ANAEROBIC TREATMENT OF DOMESTIC WASTEWATER IN PERI-URBAN AREAS

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APPROVAL SHEET

This is to certify that the Research work described in this thesis is the original work of author(s) and has been carried out under my direct supervision. I have personally gone through all the data/results/materials reported in the manuscript and certify their correctness/authenticity. I further certify that the material included in this thesis is not plagiarized and has not been used in part or full in a manuscript already submitted or in the process of submission in partial/complete fulfillment of the award of any other degree from any institution. 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 Bachelors of Engineering in Environmental Engineering Degree through the official procedures of the Institute.

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Abstract

According to the United Nations, more than 80% of the wastewater resulting from human activities is discharged into rivers or sea without any pollution removal. Unfortunately, the percentage is much higher for Pakistan as only 1% of the domestic and industrial wastewater receives treatment. This has led to the contamination of both surface and ground water, making the already limited sources of water unfit for consumption. The primary reason for the lack of treatment is the absence of wastewater treatment technologies. This study was conducted in order to explore and determine the most efficient technology for the anaerobic treatment of domestic wastewater in peri-urban regions of Pakistan. The research was divided into two phases – Phase I comprised of the optimization of Anaerobic Baffled Reactor (ABR) coupled with an Anaerobic Filter (AF) while Phase II consisted of the establishment and optimization of Anaerobic Fluidized Bed Reactor (AFBR) coupled with an Anaerobic Filter (AF). Both lab-scale setups were operated on synthetic wastewater (Chemical Oxygen Demand: 500mg/L) at a temperature of 30°C throughout the research period. Parameters such as COD, BOD, TKN and Orthophosphates-P were tested to evaluate and compare the performance of these two anaerobic technologies. During the optimization of the ABR-AF, two media namely pottery clay and polyvinylchloride (PVC) pipes were used for the AF respectively. The overall hydraulic retention time (HRT) of this setup was 23 hours (16 hours for ABR, 7 hours for AF). The experimental results of the two media used in the AF showed that PVC pipes were more effective than pottery clay even though the National Environmental Quality Standards (EPA, 1999) were met in both cases; for instance, PVC pipes reduced the BOD from an initial value of 110.9 mg/L to 44.8 mg/L. As for Phase II, 36mm wide plastic pall rings were used as the fluidized media in the AFBR and PVC pipes were used in the AF. The total HRT of this system was 24 hours (10.5 hours for AFBR, 13.5 hours for AF). Even though the AFBR-AF was effective in removing COD, BOD, TKN, and Orthophosphates-P t and met the National Environmental Quality Standards (EPA, 1999), the ABR-AF displayed better treatment performance (87% COD removal) and proved to be a more cost-effective solution.

Keywords: Anaerobic Wastewater Treatment, Anaerobic Baffled Reactor, Anaerobic Fluidized Bed Reactor, Anaerobic Filter.

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Chapter1

Introduction

1.1 Background

Pakistan is home to 207.77 million people, with a vast majority of 63.6% dwelling in rural areas. According to the Pakistan Social and Living Measurement Survey conducted in 2006, 58% of the rural households do not have any form of sanitation system in place. Resultantly, domestic wastewater is openly discharged into streams and rivers without any treatment leading to contamination of water bodies and poor hygiene and sanitation conditions.

In addition to these sanitation issues, Pakistan is also on the brink of facing water scarcity as it is losing its ground and surface water resources with each passing day (Ensink et al., 2004). The uncontrolled extraction and contamination of both surface and groundwater has resulted in the decrease of the water availability per capita from 1,299 m^3 (1996) to 1,100 m^3 (2006). It is projected that by the year 2025, Pakistan will face extreme water shortage with the water availability per capita drastically decreasing to 700 m^3.

An agrarian country like Pakistan cannot afford to face water shortage as it will lead to a myriad of issues such as food insecurity, health deterioration, poor economy etc. Hence, the need of the hour is the exploration of non-conventional water resources such as the treatment of wastewater.

As per the Sustainable Development Goal 6 which addresses the issue of water and sanitation, Pakistan is to adopt an effective wastewater management strategy which includes the installation of low-cost decentralized wastewater treatment plants if it is to improve its sanitation conditions (Shayah et al., 2008).

1.2 Magnitude of Problem

According to the World Health Organization (WHO), more than 2.5 billion people still lack access to improved sanitation facilities in developing countries causing the demise of 15 million people every year (World Heath Statistics.2013). Similarly, the United Nations (UN) has reported that more than 80% of the wastewater generated by human activities is discharged into water bodies without any treatment, and alarmingly, 1,000 children die *every single day* due to preventable water and sanitation related diarrheal diseases.

Pakistan is no exception as 62 per cent of urban population and 84 per cent of rural population do not have access to safe water. (Shay Ateeq Gulab, Pakistan Observer). This is because the lack of sewage collection systems and wastewater treatment plants in rural areas have led to the contamination of surface and groundwater, making the already limited water unfit for consumption.

1.3 Health Effects

Since there are no wastewater collection and treatment systems in place, the wastewater generated is either discharged into nearby water bodies or is collected in empty plots. The subsequent infiltration results in groundwater contamination and these stagnant pools of wastewater serve as breeding grounds for many waterborne diseases such as malaria, typhoid and diarrhea.

Distressingly, 30-40% of the diseases and deaths in Pakistan are linked to poor water quality as per the UN, and roughly 53,000 children die every year due to diarrhea alone. This issue of water pollution is severely affecting the economy as it is costing Pakistan approximately $5.7 billion which is nearly four percent of the GDP (World Bank Statistics.2012).

1.4 Research Motivation

Less than 1% of the domestic and industrial wastewater is being treated in the developed regions of Pakistan and even the centralised wastewater treatment plant in the capital city i.e. Islamabad is underperforming. This further strengthens the need for decentralised wastewater treatment plants especially in rural areas where centralised wastewater treatment plants are deemed economically unfeasible. To further reduce the costs, *anaerobic* technologies for the treatment of domestic wastewater need to be adopted as they require less land and no aeration. This study draws a comparison between two anaerobic technologies that can be implemented to treat the generated domestic wastewater in rural as well as urban areas.

1.5 Problem Statement

- There is minimal research on the efficiency of anaerobic technologies for the treatment of domestic wastewater in Pakistan
- Most of the anaerobic technologies are being developed and optimised for high strength industrial wastewater
- Currently, there are no anaerobic wastewater treatment plants for domestic wastewater in Pakistan

This study was conducted to address the issues listed above, and to provide a sustainable solution for the treatment of domestic wastewater.

1.6 Objectives

The objectives of this study are:

- Optimisation of Anaerobic Baffled Reactor-Anaerobic Filter (ABR-AF)
- Establishment and optimisation of Anaerobic Fluidised Bed Reactor-Anaerobic Filter (AFBR-AF)
- Determination of the most efficient treatment technology through a comparative study

1.7 Scope of Study

In line with the Sustainable Develop Goal 6 which calls for clean water and sanitation for all, this project aims to provide better solutions for the treatment of domestic wastewater in peri-urban and rural areas with minimal expense of energy.

Even though Pakistan has successfully been progressing towards an open defecation free (ODF) environment, the absence of a concrete wastewater treatment management system proves to be a deadlock. In order to progress, a low cost, effective treatment technology needs to be implemented.

Chapter 2

Literature Review

The major cause of surface and ground water pollution is discharge of untreated wastewater into water bodies. The absence of municipal wastewater treatment plants has led to rise of various water-borne diseases such as malaria, contamination of surface and ground water and overall poor sanitation and hygiene conditions. To solve this problem wastewater treatment is necessary.

2.1 Centralized and Decentralized Treatment of domestic wastewater

Centralized treatment plants are being used since decades for urban wastewater collection and treatment. Conventional centralized systems are not always the most appropriate solution for urban development (Cook et al.,2009). Centralized system is complex, requires trained labors and is cost-intensive. In addition to this, it has a high environmental impact and may harness waste at source (DeGisi et al., 2014). Management of wastewater system in developing countries is intensified by the rapid increase in urbanization, insufficient disposal and management of wastewater; for this the implementation of highly centralized and sophisticated treatment technologies is necessary (Libralato et al., 2012). Large land requirement and extensive collection system are a prerequisite of centralized systems. Non-uniformity in wastewater quality also requires dilution as there is less control over storm water (CODESAB, 2011).

When raw wastewater is treated next to the point of generation by using different technologies, it is known as decentralized wastewater system. Decentralized wastewater system needs small area and short distances for collection system. Moreover, water is used and reused in the same area. Decentralized systems are cost-effective as well as simple in operation since they can be monitored remotely. Similarly, in decentralized wastewater systems there is more control over the storm water and the wastewater is more concentrated (CODESAB, 2011); there is less need of water transfer as a result. Decentralized wastewater management is vital for complete wastewater treatment and environmental protection worldwide (Shayah et al., 2008).

2.2 Anaerobic Digestion of Domestic Wastewater

On a comparative scale, anaerobic systems are more sustainable and are net energy producers.

This cost-effective technology makes use of biological means to remove organic pollutant in wastewater which produces methane gas as energy resource (Tabatabaei et al., 2010). Anaerobic digestion is the only system that deals with organic wastes and provides maximum energy recovery. Since it is a closed system, there are no toxic emissions, retention of water and fertilizer content, and recovery of heavy metals. From the economic perspective, anaerobic onsite systems are considered as the most sustainable and suitable technology (Lettinga et al., 1996). The drastic shift from aerobic to anaerobic treatment has occurred in last few decades. Since aerobic systems require aeration, the associated costs and high energy demand make it unsuitable for country like Pakistan where energy is a major issue. Stability and efficiency of the system depends mainly on metabolic balance between different groups of trophic microorganisms which have different growth conditions. The varying conditions may cause instability; this is when the system suffers from any shock such as presence of toxic matter, temperature fluctuation and increase in organic loading rate (Leitao et al., 2005). Low strength organic wastewater, like municipal sewage, has been also treated in anaerobic systems (Bravo et al., 2009). Effluent quality from anaerobic system treating municipal sewage can vary widely depending on several factors such as influent characteristics, operational parameters, local conditions, reactor design, etc. Hence effluent quality cannot be defined strictly in anaerobic reactor generally (Foresti et al., 2006).

2.2.1 Anaerobic Baffled Reactor (ABR)

At the beginning of ABR, most of the solid are removed. Low sludge generation and high solid retention time (SRT) make this system suitable for use. This system is ideal for decentralized wastewater treatment because it is easy to construct, has no moving parts and therefore requires minimum maintenance. Separation of sludge is not required in this system either. Low operational and capital cost make ABR an economically feasible treatment option. A single chamber serves the purpose of both primary and secondary sedimentation are one of the reason for selection of ABR. Another major reason is the wide use of such system in tropical region. The most noteworthy advantage of the reactor is the compartmentalized structure which allows the separation of acidogenesis and methanogenesis longitudinally down the reactor allowing different microorganisms to dominate different compartments (Barber et al., 1999).

2.2.1.1 Optimum Temperature

Anaerobic digestion is strongly affected by temperature (Chae et al., 2008). Optimum temperature for mesophilic bacteria in anaerobic baffled reactor (ABR) is greater than 30^{o} C (Stucky et al., 1999)

2.2.1.2 Hydraulic Retention Time

Hydraulic retention time (HRT) plays an important role in digestion of organic matter present in wastewater. Studies show that varying the hydraulic retention time from 6 days to 3 hours gives high removal i.e. 86% Suspended Solids, 87% BOD and 84% COD. (Ramandeep et al., 2015)

2.2.1.3 Advantages of ABR

- Low construction cost
- No mechanical parts and mixing
- Simple design
- Less sludge production
- Less clogging
- Higher solid retention time
- Lower HRT
- Organic shocks stability
- Influent safety from toxic materials

2.2.2 Anaerobic Filter

Anaerobic filter is used for secondary treatment as it is a fixed-bed biological reactor from which wastewater flows and particles are removed. Organic matter degrades by the action of active biomass which is attached on the filter media surface. Comparatively, anaerobic filters have higher solid removal than anaerobic baffled reactors for treatment of domestic wastewater. Research shows that anaerobic filter requires low nutrient, and odor-free effluent is obtained. It is found that extreme actions such as passing air through the unit or permitting the pH to drop as low as 5.5 do not affect the ability of the filter for rapid recovery (Viraraghavan et al., 1983). It is found that removal efficiency of anaerobic filter is higher than the existing conventional septic tank (CST) for COD, BOD, TKN and TSS. Also, thermos-tolerant coliform removal is another key advantage of anaerobic filters. Therefore, addition of anaerobic filters can be a favorable replacement of CST for the treatment of black water, predominantly in the rural areas of the developing countries. (Sharma et al., 2014).

2.2.2.1 Optimum Temperature

The optimum temperature for the anaerobic filter is considered to be 35°C as it resulted in removal greater than 80% (Lopez et al., 2013). Also, the optimum temperature of mesophilic bacteria to grow is greater than 30°C.

2.2.2.2 Hydraulic Retention Time

Studies shows that removal efficiencies of 65% to 80 % for COD have been achieved by varying HRT from 6 to 10 hours (Wiegant et al., 2001)

2.2.3 Anaerobic Fluidized Bed Reactor

Anaerobic fluidized bed reactor is a secondary treatment process for wastewater. This system is considered to be viable for decentralized treatment of domestic wastewater. It is more suitable for urban areas as it requires less land. However, the cost of pumping the wastewater in an upflow manner makes it a comparatively costly treatment technology. The flowrate of feed is very important as it is important to retain the media present in AFBR in fluidized state (McCarty et al., 2010)

2.2.3.1 Hydraulic retention

According to research, hydraulic retention time should be greater than 3 hours for anaerobic technologies (Ramandeep et al., 2015). For Anaerobic Fluidized Bed Reactor, the optimum HRT is 8 hours (Marin et al., 1999).

2.2.3.2 Optimum temperature

Temperature plays an important role in the growth of bacteria. For anaerobic bacteria, growth is maximum at optimum temperature i.e. greater than 30^{o} C. Efficiency in removing COD will be greater than 80% at 35^{o} C (Kim et al., 2010).

2.2.3.3 Advantages of AFBR

- Uniform particle mixing leading to higher reactor efficiency
- Less sludge production
- Tolerant to heat changes
- Potential to produce biogas
- Continuous operation instead of a batch system

2.3 Selection of Media

Two medias were selected on the basis of literature review. Many different materials were studied, such as stones, perforated spheres, modular plastic panels, ceramic and plastic rings, clay fragments, calcareous seaweeds, mussel shells, other porous materials (as polyurethane foam) and stainless wire mesh (Colleran, et al., 1984).

2.3.1 Selection of Pottery Clay as Filter Media

Study shows organic matter removal measured as Biochemical Oxygen Demand (BOD) was greater than 80% and Total Phosphorus (TP) was greater than 94% using clay as filter media in Anaerobic Filter (Jenssen et al., 2010). Study found that use of baked clay support media reduces COD up to 97.5% (Gourari et.al., 1997).

2.3.2 Selection of PVC Pipe as Filter Media

This study suggested the use of PVC pipes as filter media to reduce the cost of media. (Libhaber et al., 2012). Since PVC pipes are commercially available and have a high surface area to volume ratio, it was selected as the second media for the Anaerobic Filter.

Chapter 3

Materials and Methods

3.1 Methodology

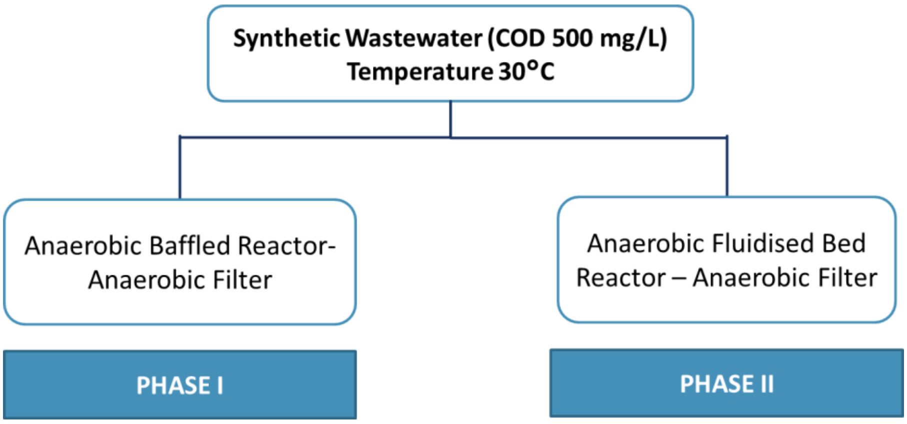


Figure 0.1 Methodology Flowchart

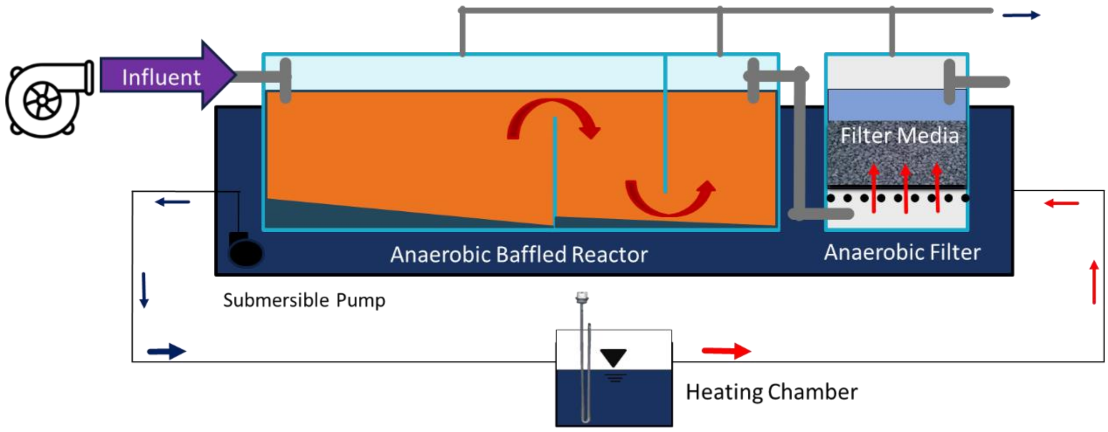
This study comprises of two phases as shown in Fig 3.1 Two anaerobic technologies i.e. Anaerobic Baffled Reactor (ABR) coupled with an Anaerobic Filter (AF) and Anaerobic Fluidized Bed Reactor (AFBR) coupled with an Anaerobic Filter (AF) were optimized and tested under the same operating conditions. In order to conduct a comparative study between two reactors, the influent characteristics and temperature were kept constant throughout the research period. The Chemical Oxygen Demand (COD) of the synthetic wastewater was set at 500 mg/L in accordance with the domestic wastewater samples collected from Tehsil Jatoi in Muzaffargarh District, and the temperature was kept at 30 degrees Celsius in order to promote mesophilic conditions that favor the growth of anaerobic microbes.

3.1.1 Phase I: Anaerobic Baffled Reactor-Anaerobic Filter

Phase I comprised of the optimization of the Anaerobic Baffled Reactor-Anaerobic Filter.

3.1.1.1 Lab Scale Experimental Set-up

The Anaerobic Baffled Reactor-Anaerobic Filter (as shown in Fig 3.2) operated on synthetic wastewater. The feed was pumped into the ABR through a peristaltic pump which, after optimization, operated at 17 revolutions per minute which is equivalent to a flow rate of 1.77 liters per hour. The two baffles located in the ABR ensured adequate mixing. The subsequent HRT of the ABR was 16 hours. After 16 hours, the wastewater moved into the anaerobic filter where the hydraulic retention time was 7 hours. In the Anaerobic Filter, the media was placed onto the mesh below which there was sludge. The wastewater moved upwards in the AF, coming into contact with the sludge as well as the filter media.



(Adapted from *Design and Optimisation of Anaerobic filter for Secondary Treatment in Decentralised Wastewater Treatment System* Research Project, 2017)

Figure 0.2 Schematic Diagram of ABR-AF

A heating chamber, along with a submersible pump, was used to circulate water in the water bath and maintain the system's temperature at 30 degrees Celsius at all times.

3.1.1.2 Size of ABR and AF

The lab scale ABR had the following dimensions:

Table 0.1 Dimensions of ABR

Parameters	Dimensions (cm)
Length	100.0
Width	33.0
Height	18.0

Total Volume = 80.0 L Effective Volume = 70.0 L

The lab scale AF had the following dimensions:

Table 0.2 Dimensions of AF

Parameters	Dimensions(cm)
Length	35.0
Width	33.0
Height	18.0

Total Volume= 21.0 L Effective Volume= 18.0 L

Mesh was placed 5.0 cm from the bottom while the filter media height was 9.0 cm.

Figure 0.3 Lab Scale Experimental Setup of ABR-AF

3.1.1.3 Seed Sludge Preparation and Inoculation

Anaerobic sludge required for the ABR and AF was prepared by collecting aerobic sludge from the MBR plant installed in NUST. It was stored in an airtight container for a period of two months. On alternate day, 20 grams of glucose (as substrate) and 10 grams of sodium bicarbonate (to adjust the pH) were added into the container. Upon the appearance of bubbles, which indicated the presence of anaerobic microbes, this seed sludge was transferred to the ABR and AF respectively. 40% volume of the reactor volume, of both ABR and AF, were filled with this sludge.

3.1.1.4 Replacement of Media in AF

In order to optimize the ABR-AF system, the effectiveness of the filter media in the AF was tested by using two low cost and readily available media namely pottery clay and PVC pipes respectively. Initially, glass was being used as the filter media but keeping in mind the dangers associated with it, the filter media was replaced. The height of the media was kept constant i.e. 9 cm in both cases. Irregular pieces (roughly 5 x 5cm) of pottery clay obtained from broken flower pots were placed in the AF (as shown in Fig 3.4) and the effectiveness was measured in terms of COD removal, BOD removal, TKN removal, Orthophosphates-P removal, VFA/Alkalinity ratio and pH. The time period for the study of this variable was 4 weeks.

Figure 0.4 Pottery Clay Pieces

Pottery clay was then replaced by PVC pipes with the following dimensions:

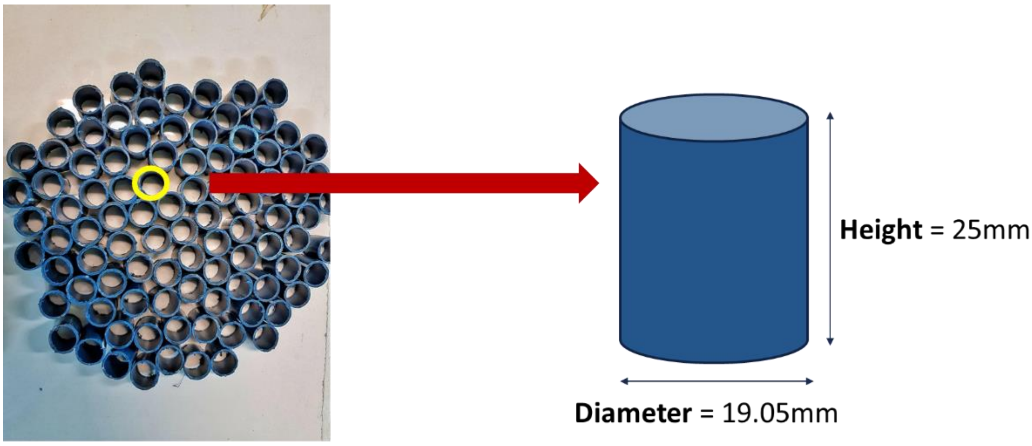


Figure 0.5 Dimensions of PVC Pipes used in AF

The study time for this variable was also 4 weeks and same parameters were tested to determine the effectiveness of PVC pipes as filter media in the AF.

3.1.2 Phase II: Anaerobic Fluidized Bed Reactor – Anaerobic Filter

Phase II focused on the establishment and optimization of the Anaerobic Fluidized Bed Reactor coupled with AF.

3.1.2.1 Lab Scale Experimental Set-up

Fig3.6 shows the schematic diagram of the AFBR. A peristaltic pump, which operated at 9 rpm, was used to pump the synthetic wastewater into the AFBR in an up-flow manner. The HRT of AFBR was 10.5 hours. Plastic pall rings were used as the fluidized media on which the biofilm was formed. The plastic pall rings have a high surface area to volume ratio that is 151 m^2/ m^3. A heating rod was placed inside to maintain the temperature at 30 degrees Celsius. After a period of 10.5 hours, the AFBR effluent moved into the anaerobic filter where the HRT was 13.5 hours. PVC pipes were used as the media in anaerobic filter in order to draw a fair comparison between the performance of the ABR-AF.

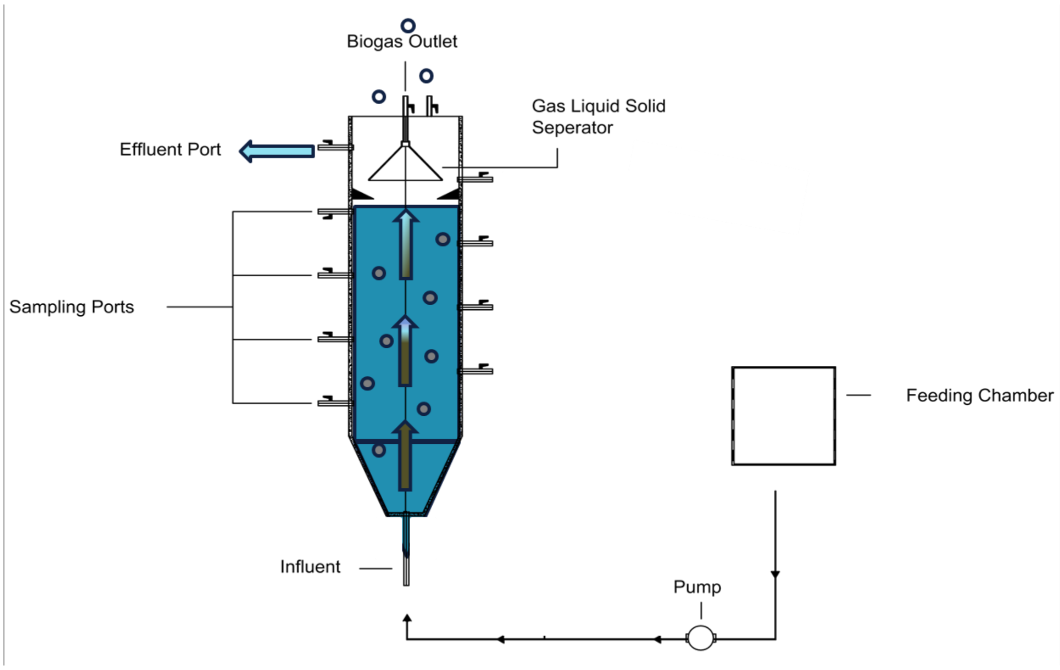


Figure 0.6 Schematic Diagram of AFBR-AF

3.1.2.2 Size of AFBR

Table 0.3 Dimensions of AFBR

Parameters	Dimensions(cm)
Top External Diameter	23.0
Internal Diameter	26.0
Height	61.7

Effective Volume = 10.0 L

Fig 3.7 shows the lab scale set up of the AFBR-AF.

Figure 0.7 Lab Scale Setup of AFBR-AF

3.1.2.3 Seed Sludge Preparation and Inoculation

The anaerobic sludge requirement for the AFBR was met by collecting 10.0 L of anaerobic sludge in an airtight container from an anaerobic continuously stirred reactor (CSTR) under study in the lab. This sludge was fed with 20 grams of glucose and 10 grams of sodium bicarbonate on alternate days for the provision of substrate and to adjust the pH. Once the seed sludge was ready, 3.0 liters of it was transferred to the AFBR which is 30% of the reactor's volume.

3.1.2.4 Fluidized Media in the AFBR

Pall rings were used as the fluidized media in the AFBR, providing sufficient surface area for the formation of biofilm. The pall rings had a width of 36mm and a length of 35mm. The surface area to volume ratio of the pall rings was 151 m^2/m^3. The up-flow velocity in the AFBR maintained these pall rings in a fluidized state which led to adequate mixing.

3.2 Analysis of Parameters

The wastewater parameters tested and analyzed are shown in Table 3.4:

Table 0.1 Parametric Analysis of Wastewater Quality

Parameters	Methods	References
Biological Oxygen Demand BOD5 (mg/l)	Titrimetric Method	APHA et al., 2012
Chemical Oxygen Demand COD (mg/l)	Close reflux method	APHA et al., 2012
Orthophosphates-p	UV Spectrophotometer Method	APHA et al., 2012
Total Kjeldhal Nitrogen	Kjeldahl Method	
pH	Electrometric Method	
Volatile Fatty Acids/Alkalinity	Volumetric Analysis	

3.2.1 Determination of Chemical Oxygen Demand

In order to determine the COD, vials were prepared using 1.5 mL of potassium dichromate ($K_2Cr_2O_7$), 2.5 mL of sample and 3.5 mL of sulfuric acid (H_2SO_4). These vials were placed in the COD digester for two hours and then titrated against ferrous ammonium sulfate (FAS) till the color of the solution turned from yellow-green to reddish brown. Two drops of Orthophenanthroline ferrous complex (ferroin) were used as an indicator.

Following equation was used to calculate the COD.

$$COD\ (mg/L) = \frac{(A-B)\times N\times 8000}{Volume\ of\ Sample\ in\ mL} \qquad \text{Equation (3.1)}$$

where: A = Volume of FAS used to titrate blank mL

B = Volume of FAS used to titrate sample mL

N = Normality of FAS

3.2.2 Determination of Biological Oxygen Demand

The test for BOD comprises of forming blank and sample BOD bottles and incubating them at 20°C for 5 days. In order to prepare the BOD bottles, 1 L of diluted was formed by adding 1 mL of concentrated sulfuric acid, 1mL of $MnSO_4$, 1 mL of iodide azide solution and 1 mL of calcium carbide into 996 mL of distilled water. 12 mL of sample wastewater was pipetted into the BOD bottle and the prepared diluted water was then poured into the bottles till the total volume reached 300 mL. The initial DO of the blank was measured using a DO meter and all bottles were placed in the incubator. After 5 days, the dissolved oxygen levels of the blank and samples was measured using a DO meter, and the following equation was used to calculate the BOD:

$$BOD\ (mg/L) = \frac{(D_0 - D_5) \times 300}{f}$$ Equation (3.2)

where: D_0 = Initial DO

D_5 = DO after 5 days incubation

f = dilution factor

3.2.3 Determination of Orthophosphates-p

For the determination of orthophosphates-p, the vials were prepared by adding 2 mL of Vanadate Molybdate reagent into a 10 mL sample. For the blank, distilled water was used instead of the sample. The tests were conducted on a spectrophotometer; the blank vial was used to set the zero value and the wavelength was set to 470 nm. The samples, after being transferred to the cuvette, were placed in the spectrophotometer and the absorbance displayed was noted down. Using the following equation, the orthophosphates-p of the samples was calculated in mg/L:

$$PO_4(mg/L) = \frac{x + 0.003}{0.014}$$ Equation (3.3)

where, x = Absorbance

3.2.4 Determination of Total Kjeldahl Nitrogen (TKN)

The procedure used for measuring Total Kjeldahl Nitrogen (TKN) of the wastewater samples was as follow:

The first step comprised of digestion in which 12.5 mL of digestion reagent was added into a distillation flask containing 25 mL of sample. This solution was then diluted by adding 200 mL of distilled water, and after thorough mixing was heated under a hood with adequate ventilation to remove fumes of acid. When the volume of the solution reduced to 25-50 mL, it was further digested for approximately half an hour. Once the colored sample turned pale green, it was no longer heated and was left to cool.

After this step, the pH of the sample was increased to 7 by the addition of sodium hydroxide-sodium thiosulfate reagent drop wise.

Once the sample was neutralized, it was transferred to a Kjeldahl flask and placed on the distillation stand. 200 mL of distillate was then collected and 50 mL of boric acid (as an absorbent solution) was used. The sample was then titrated against 0.02N NaOH until the endpoint was reached i.e. color of the sample turned light pink. Following formula was used to calculate the TKN:

$$TKN\ (\frac{mg}{L}) = \frac{A-B}{Sample\ Volume} * 280 \qquad \text{Equation (3.4)}$$

Where, A = Sample Concentration

B = Blank Concentration.

3.2.5 Determination of pH

The pH meter was used to measure the pH of the solution.

3.2.6 Determination of Volatile fatty acids/Alkalinity

The measurement of VFA/Alkalinity is two-step process.

The alkalinity was first determined by taking 20 mL sample of wastewater in a titration flask. The pH of the sample was then measured using a pH meter. If the measured pH was greater than 4.3, it was titrated against 0.02N H_2SO_4 until the pH reduced to 4.3 The amount of sulfuric acid utilized was noted and used to calculate alkalinity using the following equation:

$$Alkalinity\left(\frac{mg}{L}\right)=\frac{Volume\ of\ acid\ used*Normality\ of\ acid*50*1000}{Volume\ of\ sample\ used\ (mL)}$$ Equation (3.5)

The next step was to calculate the volatile fatty acids (VFA). In order to do so, the titration flask containing the sample obtained from the alkalinity test was further heated by placing it on a heating plate. The sample was removed when the temperature reached 60 – 70 degrees Celsius and cooled too room temperature. The pH of the sample was measured and the sample was titrated against 0.02N sodium hydroxide (NaOH) till the pH increased to 6.5. The volume of base i.e. NaOH was noted down and used in the following equation to calculate VFA:

$$VFA\left(\frac{mg}{L}\right)=\frac{Volume\ of\ base\ used*Normality\ of\ base*50*1000}{Volume\ of\ sample\ used\ (mL)}$$ Equation (3.6)

VFA was then divide by Alkalinity to get the ratio.

Chapter 4

Results and discussions

4.1 Performance of ABR-AF

The optimization of the ABR-AF was done by replacing the filter media in the AF. Two media i.e. pottery clay and polyvinylchloride (PVC) pipes were used since both are readily available and economically viable options. In order to determine and compare the effectiveness of the proposed medias, the removal efficiency of ABR-AF was measured in terms of COD, BOD, TKN, and orthophosphates-p removal.

4.1.1 Pottery Clay vs PVC pipes

Pieces of pottery clay were positioned on the mesh present in the Anaerobic Filter. The height up to which the filter media was placed was kept constant throughout i.e. 9 cm. After running the system continuously for four weeks, and conducting the respective wastewater analysis tests, pottery clay was replaced by PVC pipes. PVC pipes had a greater packing density which played a key role in its performance as a filter media in the AF.

4.1.1.1 Removal of Chemical Oxygen Demand

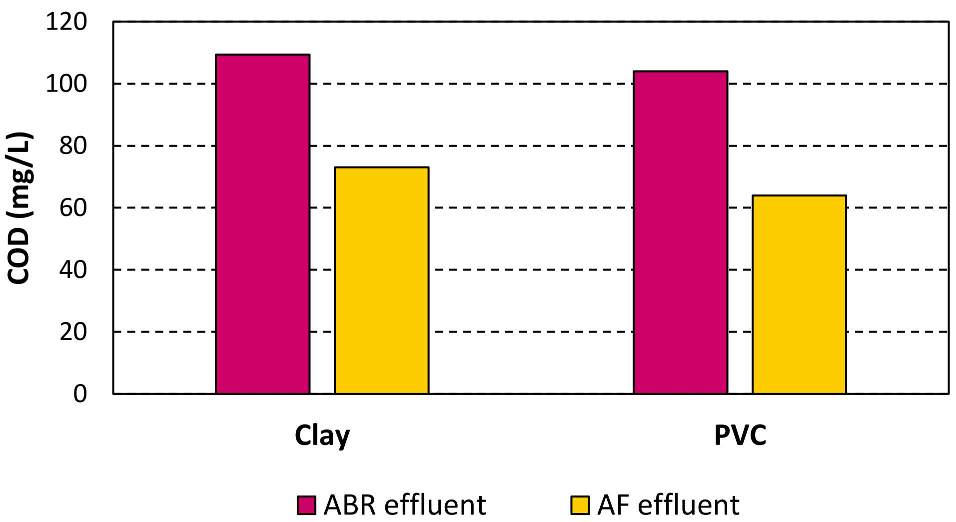


Figure 0.1 COD Removal in ABR-AF

Even though both the media effectively removed the COD, PVC pipes exhibited better removal as compared to pottery clay as shown in Fig 4.1 The AF influent had 104 mg/L of COD and the PVC pipes reduced it to 64 mg/L which equates to 39% removal whereas clay removed 33%. The higher surface area of PVC pipes led to better removal as there was more room for the growth of biofilm.

4.1.1.2 Removal of Biological Oxygen Demand

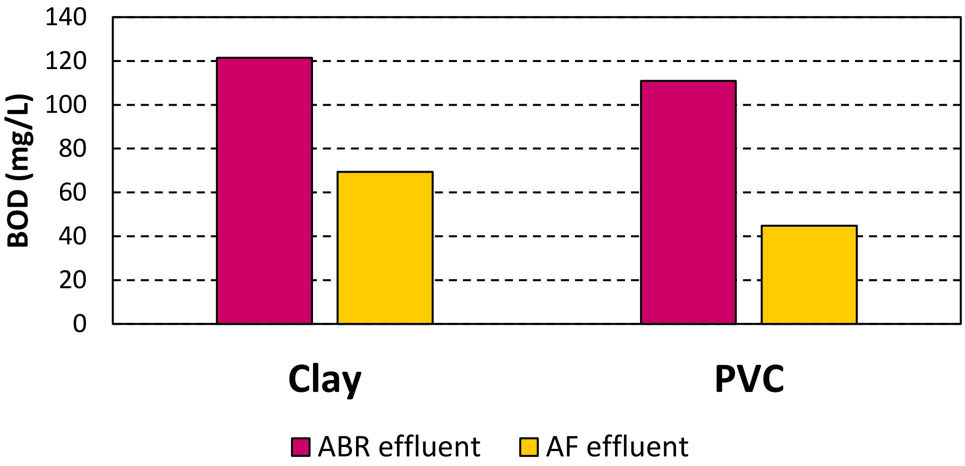


Figure 0.2 BOD Removal in ABR-AF

Similar trend was observed for the removal of BOD; the ABR-AF removed 85% of the BOD altogether when PVC pipes were used in the AF while 77% was removed when pottery clay was used. Even though both the media met the NEQS limit for inland water (EPA, 1999) which is 80 mg/L, PVC displayed greater BOD removal overall – as shown in Fig 4.2

4.1.1.3 Removal of Total Kjeldahl Nitrogen (TKN)

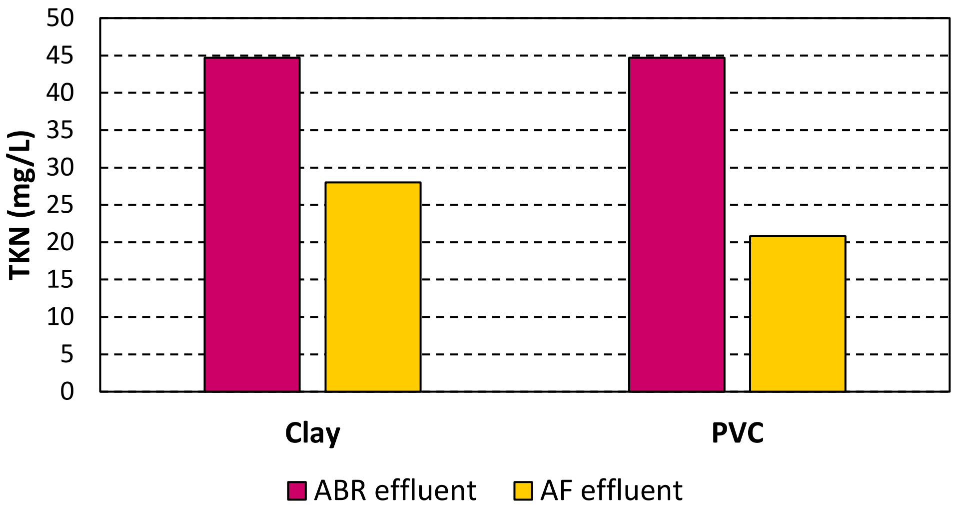


Figure 0.3 TKN Removal in ABR-AF

TKN removal was higher for AF with PVC pipes than for AF with pottery clay. As Fig 4.3 shows, PVC pipes reduced the TKN value from 44.7 mg/L to 20.8 mg/L which is equal to 53% removal whereas clay removed only 37%.

4.1.1.4 Removal of Orthophosphates-P

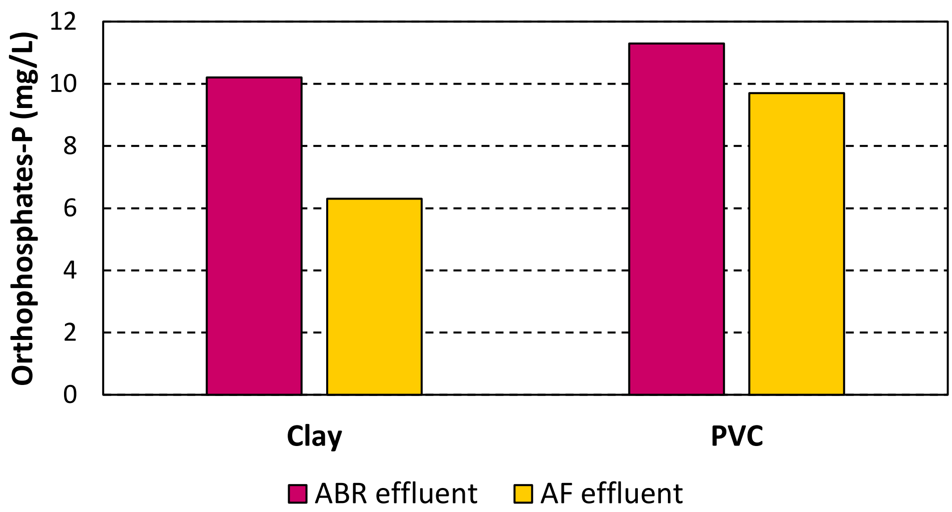


Figure 0.4 Orthophosphates-P Removal in ABR-AF

Fig 4.4 shows the removal of orthophosphates-p by pottery clay and PVC pipes. Clay proved to be a better filter media as it exhibited greater reduction of orthophosphates-p i.e. 38% whereas PVC removed only 14%. The poor performance of PVC pipes was because of the phosphate leaching that occurred due to the use of polyvinylchloride pipes as filter media. The NEQS limit is set at 40mg/L but since synthetic wastewater was used in this study, the initial orthophosphates concentration came out to be 23.9 mg/L which was already lower than the limit.

4.1.1.5 Volatile Fatty Acids/Alkalinity

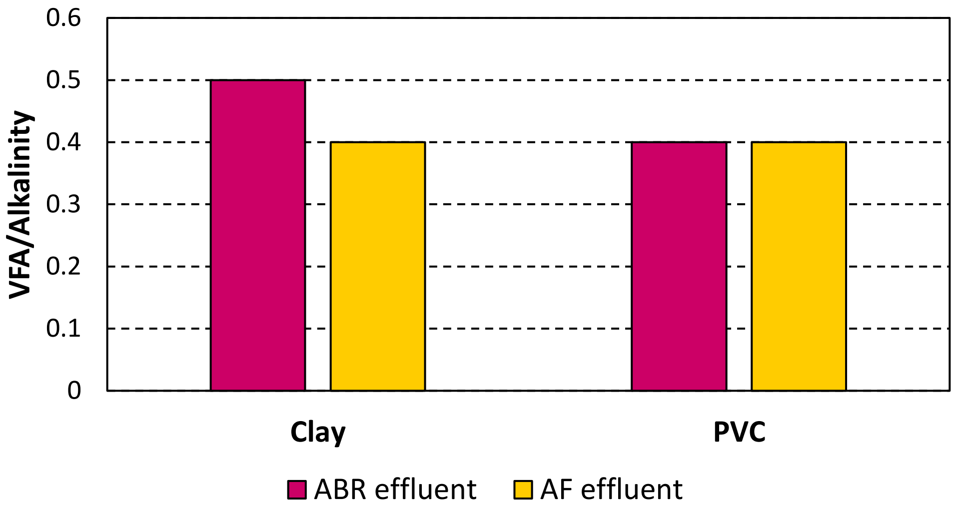


Figure 0.5 VFA/Alkalinity in ABR-AF

As Fig 4.5 shows, the VFA/Alkalinity was within the idea range which is considered to be 0.3-0.6. The variation in media did not disturb the ratio, and so the Anaerobic Filter can be categorized as a stable anaerobic system.

4.1.1.6 pH

The pH of ABR-AF was within the NEQS limit i.e. 6-9 during the entire research period. When pottery clay was used, the pH of the AF was 8.3 while the pH of AF was 6.2. The difference in pH can be associated with the chemical composition of the filter media. Similarly, the pH of ABR remained between 7.1-7.4 during the time period.

4.1.1.7 Result Summary for Phase I

Table 0.1 Comparison of Pottery Clay and PVC Pipes

Parameter	Clay	PVC Pipes
	ABR-AF Removal %	
COD (mg/L)	85	87
BOD (mg/L)	77	85
TKN (mg/L)	42	57
Orthophosphates-P (mg/L)	74	59

Table 4.1 shows the comparison of pottery clay and PVC pipes in terms of removal percentage of the ABR-AF system. It can be concluded that PVC was much more effective as media in anaerobic filter as the removal percentage of parameters such as COD, BOD, TKN were higher for PVC than clay. For example, anaerobic baffled reactor coupled with an anaerobic filter using PVC removed 85% of the BOD while clay only removed 77%. Analyzing the effectiveness of PVC pipes as media as well as its economic and commercial viability, we have suggested PVC pipes of length 0.5 to 1 inches and of diameter 1-2 inches for the full-scale plant in Muzaffargarh.

4.2 Performance of AFBR-AF

The second anaerobic treatment technology, AFBR-AF, operated at an HRT of 24 hours. Since this system ran for a period of four weeks only, the effects of varying the HRT and fluidized media could not be explored nor was the system completely stabilized. However, the AFBR-AF still proved to be an efficient technology for the treatment of domestic wastewater as all the parameters tested met the National Environmental Quality Standards (EPA, 1999).

4.2.1 Removal of Chemical Oxygen Demand

As shown in Fig 4.6, the AFBR-AF removed 71% COD overall as it brought down the initial value of 500mg/L to 147 mg/L – within the National Environmental Quality Standards. The AFBR was more effective as compared to the AF as it removed 53% of the COD while the AF only removed 37%, however the AFBR cannot be adopted as a single unit because it failed to meet the NEQS limit i.e. 150 mg/L.

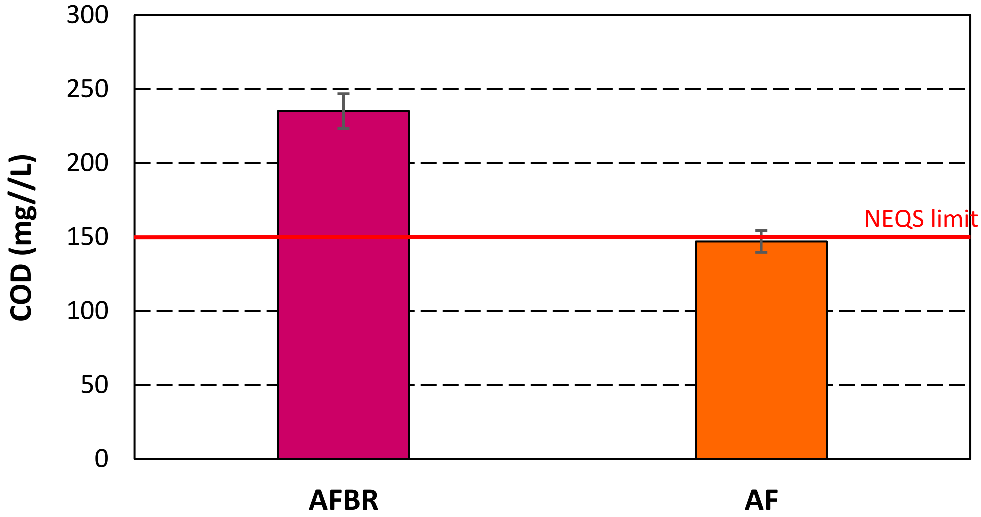


Figure 0.1 COD Removal in AFBR-AF

4.2.2 Removal of Biological Oxygen Demand

In terms of BOD removal, the AFBR removed 53% of the BOD while AF removed 56% of the BOD. The initial BOD value of the influent was 300 mg/L, and after treatment it came down to to 62.5 mg/L which reflects an overall removal of 79%. As seen in the Fig 4.7, the AFBR-AF met the NEQS limit of 80 mg/L.

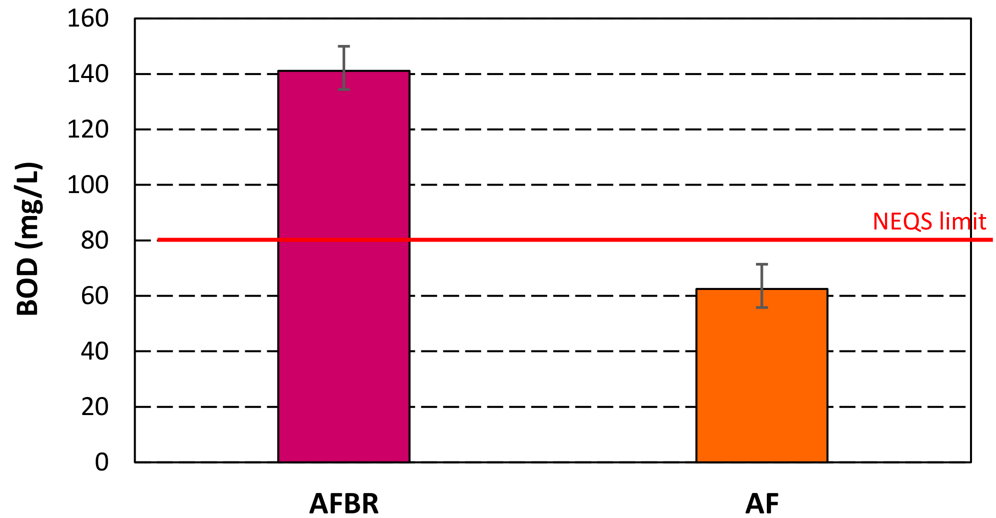


Figure 0.2 BOD Removal in AFBR-AF

4.2.3 Removal of Total Kjeldahl Nitrogen

As for the removal of TKN, the AFBR had an overall poor removal performance as it only removed 15% of the initial TKN. Similarly, the AF did not demonstrate a significant removal percentage either. The TKN of the effluent, however, did decrease down to 32.5 mg/L.

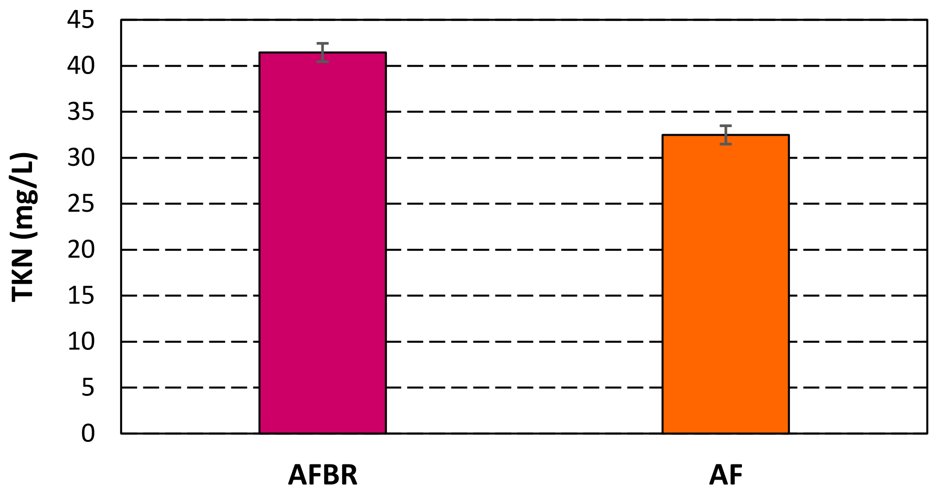


Figure 0.3 TKN Removal in AFBR-AF

4.2.4 Removal of Orthophosphates-P

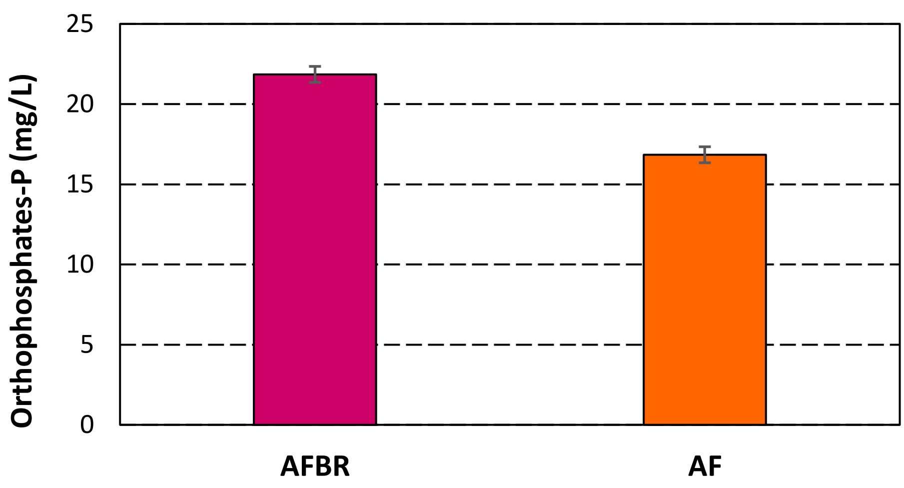


Figure 0.4 Orthophosphates-P Removal in AFBR-AF

Fig 4.9 shows the removal of Orthophosphates-P by the AFBR and AF respectively. The lowest removal percentage by the AFBR was observed here i.e. only 9%. However, the effluent quality still met the NEQS limit of 40 mg/L.

4.2.5 VFA/Alkalinity

In order to determine the stability of the system, the Volatile Fatty Acids to Alkalinity ratio (VFA/Alkalinity) was calculated. The VFA to Alkalinity ratio of both AFBR and AF met the standard range which is considered to be 0.3-0.6, as show in Fig 4.10. However, the ratios were generally on the higher side as compared to the ratios obtained for the ABR-AF. This is because the study period of AFBR-AF was only a month, and such anaerobic systems take time to stabilize.

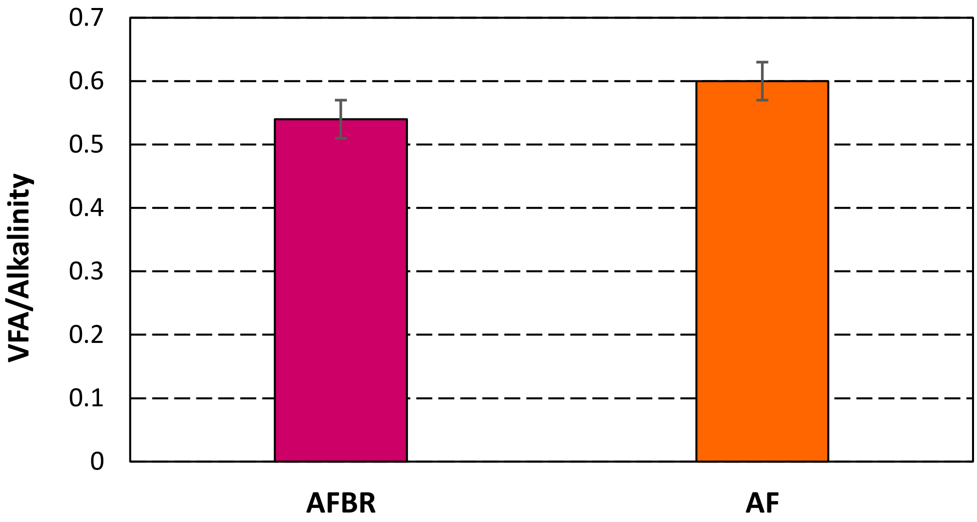


Figure 0.5 VFA/Alkalinity in AFBR-AF

4.2.6 pH

Throughout the analysis of AFBR-AF, the pH of the system remained stable and within the limit specified by NEQS for inland waters i.e. 6-9.

4.2.7 Result Summary of AFBR-AF

Table 4.2 shows the performance of anaerobic fluidized bed reactor coupled with an anaerobic filter at a 24-hour HRT. The treatment technology was successful in removing COD, BOD, TKN and orthophosphates-p, therefore can be used to treat municipal wastewater as the effluent quality met the NEQS.

Table 0.1 Performance of AFBR-AF

Parameter	Synthetic Wastewater	Anaerobic Fluidized Bed Reactor	Anaerobic Filter	NEQS (EPA,1999)
COD (mg/L)	500.0	235.1	147.0	150
BOD (mg/L)	300.0	141.1	62.5	80
TKN (mg/L)	48.5	41.4	32.5	-
Ortho phosphate-P (mg/L)	23.9	21.9	16.8	40
VFA/Alkalinity	-	0.5	0.6	-
pH	7.8	6.8	7.2	6-9

4.3 Comparison of ABR-AF and AFBR-AF

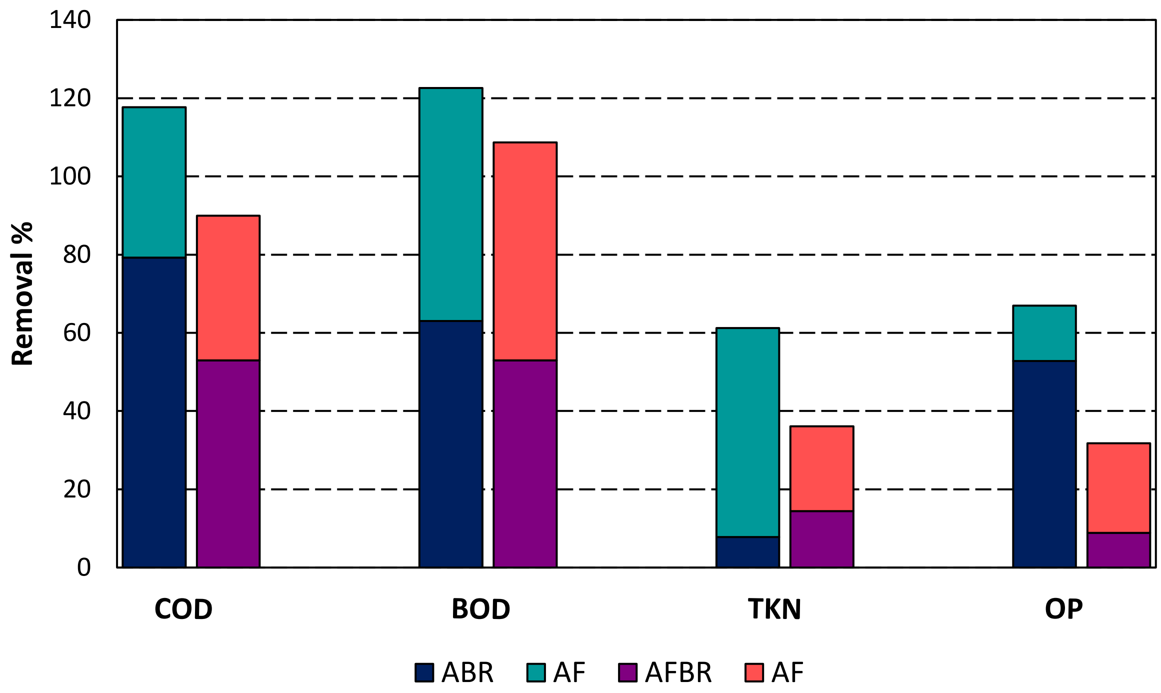


Figure 0.1 Comparison of ABR-AF and AFBR-AF

The ultimate goal of this study was to determine the most efficient treatment technology by drawing a comparison. Out of the two anaerobic technologies i.e. ABR-AF and AFBR-AF, the ABR-AF proved to be more efficient.

Fig 4.11 shows the removal percentages of both ABR and AFBR coupled with the same AF which contained PVC pipes as the filter media. Even though the two systems were effective in treating the synthetic wastewater but ABR-AF is much more efficient when it comes to the removal of COD, BOD, TKN and Orthophosphates. For instance, ABR removed 5 times more Orthophosphates-p than AFBR and ABR-AF collectively removed 87% of the COD while AFBR-AF removed around 71%.

Table 0.1 Comparison of the Performance of ABR-AF and AFBR-AF

Parameter	Synthetic Wastewater	ABR-AF effluent	AFBR-AF effluent	NEQS (EPA, 1999)
COD (mg/L)	500.0	64.0	147.0	150
BOD (mg/L)	300.0	44.8	62.5	80
TKN (mg/L)	48.5	20.8	32.5	-
Orthophosphate-P (mg/L)	23.9	9.7	16.8	40
VFA/Alkalinity	-	0.4	0.6	-
pH	7.8	6.2	7.2	6-9

Shown in Table 4.3 are the results of the ABR-AF and AFBR-AF. Both systems were successful in meeting the National Environmental Quality Standards but when compared, the ABR-AF exhibited better treatment performance.

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

While comparing the two anaerobic systems i.e. ABR-AF and AFBR-AF, it was concluded:

- PVC pipes were more effective as media in AF as compared to pottery clay.
- ABR-AF exhibited better treatment performance than AFBR-AF in terms of COD, BOD, TKN, and Orthophosphates-P even though both systems met the NEQS
- Design, manufacturing and operation of ABR-AF is relatively simpler than that of AFBR-AF as ABR-AF is a gravity driven and energy free system.

5.2 Future Recommendations

- Explore the effects of variations in synthetic media size, density, and surface roughness for Anaerobic Filter (AF).
- Determine the optimal HRT and impact of internal recirculation on Anaerobic Fluidised Bed Reactor (AFBR).
- Explore the biogas potential of both the anaerobic systems.

References

Aiyuk S., Forrez I., Verstraete W. (2006). Anaerobic and complementary treatment of domestic sewage in regions with hot climates — a review. Bioresource. Technol. 97, 2225–2241

Al-Shayah M., Mahmoud N. (2008) Start-up of an UASB-septic tank for community on-site treatment of strong domestic sewage, Bioresource Technology, 99: 7758–7766.

APHA, AWWA, WED, (2005) "Standard Methods for the Examination of Water and Wastewater", 21st edition, American Public Health Association, Washington, DC.

Burghate S.P., Ingole N.W. (2013). Fluidized Bed Biofilm Reactor – A Novel Wastewater Treatment Reactor. International Journal of Research in Environmental Science and Technology 2013; 3(4): 145-155.

Chae K.J., Jang A.M., Yim S.K. (2006). The Effect of Digestion Temperature and temperature shock on the biogas yields from the mesophilic anaerobic digestion of swine manure. *Bio Resourse Technology*, 6.

Dahab M.F., Young J.C. (2006). Effect of Media Design on the performance of Fixed-Bed Anaerobic Reactors. 15 (8-9) 369-383.

Ensink J.H.J., Mahmood T., Hoek W.V.D. (2004). A nationwide assessment of wastewater uses in Pakistan: an obscure activity or a vitally important one? Water Policy 6: 197-206.

Jaafari J., Mahvi A.H., Kamani H., Hoseini M. (2014). Influence of upflow velocity on performance and biofilm characteristics of anaerobic fluidized bed reactor (AFBR) in treating high-strength wastewater. Journal of Environmental Health Science & Engineering 2014 12:139.

Kapusta S., Bodik I., Gasparikova E. (2005). Evaluation of Anaerobic-Aerobic Wastewater Treatment Plant Operations. Polish Journal of Environmental Studies vol. 14, no. 1, 29-34.

Kobayashi H.A., Stenstorm M.K., Mah R.A. (2003). Treatment of low strength domestic wastewater using the anaerobic filter. Water Research, Volume 17, Issue 8.

Ladu J.L.C., Lu X. (2014). Effects of hydraulic retention time, temperature, and effluent recycling on efficiency of anaerobic filter in treating rural domestic wastewater. Water Science and Engineering, 7(2): 168-182

Leitao R.C., Haandel A.C.V., Zeeman G., Lettinga G. (2005) “The effects of operational and environmental variations on anaerobic wastewater treatment systems: A review” Bioresource Technology, 97: 1105–1118

Lettinga G. (1996). Sustainable integrated biological wastewater treatment. Water Sci. Technol. 33 (3), 85–98

Manariotis L.D., Grigoropoulos S.G. (2002). Low-strength Wastewater Treatment using an Anaerobic Baffled Reactor. Water Environ res. 2002 mar-apr; 74(2): 170–176.

Mccarty P.L, Bae P.L, Kim J, Lee E, Shin C. (2015). Anaerobic Fluidized Bed Membrane Bioreactors for the Treatment of Domestic Wastewater. Anaerobic Biotechnology: pp. 211-242.

Mccarty P.L., Bae J., Kim J. (2011). Domestic Wastewater Treatment as a Net Energy Producer - can this be achieved? Environ. Sci.Technol. 45, 17, 7100-7106.

Nasr F.A., Doma H.S., Nassar H.F. (2009). Treatment of Domestic Wastewater using an Anaerobic Baffled Reactor followed by a duckweed pond for agricultural purposes. The Environmentalist, volume 29, number 3, page 270.

Nasr F.A., Mikhaeil B. (2013) “Treatment of domestic wastewater using conventional and baffled septic tanks” Environmental Technology, 34: 2337–2343

Passig F.H., Picanco A.P., Blundi C.E. (2001). Microbiological study of the development of biofilm in an Anaerobic Fixed Bed Reactor. *Research Gate*, 5.

Raghavan D.S.S., Qiu G, Song Y., Ting Y.P. (2016). Anaerobic Treatment of Low-strength Wastewater. Biological Treatment of Industrial Effluents, Pages 293–320.

Reynaud N., Buckley C.A. (2016). The anaerobic baffled reactor (ABR) treating communal wastewater under mesophilic conditions: a review. Water Science and Technology, Volume 73, Issue 3

Sharma M.K., Khursheed A., Kazmi A.A. (2014). Modified septic tank-anaerobic filter unit as a two-stage onsite domestic wastewater treatment system. Environ. Technol. 35 (17), 2183–2193.

Sirinukulwattana T., Pungrasmi W. (2013). Treatment of Low-strength Wastewater by Rubber Granules Media AFBR without internal recirculation. Journal of Water Sustainability, Volume 3, Issue 2, June 2013 97-106.

Tilche A., Bortone G., Garuti G., Malispina F. (1993). Post-treatments of anaerobic effluents. Antonie van Leeuwenhoek, Journal of Microbiology. Volume 69, Issue 1, pp 47–59

Tonon D., Tonetti A.L., Filho B.C. (2015). Wastewater treatment by anaerobic filter and sand filter: Hydraulic loading rates for removing organic matter, phosphorus, pathogens and nitrogen in tropical countries. Ecological Engineering, 7.

Vakil K.A., Sharma M.K., Bhatia A., Kazmi A.A., Sarkar S. (2014). Characterization of greywater in an Indian middle-class household and investigation of physicochemical treatment using electrocoagulation. Sep. Purif. Technol. 130, 160–1