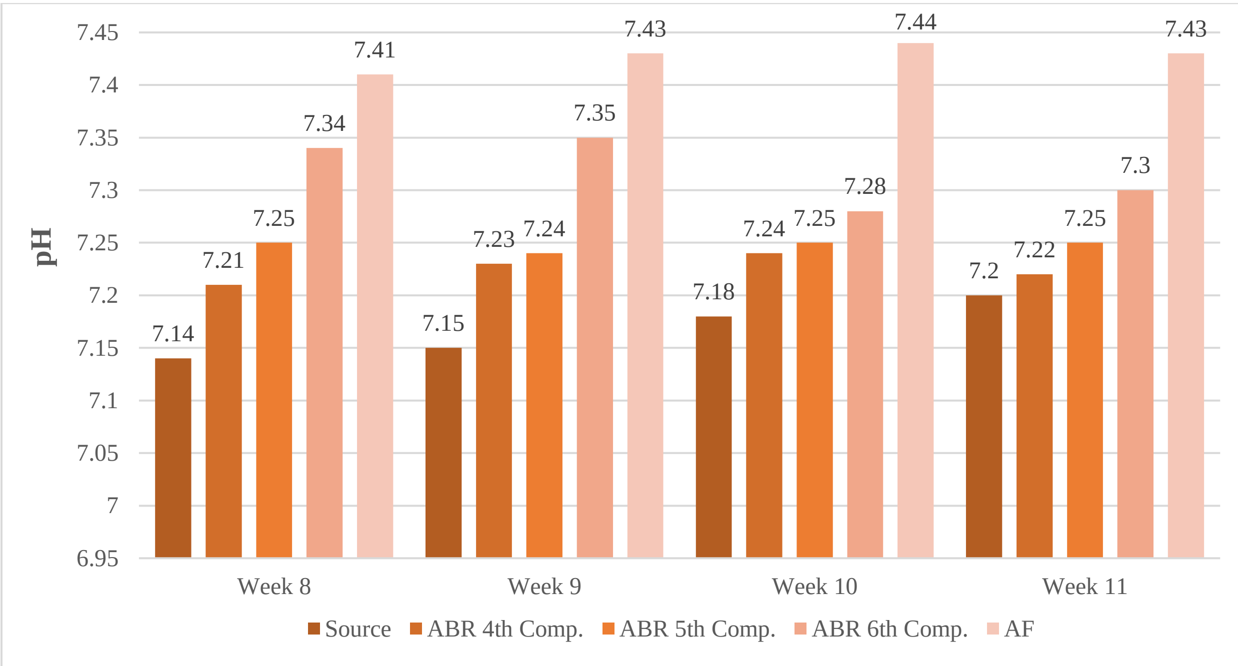

Figure 29: pH using GAC Media

4.2.6 Oxidation Reduction Potential (ORP)

A good anaerobic system has an ORP range of -300 to -450 mV. When we replaced PVC media of 20 mm length with GAC in AF, conditions again became aerobic for AF as shown in the graph, ORP was increased to 22 mV. However, with the passage of time, anaerobic conditions prevailed and ORP gradually dropped to -268 mV. For ABR, conditions continued in anaerobic phase since there was no change in operational condition of ABR.

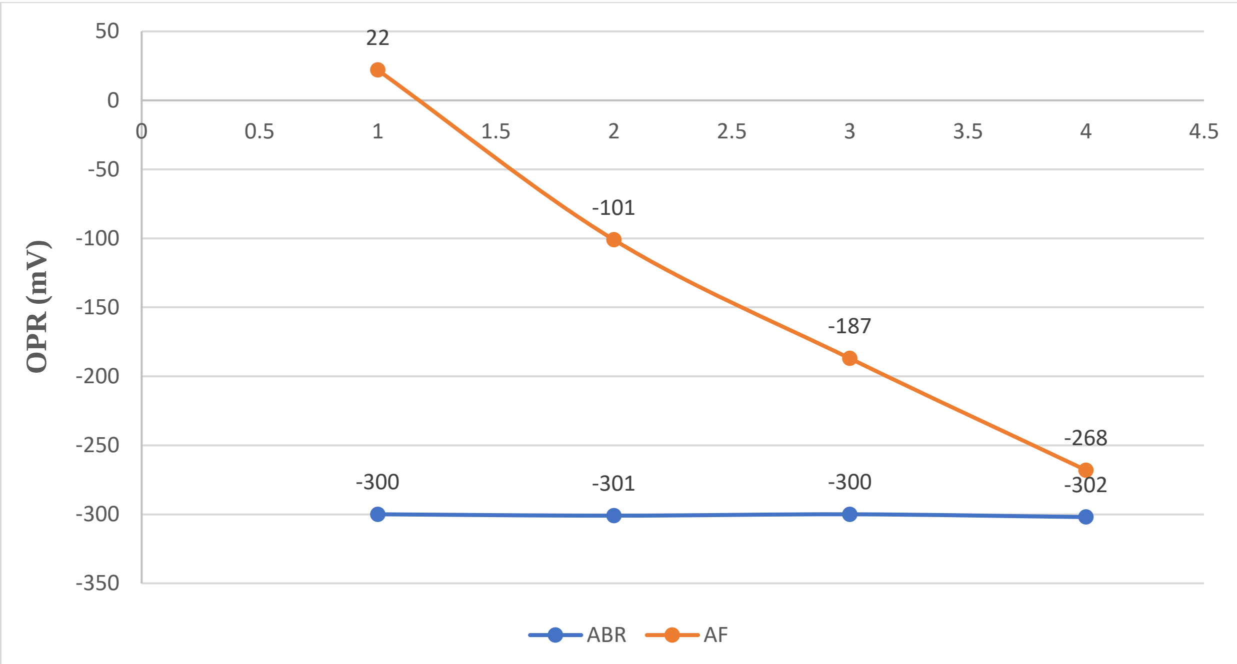

Figure 30: ORP using GAC Media

4.2.7 Temperature

Temperature in second phase of project also did not vary much as the setup was installed in a closed space. Average effluent temperature was recorded as 13ºC.

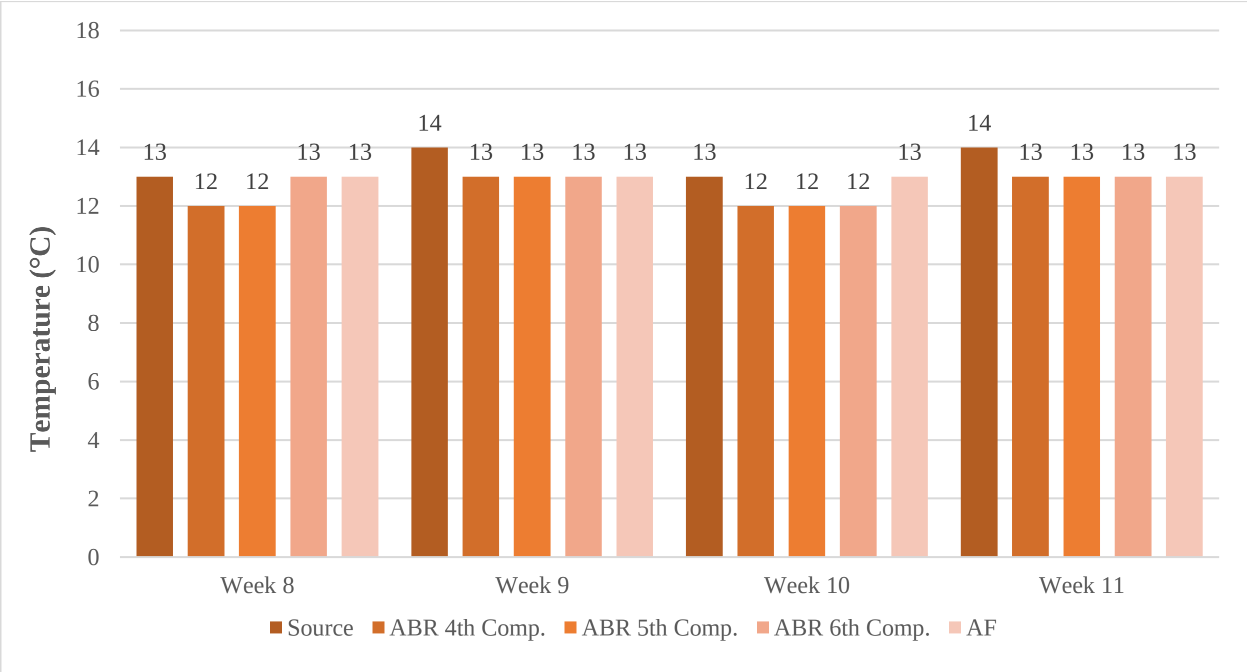

Figure 31: Temperature using GAC Media

4.3 Summary of Results

During the entire project, three different filter media were compared namely; PVC media of 25 mm length, PVC media of 20 mm length and GAC made of coconut shell. Our study aimed to find out most optimum filter media among these three. Following table proves that highest removal efficiencies were achieved using GAC as filter media for treating real domestic wastewater.

Table 4: Comparison of Removal Efficiencies using Three Types of Filter Media

Regulatory Parameters	***Average Removal % of Effluent using PVC Media of 25 mm***	***Average Removal % of Effluent using PVC Media of 20 mm***	***Average Removal % of Effluent using GAC Media***
TSS	77.5	79.3	86.7
TP	43.3	60.3	66
TKN	16.9	20.3	25.7
COD	52.5	61	72

Table 5: Comparison of Operational Parameters using Three Types of Media

Operational Parameters	***Average Value of Effluent using PVC Media of 25 mm***	***Average Value of Effluent using PVC Media of 20 mm***	***Average Value of Effluent using GAC Media***
pH	7.37	7.36	7.43
Temperature	13.3℃	12.5℃	13℃

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The following conclusions can be drawn from the study:

- PVC media of 20 mm length is more efficient (61% COD removal) than PVC media of 25 mm length (52.5% COD removal) for treating real domestic wastewater because of its increased surface area.
- GAC proves to be the most optimum filter media (72% COD removal) for treating real domestic wastewater.
- Combined system (ABR-AF) with total HRT of 24 hours produced treated wastewater that met NEQS (PAK-EPA, 2000) of COD concentration (150 mg/L) i.e. 72% COD removal with average effluent COD of 97 mg/L.
- The filter media was not fouled during the entire research.
- Effluent's pH remained in the range of 7.3 to 7.5.

5.2 Recommendations

Considering the results and conclusion, following recommendations can be proposed:

- Treated wastewater from DWTS may prove to be suitable for non-potable water applications such as landscaping and horticulture.
- Treated wastewater can further get utilized in recharging groundwater, car washing and firefighting after going through tertiary treatment such as constructed wetlands or membrane filtration.
- Low cost and locally available material that can replace and mimic activated carbon as filter media needs to be explored in order to reduce high cost of activated carbon for treating domestic wastewater. One such filter media can be locally available or produced biochar from green raw materials as rice husk or wood chips.
- Although NEQS were met using combination of ABR and AF, however, if high quality non-portable reuse is required, polishing can be achieved using membrane and disinfection using chlorine.
- To ensure uninterrupted and a full gravity flow, some level difference to be provided between different compartments of ABR.

- Investigating biogas production potential of DWTS using PVC and GAC filter media and comparing them.
- Investigating composition and energy content of biogas formed.
- Investigating regeneration capacity of GAC after using it for treatment of domestic wastewater.

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