Comparison of Up flow Anaerobic Sludge Blanket Reactor with Anaerobic Moving Bed Bioreactor for Treatment of Textile (De-Sizing) Wastewater

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Islamabad, Pakistan

(2019)

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Comparison of Up flow Anaerobic Sludge Blanket Reactor with Anaerobic Moving Bed Bioreactor for Treatment of Textile (De-Sizing) Wastewater

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Annex A To NUST Letter

Dated: 31 May 2019

THESIS ACCEPTANCE CERTIFICATE

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ABSTRACT

Our research focused on the treatment of De-sizing Wastewater by utilizing two treatment technologies i.e. Up flow Anaerobic Sludge Blanket Reactor (UASB) and Anaerobic Moving Bed Bioreactor (An-MBBR). Our aim was to determine the most efficient treatment technology between the two by optimizing their respective treatment performance. Different intermittent phases were introduced during the continuous operation of UASB reactor treating synthetic de-sizing wastewater. Initially the reactor was operated at Hydraulic Retention Times of 16, 20 and 24 hours for maximum removal rates. The similar conditions were operated for Anaerobic Moving Bed Bioreactor (An-MBBR) and removal rates were identified. Our aim was focused on identifying the treatment technology having maximum COD, TKN, TP and Ammonia Nitrogen removal efficiency and varying hydraulic retention times. During this research we designed a lab scale An-MBBR setup and compared its removal efficiency with the existing UASB Reactor setup available in the laboratory. De-sizing wastewater was synthesized based on the effluent composition obtained from Kohinoor Mills, Kasur. Both reactors were fed with this synthetic wastewater and testing was conducted respectively. The complete research along with conclusions drawn will be discussed in detail in the following sections.

ACKNOWLEDGEMENTS

First of all our humble gratefulness is for Allah Almighty for giving us strength, vision and capability to complete this project.

We would like to express special thanks to our supervisor **Engr. Amal Sarfraz** for her guidance and support throughout the course of this research. She has been a great mentor, a visionary and a source of motivation at each step.

Special thanks to **Dr.Sher Jamal Khan**, Professor, IESE, NUST for his kind sharing of knowledge and his help in this research.

We would like to extend our special thanks to **Engr. Aamir Khan** for his relentless efforts and support. Without his support and technical help during this research the completion of our final year project would not have been possible.

A sincere thanks to our families who stood by us.

Last but not the least, our humble thanks to Associate Dean, **Dr. Imran Hashmi** and all faculty members.

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LIST OF ABBREVIATIONS

AN	Ammonia Nitrogen
An-MBBR	Anaerobic Moving Bed Bioreactor
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
EC	Electrical Conductivity
F/M	Food/Microorganisms ratio
GLSS	Glass Liquid Solid Separator
HRT	Hydraulic Retention Time
IP	Influent Pump
MLSS	Mixed Liquid Suspended Solids
MLVSS	Mixed Liquid Volatile Suspended Solids
MBR	Membrane Bioreactor
NEQs	National Environmental Quality Standards
TN	Total Nitrogen
OLR	Organic Loading Rate
ORP	Oxidation Reduction Potential
TSS	Total Suspended Solids
VSS	Volatile Suspended Solids
TKN	Total Kjeldahl Nitrogen
UASB	Upflow Anaerobic Sludge Blanket
VSS	Volatile Suspended Solids
VFA	Volatile Fatty Acid

1. INTRODUCTION

1.1. Background

Textile sector is the major economical backbone of Pakistan which is the 8th largest exporter of textiles in Asia. Having major influence on GDP of 9.5% and a source of income to 15 million people of Pakistan i.e. 30% of working force of the country, textile industry is currently facing many financial, economic, social and environmental challenges. In spite of the introduction of textile policy, its full implementation is unforeseen. It catches public attention towards the standpoint of pollution, despite earning a huge amount of foreign exchange. In environmental sector, one of the biggest challenges of textile industries is meeting the international environmental protocols. Almost every textile plant running in region emits toxic effluent into air as well as generates concerns for ground and surface water. Multiple processes for synthetic or natural fabric production in various types of textile industries have the major concern related to use and release of hazardous chemicals especially those that generate the finished products and make their way to effluent streams. Much of scientific research is focused on the use of green technologies using end-of-pipe solutions for these intense problems for reducing chemical and energy usage.

One of the major challenges faced by the industry in environmental sector is the requirement to meet International Environmental Protocols. The wastewater effluent discharged from textile industries contains high concentration of pollutants and requires proper treatment to render it safe for disposal. The SDG relevant to our project is Goal 6 that is Clean Water and Sanitation which aims to improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

Figure 1.1: Sustainable Development Goals (SDG's)

Textile wastewater carries considerable pollution load in terms of Chemical oxygen demand (COD), Biological oxygen demand (BOD), Total suspended solids (TSS), Total dissolved solids

(TDS) and heavy metals. The values of these parameters are always found to be high as compared to National Environmental Quality standards (NEQs) set by the government.

Processes Involved	Textile Effluent Characteristics
Singering, Desizing	High BOD and TSS, Neutral pH
Scouring	High BOD, TSS, alkalinity and temperature
Bleaching, Mercerizing	High BOD, TSS and alkalinity
Heat-settling	Low BOD and TSS, alkaline wastewater
Dyeing, Printing & Finishing	Wasted dyes, High BOD, COD and TSS, neutral to alkaline wastewater

Table 1.1: Textile Processes Producing Hazardous Textile Wastewater

Source: Carmen & Daniela (2010)

Two major processes are involved in the textile industry. The first process is called Dry Process. This category includes yarn manufacturing, yarn texturing, unfinished fabric manufacturing, fabric coating, fabric laminating, fabric dipping, etc. Dry Processing consists of spinning, knitting and weaving of fabrics.

The second category in textile production is termed as Wet Process. Wet process is usually done on the manufactured assembly of interlacing fibers, filaments, and yarns having substantial surface area in relation to its thickness, and adequate mechanical strength to give it a cohesive structure. All the processes of this stream are carried out in an aqueous state or aqueous medium. The main processes include: Singeing, Desizing, Scouring, Bleaching, Mercerizing, Dyeing, Printing, Finishing. Acids, bases, salts, surfactants, oxidizing agents and reducing agents are the major chemicals that are widely used in wet processing industry

Untreated effluent from dyed textile production is highly colored and thus, objectionable and offensive, if discharged into the open streams without being treated properly. Even though the dye concentration is well below 1 ppm i.e., its concentration lower than many other hazardous chemicals, dye is highly visible through naked eye and it becomes the top parameter to be detected in such wastewater. Many physical, chemical and biological conventional techniques are reported to be competently involved in removal, alteration, or isolation of these pollutants. However, these technologies are reported to be expensive, uneconomical and not feasible to get installed at large scale in developing countries like Pakistan, who is facing serious financial and economic constraints.

De-sizing is an essential stage in textile processing. It is the process of removal of size material applied on warp threads of a fabric to facilitate the process of weaving. Size forms a stiff, hard and smooth coating on warp yarns to enable them to withstand the cyclic tensions during weaving and reduce breakage. Sizing agents often resist the dyes and chemicals commonly used in textile processing, hence their removal is required before any wet processing can take place. Most sizing agents are starch-based, for reasons of economy and weaving performance. Starch and polymers being insoluble are converted into water soluble compounds in order to ease their removal. Sizing agents are mostly starch-based and resist dyes and chemicals. Starch and polymers (insoluble) are converted into their simple sugars or simple water soluble polymers to ease their removal.

Pakistan textile wastewater generation is around 51% annually. Due to lack of proper treatment of textile wastewater effluent untreated de-sizing wastewater is directly discharged into water bodies. This results in degradation of water quality and depletion of water resources. Severe damage is caused to aquatic life and ecosystems. Human health is also adversely affected as a result of this practice.

1.2. Objectives

Direct application of anaerobic processes in textile wastewaters treatment has been limited (Işik & Sponza, 2008). First objective included optimization of Upflow Anaerobic Sludge Blanket reactor treatment performance for de-sizing wastewater**.** Up flow anaerobic sludge blanket technology is a form of anaerobic digester used in wastewater treatment. UASB reactor is a methane-producing digester, which uses an anaerobic process, forming a blanket of granular sludge and is processed by the anaerobic microorganisms. UASB reactor is based on the three-phase separator enabling the reactor to separate gas, water and sludge mixtures under high turbulence conditions. A 3 phases (Gas-Liquid-Solid or GLS) separator located above the sludge blanket is required to separate the solid particles from the mixture (gas, liquid, and solid) after treatment and allowing liquid and gas to leave the UASB reactor. The influent is pumped to the UASB reactor from the bottom by Peristaltic pump. It moves upwards and comes into contact with a high concentration of biomass in the sludge bed. It then continues to move upwards and the remaining substrate contacts with the biomass again in the sludge blanket having a less dense biomass concentration as compared to the sludge bed below. Afterwards the treated wastewater is collected by the effluent collection system. The biogas generated is collected as a valuable fuel. UASB is a technology having many advantages. First of all no primary settling is required before UASB. This technology is compact and has lesser area requirements. Mechanical parts are not required making it a favourable treatment technology. A major advantage is that up to 90% COD reduction can be achieved. UASB has low sludge production and thus infrequent de-sludging is required. It can withstand high organic loading rates such as those up to 10kg BOD/m^3/d. Lastly, due to UASB employing anaerobic process biogas is produced which may be captured and used as an energy source.

Second objective involved designing a Lab scale Anaerobic Moving Bed Biofilm reactor. Lastly we aimed to optimize the treatment performance of An-MBBR for de-sizing wastewater. The anaerobic moving bed biofilm reactor retains appropriate microbiological community in the system by biofilm development on carrier elements or “media” (i.e. polyethylene) to aid in biofilm growth known as an **attached growth process**. Microorganism growth occurs on moving solid carriers resulting in formation of stable biofilm/fixed film. The carriers used are usually made up of polyethylene with a density closer to 1 g/cm3 which allows them to move freely even with 70 % of the volume occupied by carriers in a reactor (Metcalf & Eddy, 2013). An optimal contact time is allowed between biomass and substrate. The characteristics of the carrier material such as the specific area, filling fraction *(volume of carrier in empty reactor)*, surface roughness, porosity, strength, and durability determine the capability of biomass attachment and the treatment efficiency of An-MBBR. It is a stable system that could be cost-effective under highly variable industrial loads. An optimal contact time is allowed between biomass and substrate. In order to retain the media in suspension, mechanical mixing is employed in anaerobic configurations. The influent is pumped to the Anaerobic moving bed bioreactor from the bottom by Peristaltic pump. The reactor is filled with anaerobic sludge to promote anaerobic digestion along with polyethylene media. The influent moves upward and comes into contact with the carriers. Mechanical mixing within the reactor is provided within the reactor to keep the carriers in suspension. After the biofilm development on media, treated wastewater will move upwards and is collected within the effluent tank. Biogas generated is collected in the tyre tube connected to the reactor. It has a high treatment efficiency compared to other technologies as the An-MBBR media upon which the biofilm develops is physically retained in the system while UASB granules may disintegrate or float under high loads, leading to washout and significant loss in the treatment capacity (Lu et al., 2015). Therefore, when treating highly variable influent An-MBBR would be preferred. It has low capital, operational, maintenance and replacement cost as the whole treatment process could be achieved within a single reactor. Hence, a smaller area is required for its operation. As An-MBBR has reduced sludge production so sludge recycling is not required and hence there are no problems such as sludge bulking.

2. LITERATURE REVIEW

2.1 Literature Review for UASB

The first relevant literature we came across during our literature review was titled:
Treatment of textile dyeing wastewater using two-phase pilot plant UASB reactor with sago wastewater as co-substrate. (M.Senthilkumar, G.G. 2011)

The purpose of this study was found to be the decolourization and removal of degradable organics using tapioca sago wastewater as a co-substrate in a pilot scale two-phase Upflow Anaerobic Sludge Blanket (UASB) reactor. Findings from this study are listed as follows:

- Maximum COD and color removal efficiency achieved was 88.5 and 91.8% respectively at 24 h HRT at optimum mixing ratio 70:30
- Maximum biogas production was 312 L/d at a rate of 0.42 L Biogas/g COD for a mixing ratio of 70:30
- Optimum OLR was 5.6 kg COD/m^3 d from different OLRs with respect to mixing ratios
- VFA/alkalinity ratio at optimum mixing ratio was 0.04 which indicates that the reactor is under stable condition

From these findings we realized maximum efficiency was observed at 24 hrs H.R.T and hence we employed this parameter in our operating parameters. Similarily VFA/alkalinity ratio was preferred at 0.04 which we also incorporated in the operating parameters.

The second literature under observation was the study of effect of temperature on biodegradation of textile dyeing effluent using pilot scale UASB Reactor (G.Gnanapragasam, V.A. 2016)

The purpose of this research was to study the effects of varying temperatures in order to check COD removal efficiency and biogas production at a fixed HRT utilizing an Upflow Anaerobic Sludge Blanket Reactor (UASB). The findings of this study are as follows:

- COD and color removal efficiency of 97% and 96% respectively were obtained at 45°C at 24 hr HRT.
- Volatile fatty acid and alkalinity ratio was under control and the reactor was operated at stable conditions.
- Maximum production of biogas was about 0.512 m3 /d.

From this literature we again observed maximum removal efficiency at a fixed H.R.T of 24 hrs which further solidified this operating parameter.

The third literature was titled:

UASB reactor startup for the treatment of municipal wastewater followed by advanced oxidation process

(Z.A. Bhatti, F.M. 2013)

The purpose of this study was lowering the HRT from 48hr to 24hr by addition of nutrients to achieve maximum removal efficiency in a UASB rector.

The results obtained are stated as follows:

- This treatment process was successful to reduce the COD by 99%
- Total Suspended Solids (TSS) by 73%
- Total Nitrogen (TN) by 84%
- Turbidity by 67%

2.2 Literature Review for An-MBBR

First literature we came across which we considered to be the most relevant to our project was titled Industrial Wastewater Treatment With Anaerobic Moving Bed Biofilm Reactor: *(Alessandro di Biase. 2016)*

The purpose of this study was to observe the development and optimization of the moving bed biofilm reactor technology under anaerobic conditions

The findings of this study are shown in table 2.2(a)

	Parameter	Unit	Minimum	Maximum	Average
Effluent	pH		6.7	7.3	7.0
	Alkalinity	$kgCaCO_3$	1.3	2.0	1.6
	TSS	$kgTSS/m^3$	0.1	0.8	0.3
	VSS	$kgVSS/m^3$	0.1	0.8	0.3
	sCOD	$kgsCOD/m^3$	0.1	1.8	0.7
	TCOD	$kgTCOD/m^3$	0.3	2.6	1.1
	BOD_5	$KgBOD_5/m^3$	0.2	2.0	0.9

Table 2.2 (a) An-MBBR Literature Findings

Anaerobic treatment of winery wastewater in moving bed biofilm reactors

(*Sheli Chai, J.G., et al.,2014)*

The purpose of this study was to check the OLR and COD removal efficiencies with varying HRT.

The findings of this study are shown in table 2.2 (b).

Parameters	Values	
HRT (day)	1.55	2.49
COD (%)	80	80
OLR (gCOD/Ld)	29.59	18.43

Table 2.2 (b) An-MBBR Findings at Varying OLR

Another literature we observed was titled:

Performance and design considerations for an anaerobic moving bed bio-film reactor for treating brewery wastewater: Impact of surface area loading rate and temperature

(A. di Biase, T.R.D., et al., 2015)

The purpose behind this study was variation of parameters such as temperature H.R.T. and media fill in an An-MBBR to check treatment efficiency. Hydraulic retention time was varied considering HRT at 24, 18, 12, 10, 8 and 6 hrs at media fill of 40% and temperature 35^{o}C. Temperatures were varied at 15, 25 and 35^{o}C at 50% media fill and 18hr HRT.

The findings are stated as follows:

› Best performance was observed at 35^{o}C temperature, 40% media fill when HRT was 18hours. This corresponded with 92% removal of soluble COD (sCOD).

› Even though biomass concentrations were higher at lower temperature, the bio-film acclimated to 25^{o}C and 15^{o}C performed significantly slower than that acclimated to 35^{o}C.

3. MATERIALS & METHODS

Details of materials and methods used during this research are briefly explained in this chapter. This include reactor design and operational procedure, feed solutions, sample preparation, analysis techniques performed and equipment specification used.

3.1 Feed Solutions

3.1.1 Synthetic Wastewater Preparation

Synthetic textile wastewater was prepared duplicating the samples tested from real textile effluent. All laboratory synthetic feeds were prepared using fresh tap water, dyes, major organics and trace additives. The synthetic feed is stable and soluble in water. The COD: N: P ratio of feed is 100: 10: 1 which is essential for biomass growth.

Sr. No.	Parameter	Units	Value
1.	Chemical Oxygen Demand (COD)	mg/L	8000
2.	Sulfate	mg/L	900
3.	Conductivity	µS/cm	11582
4.	pH	-	11.57
5.	Oxidation Reduction Potential (ORP)	mV	-105.9
6.	Total Phosphate (TP)	mg/L	11.04
7.	Total Nitrogen	mg/L	77.66

Table 3.1.1 (a): Composition of De-sizing Wastewater

Source: Kohinoor Mills, Kasur

The synthetic substrate was prepared everyday where concentrated synthetic feed of 125 mL was diluted in 12 L of tap water. Addition of sodium bicarbonate ($NaHCO_3$) was done to maintain suitable buffering in reactor. Usually 0.5g of $NaHCO_3$ as $CaCO_3$, per 2g of COD was added. Three trace elements were added in feed according to Metcalf & Eddy, (2003).

Sr. No.	Chemical	Units	Amount	Reference
1.	Glucose	Grams (g)	480	Metcalf & Eddy, (2003)
2.	Ammonium Chloride	Grams (g)	300	
3.	Monopotassium Phosphate	Grams (g)	40	
4.	Magnesium Sulfate	Grams (g)	0.5	

5.	Calcium Chloride 2-Hydrate	Grams (g)	0.25	
6.	Zinc Chloride	Grams (g)	0.25	
7.	Cobalt Chloride	Grams (g)	0.25	

Table 3.1.1 (b): Composition of Synthetic Wastewater

3.2 Sample Preparation

Mostly the samples are analyzed immediately after being withdrawn from reactor.

3.3 Sample Analysis

To determine the reactor performance, several parameters are frequently analyzed in laboratory. All parameters are analyzed on daily basis for UASB and An-MBBR at 16, 20 and 24 hours Hydraulic Retention Time (HRT).

Effluent samples were analyzed for COD, VFA, pH, ORP, alkalinity, Total Phosphates,TKN and orthophosphates.

COD of influent and effluent samples was determined using closed reflux colorimetric method using COD digestor which digests the COD viols at 120 – 150^{o}C temperature. The COD viols were prepared using 100 dilutions and H_2SO_4 and $K_2Cr_2O_4$ as reagents and 2.5 ml of sample and then digested viols were cooled to room temperature and titrated against ferrous ammonium sulfate (FAS) solution to get the COD concentration in effluent.

VFA and Alkalinity were titrimetrically determined using 0.02N H_2SO_4 solution for 20 ml effluent sample for determination of alkalinity and 0.1N NaOH for determination of VFA in effluent. These parameters are determined once a week whose accuracy is dependent on sample characteristics and is done to estimate the reactor efficiency.

pH was determined using pH meter (OAKTON 300 series) using glass pH probe which is always dipped in 0.1M KCl solution. pH probe was calibrated once a week using 4.00, 7.00 and 10.00 buffer solutions. pH measurements are made as soon as samples are withdrawn from reactor with little or no agitation to minimize the loss of carbon dioxide. Frequent pH measurements were done to monitor the efficiency of reactor system, because changes in pH value towards the acidic range indicates potential imbalance of methanogenic or facultative acidogenic bacterial activity. A sharp drop in pH also indicates the accretion of volatile acids and less alkalinity production hampering buffer capacity of reactors.

TKN (Total Kjeldahl Nitrogen) was measured using the Kjeldahl apparatus, using 25 ml of prepared sample, adding 50 ml of distilled water and 12.5 ml of digestion reagent with glass beads and put to digestion chamber at 300 -400ºC. After cooling the sample, pH is adjusted in alkaline range using $NaOH-Na_2S_2O_3$ reagent. Dilute the sample with distilled water and add phenolphthalein indicator. Place the sample in distillation stand and connect with condenser whose tip is inserted in 50 ml of boric acid solution. As the ammonia gets absorbed in boric acid, the solution changes its color. Titrate against 0.02N of H_2SO_4 acid for quantifying the amount of ammonia in effluent sample

Orthophosphate concentration was measured by adding 1 ml of Vanadate-molybdate reagent in 5 ml of prepared sample and measures the concentration using UV-Vis spectrophotometer at 470nm absorbance.

Sr. No.	Parameter	Testing Methodology	Reference
1.	Chemical Oxygen Demand (COD)	Close Reflux Titration Method	APHA (2012) Standard Methods for the Examination of Water and Waste Water
2.	Total Phosphate (TP)	Spectrophotometric Method	
3.	Total Nitrogen (TKN)	Kjeldahl Distillation Method	
4.	pH	pH Meter	
5.	Oxidation Reduction Potential (ORP)	ORP Meter	
6.	Volatile Fatty Acids (VFA)	Titration	
7.	Alkalinity	Titration	
8.	Ammonia Nitrogen	Distillation Method	

Table 3.3 Summary of parameters analyzed during experimental study

3.4 Start-up and Acclimatization Phase

Aerobic sludge was obtained from full scale membrane bioreactor (MBR) plant. This aerobic sludge was blended with 0.5 L of fresh cow dung as seed sludge, 2g of glucose and 0.5g of $NaHCO_3$. The sludge was mixed and put in incubator at 35ºC. Scum, live worms and dead microbes were removed at 48 hrs HRT with effluent discharge and addition of fresh feed. The sludge was placed in air tight jars and flushed with nitrogen gas N_2 to remove oxygen bubbles to maintain strict anaerobic conditions. The reactor content was mixed during last 5 minutes of flushing to enhance the removal of dissolved oxygen. The reactor was mixed daily for complete substrate and microbial connection.

3.5 Experimental Design and Setup

The experimental study was conducted in Water and Wastewater Lab in Institute of Environmental Sciences and Engineering, NUST, Pakistan by setting up a laboratory scale UASB reactor with working volume of 10.87 L and An-MBBR with working volume of 10L.

3.5.1 UASB Reactor Configuration and Fabrication

One UASB reactor was used for conducting our research. This reactor was manufactured prior to our project for the treatment of textile wastewater. The dimensions and descriptive schematic diagram of reactor section and plan view is shown in Figure 4 & 5. The reactor was constructed by Acrylic Arts, Lahore under the engineering supervision of 3W systems, Lahore using acrylic sheet and were cylindrical in shape with cone shape bottom. The reactor was 24.4 inches in height and 6.2 in internal diameter. The total volume of reactor was 10.87 L of which 9.978 L was working volume and the remaining 0.89 L was occupied by GLSS in head space of reactor.

Eight sampling ports were installed at 100 mm interval along the length, from the bottom of reactor for feeding, wasting and sampling. Reactor had two other ports above the hopper at top of reactor at 50 mm interval installed in opposite directions. The top most was effluent port while the other below was used for effluent recirculation. All the ports were 7 cm (2.75 inches) long with 1 cm (0.4 inches) internal diameter and were made of stainless steel tubes. The ports were reinforced by stainless steel connectors, ball valves and threaded nipples.

The influent port of 2.75 inches length and 0.4 inches internal diameter was steel-clad with isolation valve placed vertically at the bottom of reactor. The influent enters in the reactor from the bottom conical shape funnel with upper diameter of 52 mm. The top of reactor was fitted with plate having same outside diameter of 230 mm (9 inches) as blind flange of reactor. The plate and blind flange was 0.4 and 0.5 inches thick respectively. The blind flange has eight, 0.39 inches holes in which stainless steel butterfly bolt and nuts were used to fasten the reactor into single reactor. A 0.12 inch thick rubber gasket was used in between flange and top plate to ensure air and leak proof seal.

The top plate of reactor has three holes. The middle hole has diameter of 0.47 inches containing a port reinforced with stainless steel connectors, ball valve and thread nipples. This hole is further connected to an acrylic dome used as Gas-Liquid-solid separator inside the reactor. The bottom of funnel shape dome has diameter of 100 mm (4 inches) taking 4.4 inches length from the top of reactor. The dome is curved at 45^{o} leaving a space of 25 mm from the walls of reactor. Below GLSS dome is the 0.98 inches thick cylindrical hopper made of acrylic sheet is tilted at 45^o. This is used for the retention of scum or suspended solids from escaping into the effluent. The other two holes on either side of middle hole on top plate are pressure relief valves to release the pressure exerted by the production of biogas.

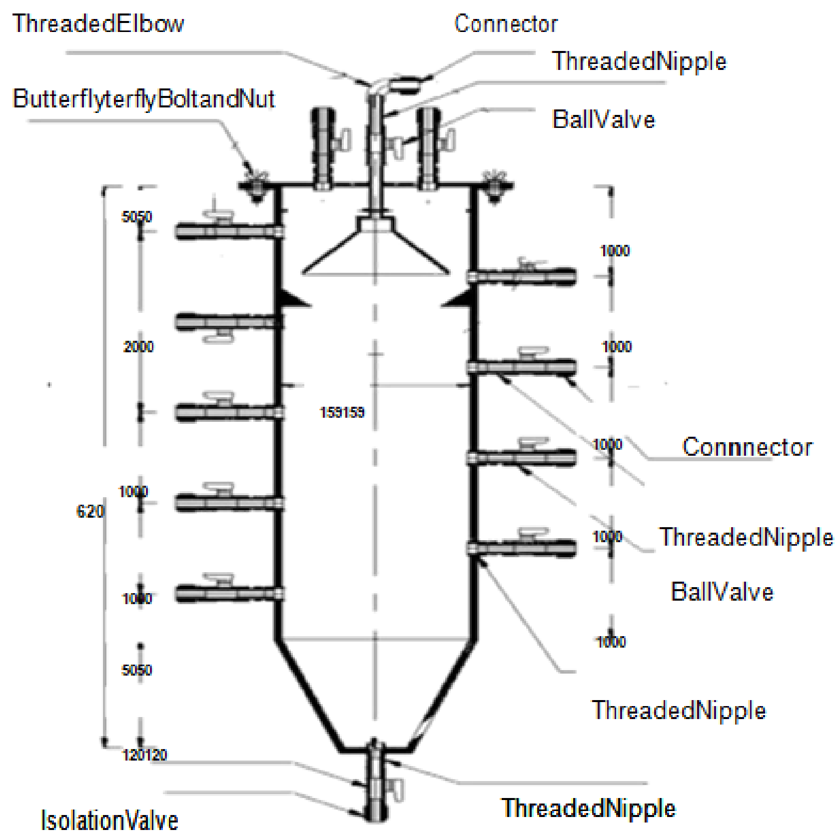

Figure 3.5.1(a): Cross sectional view of UASB reactor

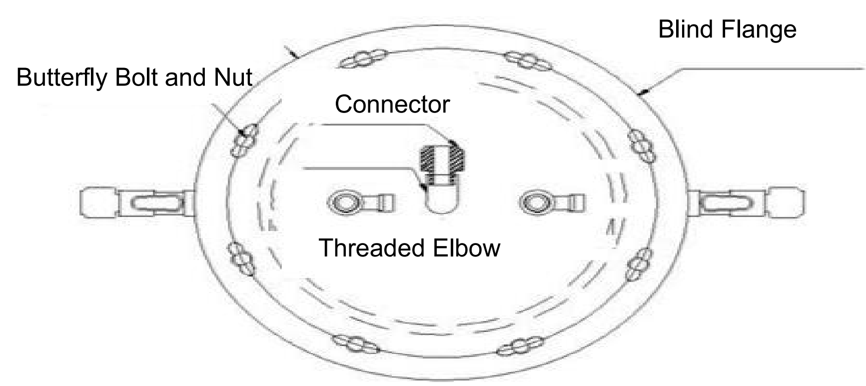

Figure 3.5.1 (b): Top view of UASB reactor

3.5.2 An-MBBR Reactor Configuration and Fabrication

The dimensions and descriptive schematic diagram of reactor section and plan view is shown in Figure 3.5.2.The reactor was 8.74 inches in diameter and 12.2 in height. The total volume of reactor was 12 L of which 10 L was working volume and the remaining 2L was occupied by GLSS in head space of reactor.

Four sampling ports were installed along the length, from the bottom of reactor for feeding, wasting and sampling. Reactor had three other ports at top of reactor installed in opposite directions. One was a mixer port, biogas port and an extra port to allow for temperature sensor later on in experimentation if required. A port was installed to allow for effluent recirculation if necessary. The ports were reinforced by stainless steel connectors, ball valves and threaded nipples.

The influent enters in the reactor from the bottom where a pipe is provided inside reactor with perforations at equal intervals to allow for equal distribution of influent inside the reactor. The top of reactor was fitted with plate having same outside diameter as that of reactor.

The top plate of reactor has three holes. The middle hole has diameter of 0.47 inches containing a port reinforced with stainless steel connectors, ball valve and thread nipples. Another port is provided parallel to the influent port that allows us to drain reactor easily when necessary and can also be used in re-circulation when required. Table 3.5.2 shows detailed design parameter for our setup. The reactor was manufactured from Murree Road Rawalpindi using acrylic sheet and was cylindrical in shape.

Sr No	Parameter	Units	Value
1	Diameter of the Tank	Inches	8.744
2	Height of the Tank	Inches	12.2
3	Volume of the Tank	Liters	12
4	Diameter for effluent port located 2’’ below from top	Inches	0.5
5	Diameter for extra port located 1'' from bottom	Inches	0.5
6	Diameter for influent port located 0.5’’ from bottom	Inches	0.5

7	Diameter for biogas port located 2.19'' horizontally on top	Inches	0.5
8	Diameter for the recirculation port located 4'' below from top	Inches	0.5
9	Diameter for extra port located 6.56'' horizontally on top	Inches	0.5
10	Diameter for mixer port located 4.372'' horizontally on top	Inches	0.39
12	Mixer Speed	rpm	20
13	Length of Mixer	Inches	8.13
14	Length of Perforated Pipe	Inches	8.744
15	Distance of Perforations	Inches	0.75
16	Diameter of connectors	Inches	0.4
17	Diameter of biogas port connector	Inches	0.3
18	Diameter of Perforations	Inches	0.2
19	Diameter of tank Lid	Inches	10

Table 3.5.2: Detailed Design Parameters

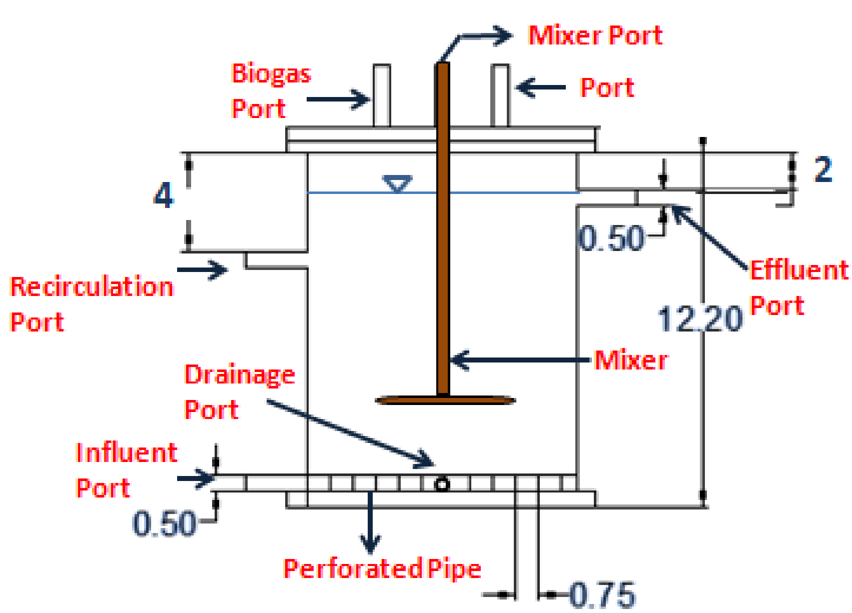

Figure 3.5.2 (a) Cross-sectional View of An-MBBR Setup

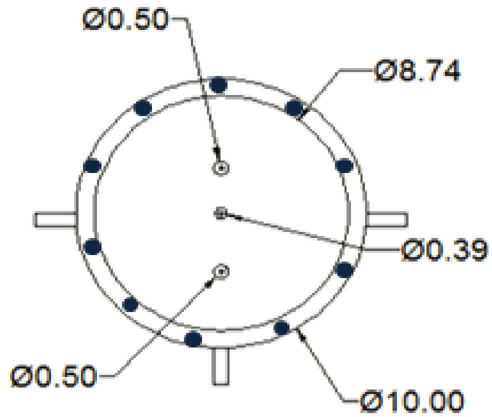

Figure 3.5.2 (b) Top View of An-MBBR Setup

3.6 Setup Installation

3.6.1 UASB Installation

The influent is pumped to the UASB reactor from the bottom by Peristaltic pump. It moves upwards and comes into contact with a high concentration of biomass in the sludge bed. It then continues to move upwards and the remaining substrate contacts with the biomass again in the sludge blanket having a less dense biomass concentration as compared to the sludge bed below. Afterwards the treated wastewater will be collected by an effluent collection system. The biogas generated will either travel to biogas counter or be stored in biogas collection bags. Figure 3.6.1 shows schematic of UASB.

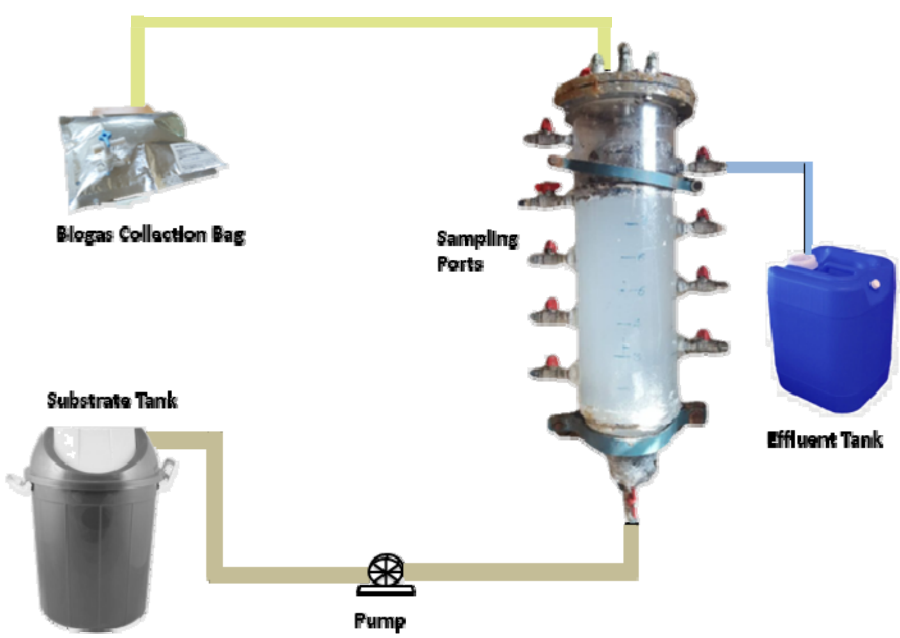

Figure 3.6.1 Schematic for UASB

(Source: Young Hu et al., 2015)

3.6.2 An-MBBR Installation

The influent is pumped to the Anaerobic moving bed bioreactor from below by Peristaltic pump. The reactor is filled with anaerobic sludge to promote anaerobic digestion along with polyethylene media. The influent moves upward and comes into contact with the carriers. Mechanical mixing within the reactor is provided to keep the carriers in suspension. Afterwards treated wastewater will move upwards and be collected within the effluent tank. Biogas generated is stored in biogas collection bags.

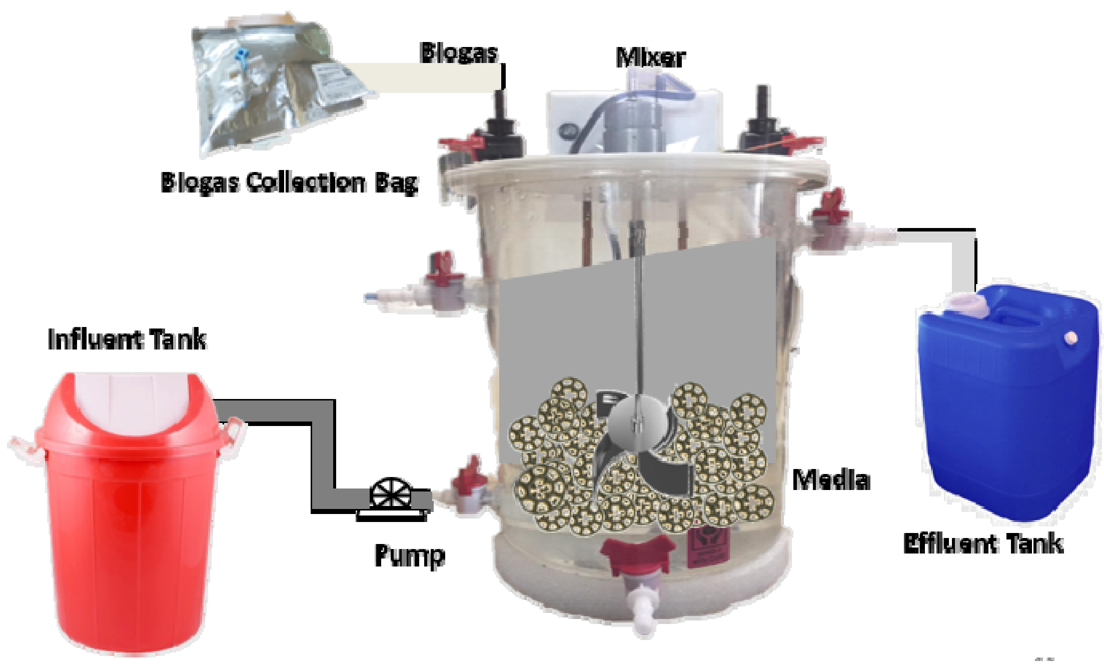

Figure 3.6.2 Schematic for An-MBBR

(Source: Biase, 2016)

3.7 Reactor Operation and Methodology

Both reactors were initially seeded with semi flocculent granular anaerobic sludge which was acclimatized from aerobic sludge obtained from full scale membrane bioreactor (MBR) plant installed at NUST, Islamabad and were initially operated at HRT of 16 hrs.

3.7.1 UASB Operation

Operational parameters for UASB are summarized in Table 3.7.1

Operating Parameters	Units	Values
Reactor Volume	Liters (L)	10.9
Working Volume	Liters (L)	10.8
Hydraulic Retention Time (HRT)	Hours (hr)	16, 20, 24
Organic Loading Rate	kg COD m^3/d	0.40-1.10
Up-flow Velocity	m/hr	0.5
Mixed Liquor Suspended Solids (MLSS)	mg/L	6000-7700
MLVSS/MLSS	-	0.6-0.7
VFA/Alkalinity	-	0.3-0.4
pH	-	6.8-7.2

Table 3.7.1 Operating Parameters for UASB

3.7.2 UASB Methodology

De-sizing wastewater was characterized and synthetic feed was prepared on regular basis as the system was continuous. The setup was acclimatized with anaerobic sludge and above mentioned operating parameters in table 3.7.1 were varied. Samples from influent and effluent ports were collected for testing.

3.7.3 An-MBBR Operation

Operating parameters for An-MBBR are shown in Table 8.

Operating Parameters	Units	Values
Reactor Volume	Liters (L)	12
Working Volume	Liters (L)	10
Hydraulic Retention Time (HRT)	Hours (hr)	16, 20, 24
Media Fill	%	50

Up-flow Velocity	m/hr	0.5
Organic Loading Rate (OLR)	kg COD m^3/d	0.40-1.10
Media Density	g/cm^3	0.98
VFA/Alkalinity	-	0.3-0.4
pH	-	7-8

Table 3.7.3 Operating Parameters for An-MBBR

3.7.4 An-MBBR Methodology

De-sizing wastewater was characterized and synthetic feed was prepared regularly. The setup was acclimatized with anaerobic sludge and above mentioned operating parameters in table 8 were varied. Samples from influent and effluent ports were collected for testing

4. RESULTS & DISCUSSION

4.1 Up-flow Anaerobic Sludge Blanket Reactor (UASB)

A total load of 8000 mg/L COD was applied for each continuous (feeding) and intermittent (non-feeding) combination at 16, 20 and 24 hrs HRT. This was done to optimize the adequate non-feeing (intermittent) period provided during the continuous operation of reactor. Acclimatization phase of UASB reactor lasted for one month until removal efficiency became constant. The length of each run was dependent on biomass adaptation to complex substrate in the feed and sludge characteristics.

Initially the reactor was operated with continuous feeding for 16 hrs HRT at input OLR of 2 kg COD/m^3-d . COD removal efficiency of 52.9% was achieved (Figure 8). High COD concentration in effluent was due to large suspended solids concentration in non-granulated anoxic sludge with low retention capacity. Gradual formation of granulated sludge leads to decrease in effluent SS concentration with improved removal rates. The delay in achieving maximum removal rates in lab scale UASB reactor demanded time for acclimatization of sludge to substrate. Initially, due to low acclimatization of sludge to influent substrate, the steady state was maintained for a week at low COD removal rates.

The experimental test results for UASB will be discussed in the following sections:

4.1.1 Chemical Oxygen Demand (COD)

The following graphs show COD removal over the course of 7 days at hydraulic retention time of 16, 20 and 24 hours.

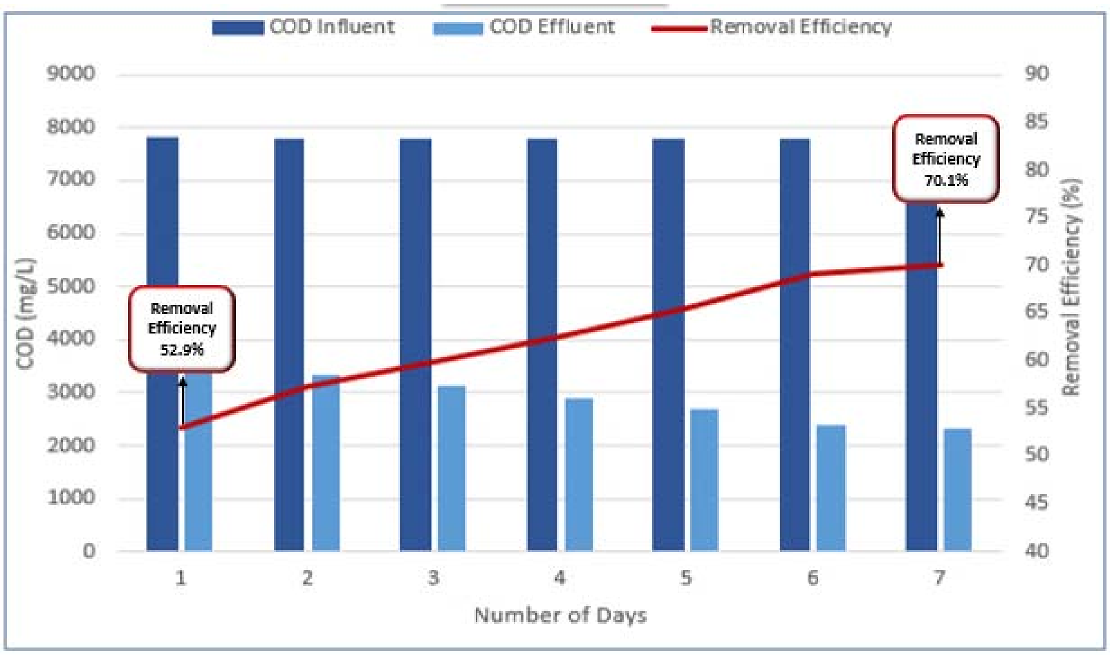

Figure 4.1.1 (a) COD Removal Efficiency at 16 Hour H.R.T.

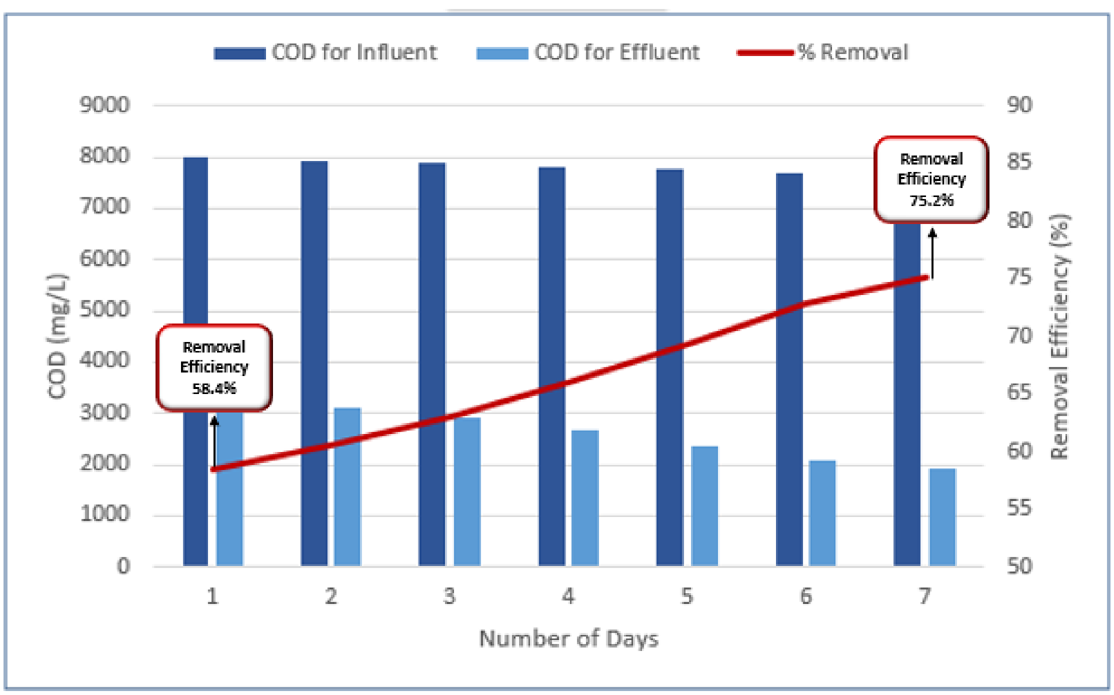

Figure 4.1.1 (b) COD Removal Efficiency at 20 Hour H.R.T.

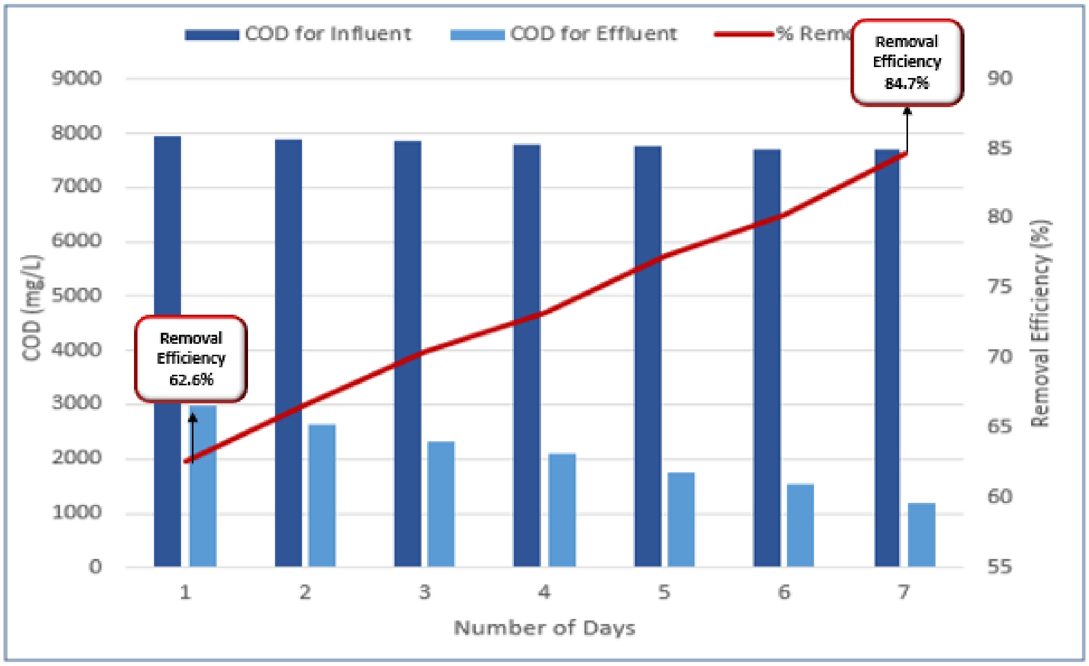

Figure 4.1.1 (c) COD Removal Efficiency at 24 Hour H.R.T.

4.1.2 Total Phosphorous (TP)

The following graphs depict Total Phosphorous removal over the course of 7 days at hydraulic retention time of 16, 20 and 24 hours.

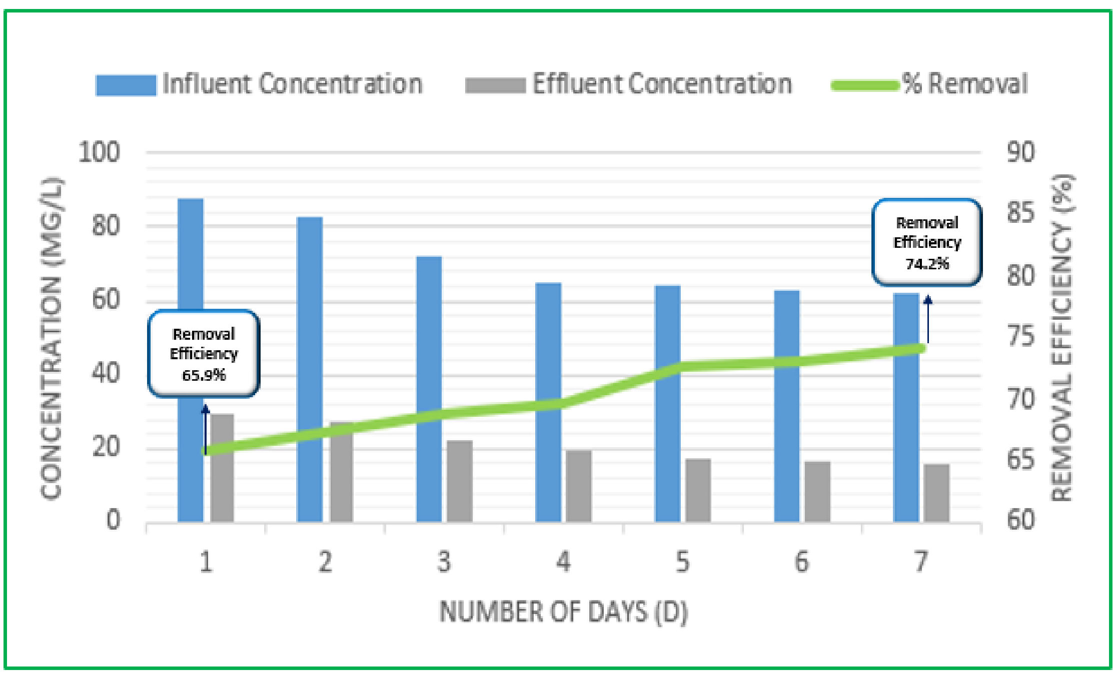

Figure 4.1.2 (a) TP Removal Efficiency at 16 Hour H.R.T.

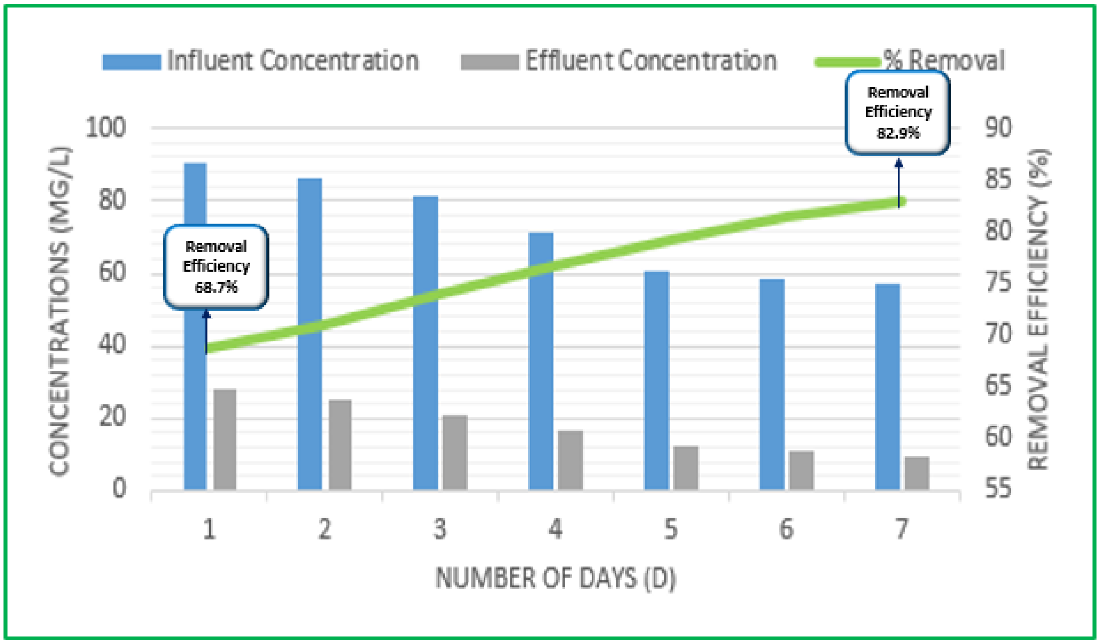

Figure 4.1.2 (b) TP Removal Efficiency at 20 Hour H.R.T.

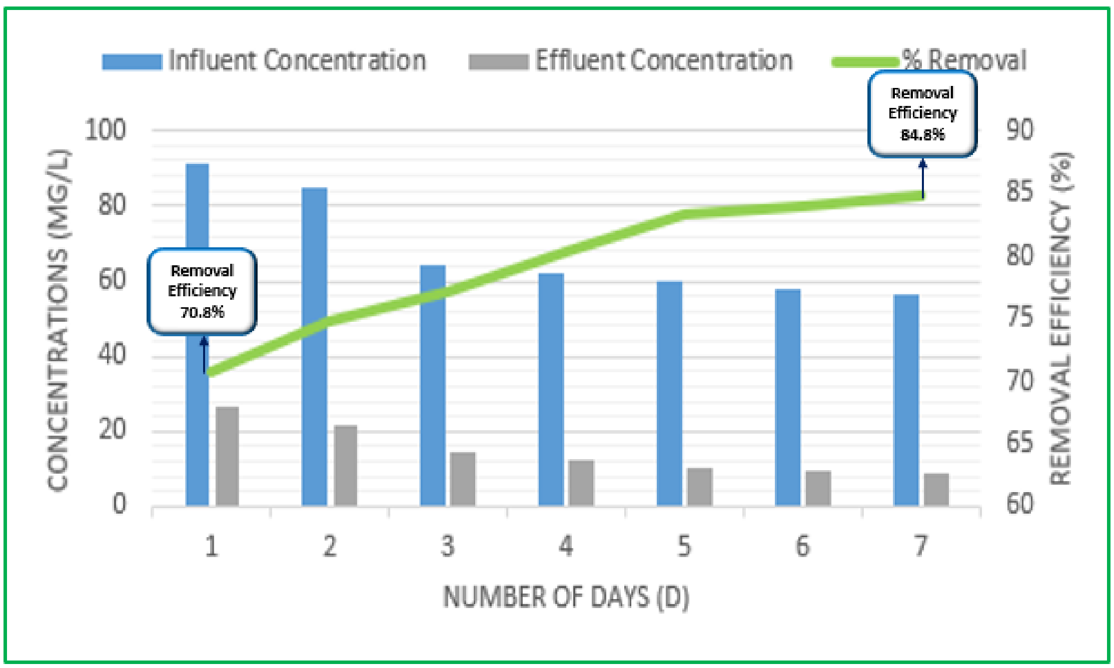

Figure 4.1.2 (c) TP Removal Efficiency at 24 Hour H.R.T.

4.1.3 Total Kjedahl Nitrogen (TKN)

The TKN removal over the course of 7 days at hydraulic retention time of 16, 20 and 24 hours are given in the following graphs.

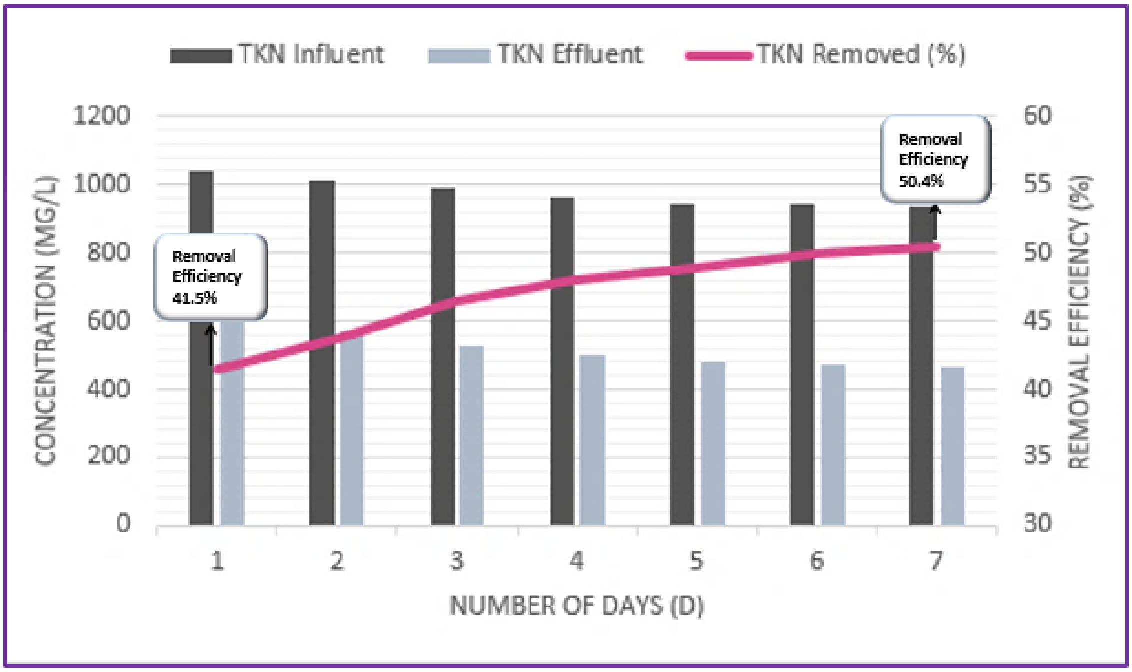

Figure 4.1.3 (a) TKN Removal Efficiency at 16 Hour H.R.T.

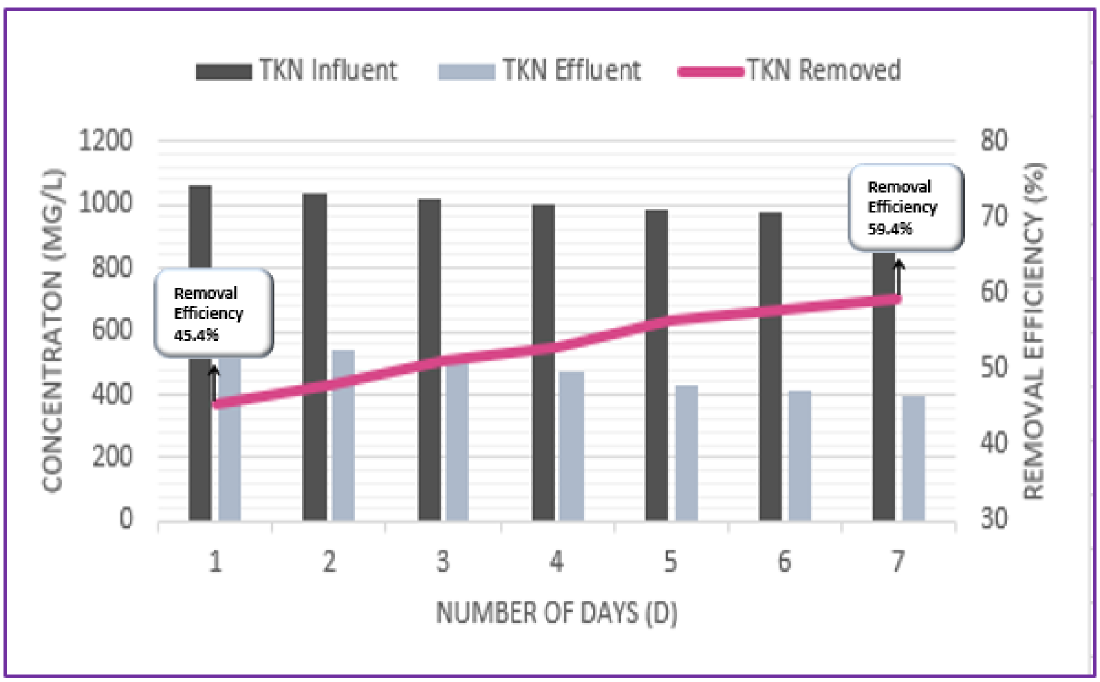

Figure 4.1.3 (b) TKN Removal Efficiency at 20 Hour H.R.T.

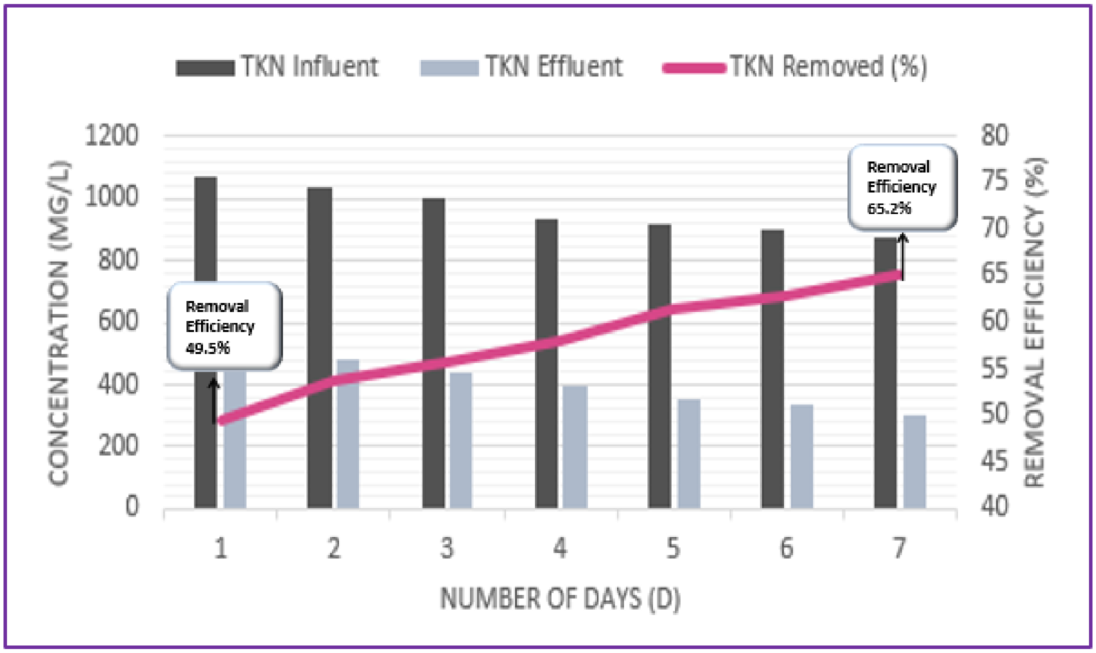

Figure 4.1.3 (c) TKN Removal Efficiency at 24 Hour H.R.T.

4.1.4 Ammonia Nitrogen

The graphical results for ammonia nitrogen over the course of 7 days at hydraulic retention time of 16, 20 and 24 hours are shown in the following graphs. Highest removal efficiency was observed at 24 hours H.R.T.

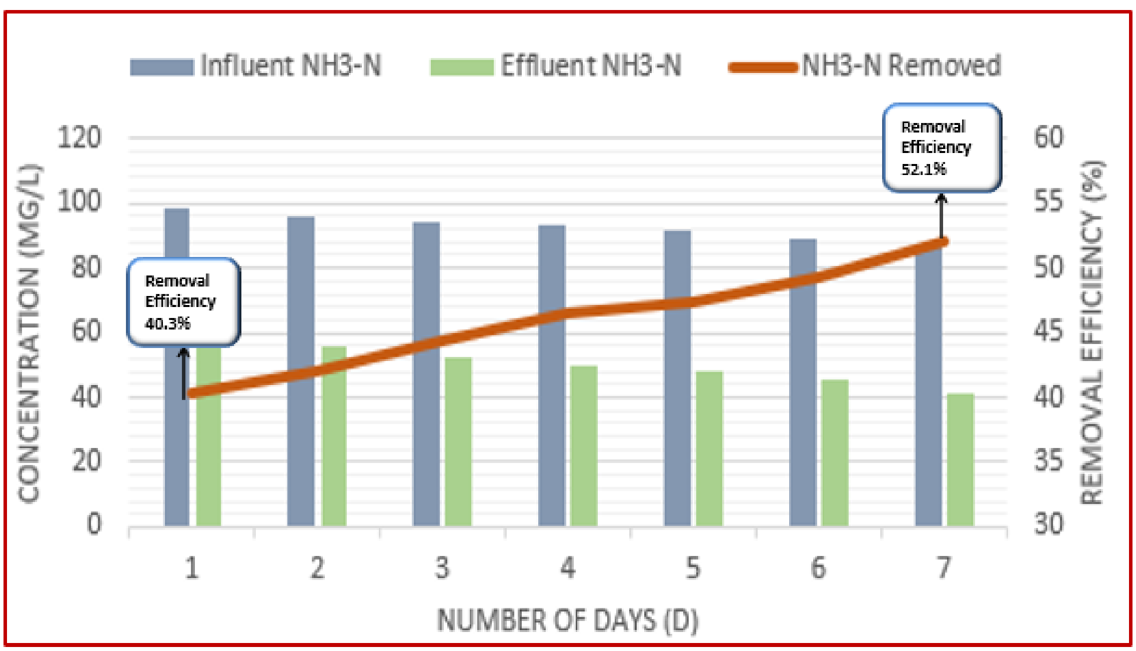

Figure 4.1.4 (a) AN Removal Efficiency at 16 Hour H.R.T.

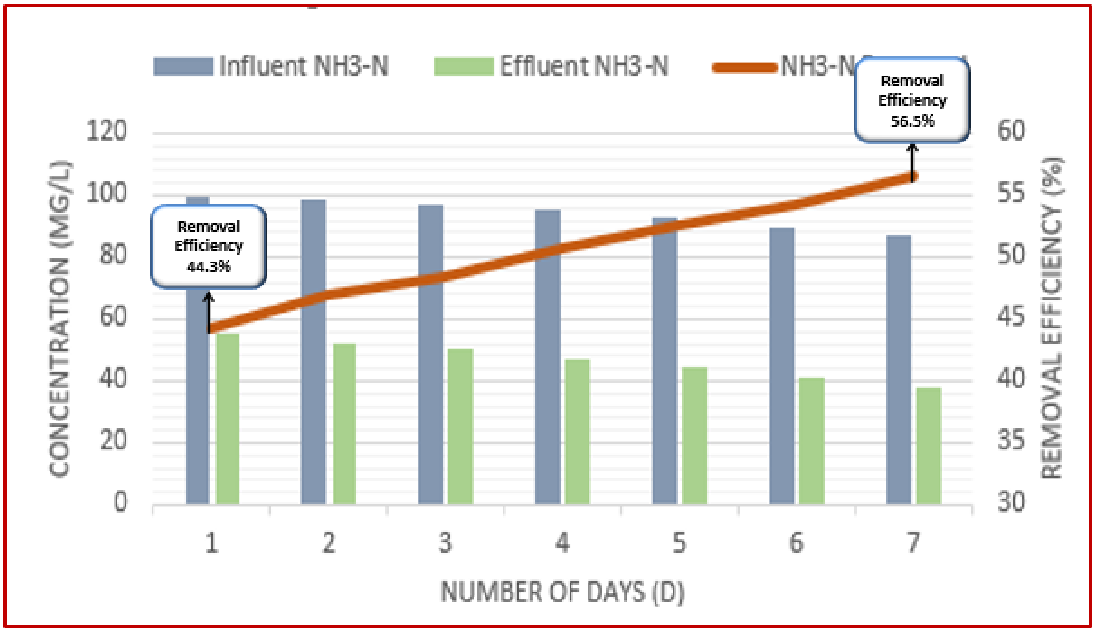

Figure 4.1.4 (b) AN Removal Efficiency at 20 Hour H.R.T.

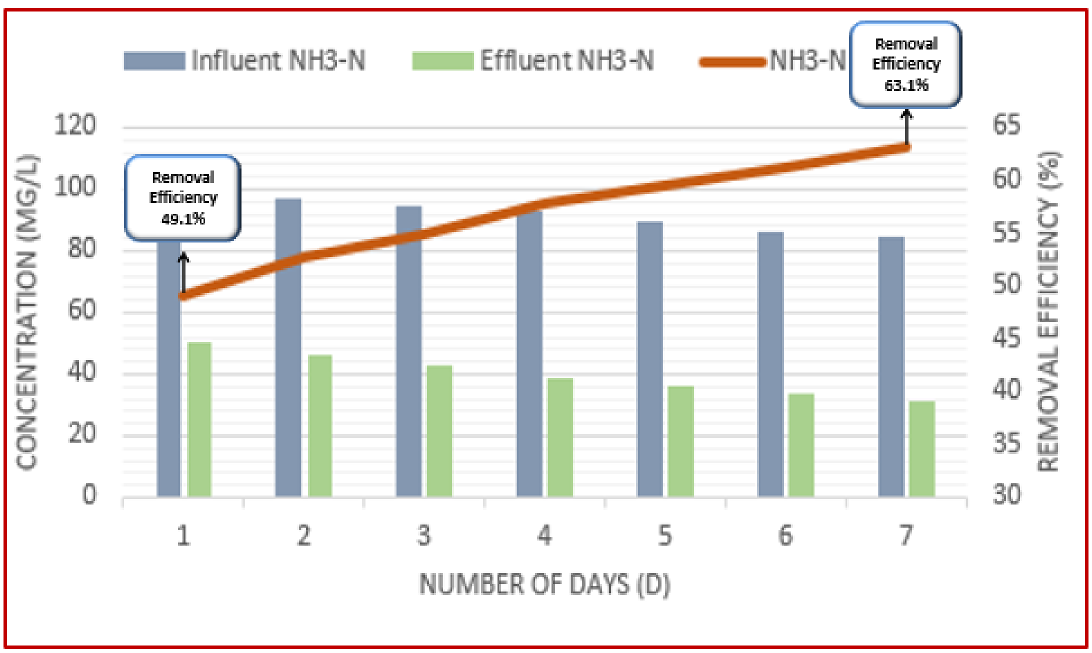

Figure 4.1.4 (c) AN Removal Efficiency at 24 Hour H.R.T.

4.1.5 Summary of Results for UASB

The following table depicts a summary of results from tests conducted on Up flow Anaerobic Sludge Blanket (UASB) Reactor.

Parameters	Units	Hydraulic Retention Time (H.R.T.)		
		16 (Hours)	20 (Hours)	24 (Hours)
Chemical Oxygen Demand (COD)	mg/L	2319	1907	1181
Total Phosphate (TP)	mg/L	10.96	9.77	8.61
Total Nitrogen (TKN)	mg/L	465.5	392	303.8
Ammonia Nitrogen (NH_3–N)	mg/L	41.7	37.8	31.1
Oxidation Reduction Potential (ORP)	mV	-152.3	-166.7	-169.6
Volatile Fatty Acids/Alkalinity	-----	0.35	0.37	0.38
pH	-----	6.2	6.6	7.1

Table 4.1.5 Results Summary for UASB

4.2 Anaerobic Moving Bed Bioreactor (An-MBBR)

A total load of 8000 mg/L COD was applied for each continuous (feeding) at 16, 20 and 24 hrs HRT. Continuous mixing was provided throughout reactor operation. Acclimatization phase of An-MBBR reactor lasted for three weeks until removal efficiency became constant. The length of each run was dependent on biomass adaptation to complex substrate in the feed and sludge characteristics. Polyethylene media was collected and placed in a container with anaerobic granular sludge to enhance microbial growth on media. Mixing provided has to be optimum to allow for contact between media and organic matter present in wastewater influent. Mixing cannot be too fast since that could cause media to detach from the microbial biofilm.

Initially the reactor was operated with continuous feeding for 16 hrs HRT. COD removal efficiency of 69.5% was achieved (Figure 20). High COD concentration in effluent was due to insufficient biofilm development at the early stages of reactor operation. Gradual biofilm development and sufficient agitation of media to contact with the substrate lead to a decrease in effluent suspended solids concentration with improved removal rates. The delay in achieving maximum removal rates in lab scale An-MBBR reactor demanded time for acclimatization of sludge to substrate.
The experimental test results for An-MBBR will be discussed as follows:

4.2.1 Chemical Oxygen Demand (COD)

The following graphs show COD removal over the course of 7 days at hydraulic retention time of 16, 20 and 24 hours. Initially the COD removal efficiency was observed to be 52.8% which later increased to 69.5%.

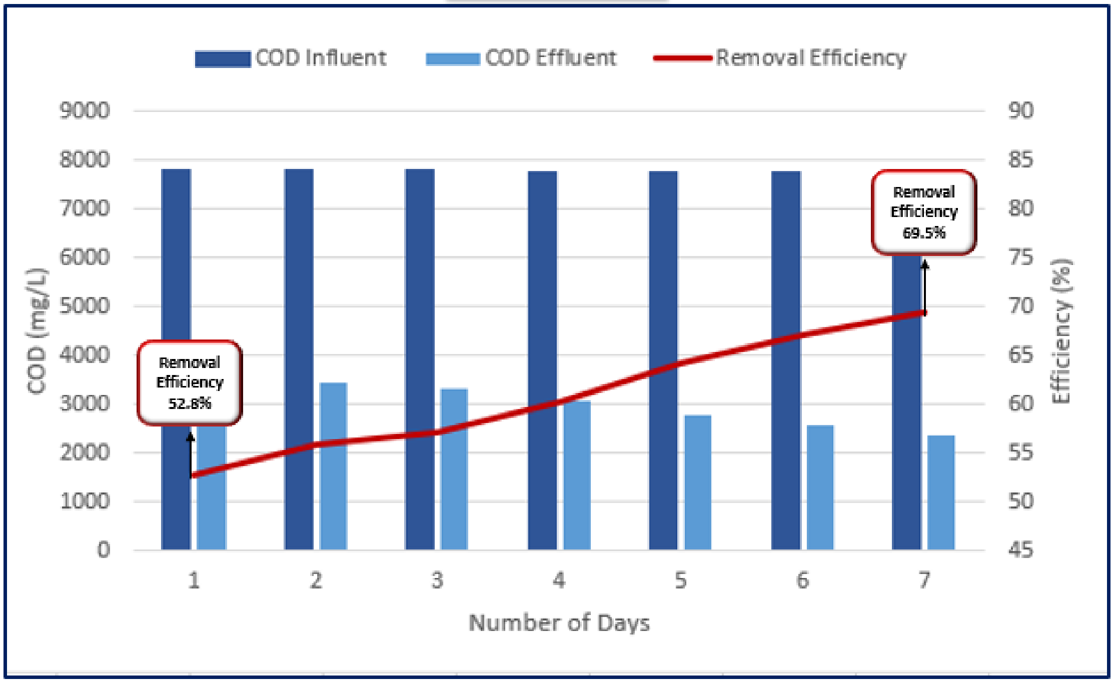

Figure 4.2.1 (a) COD Removal Efficiency at 16 Hour H.R.T.

As H.R.T. was increased from 16 to 20 hours H.R.T. an observed increase in COD removal efficiency occurred. Initially at 20 hours H.R.T. COD removal was 56.7% which later shifted to 79.2% removal efficiency. This is because a higher H.R.T. allowed for more contact time between biofilm and substrate allowing for microbial degradation.

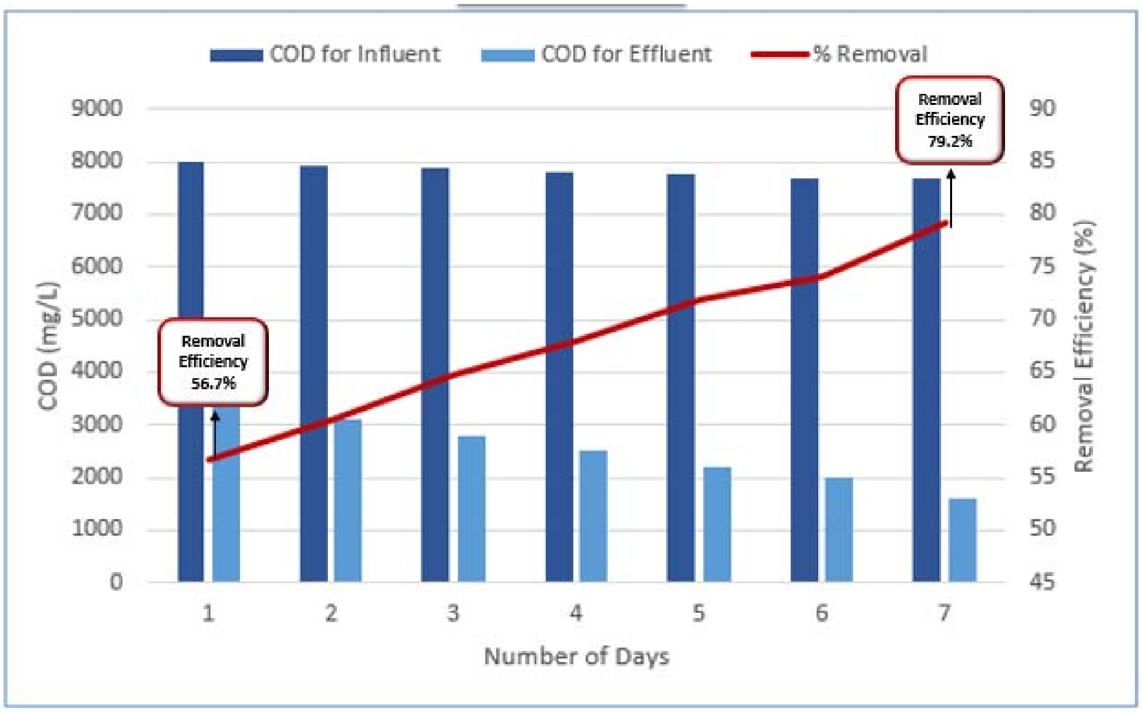

Figure 4.2.1 (b) COD Removal Efficiency at 20 Hour H.R.T.

At the highest H.R.T. value i.e. 24 hours highest COD removal efficiency was obtained (87.7%).

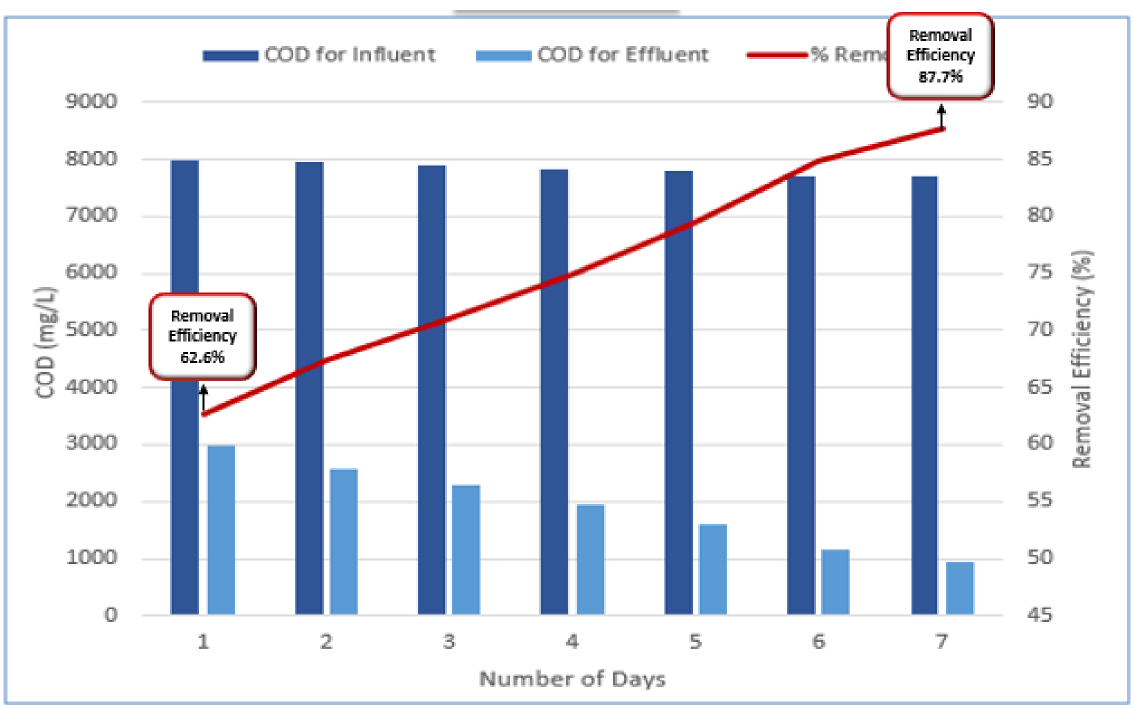

Figure 4.2.1 (c) COD Removal Efficiency at 24 Hour H.R.T.

4.2.2 Total Phosphorous

The following graphs depict Total Phosphorous removal over the course of 7 days at hydraulic retention time of 16, 20 and 24 hours. Initially the removal efficiency of total phosphorous was observed to be 66.9% which later increased with time to 78.2%.

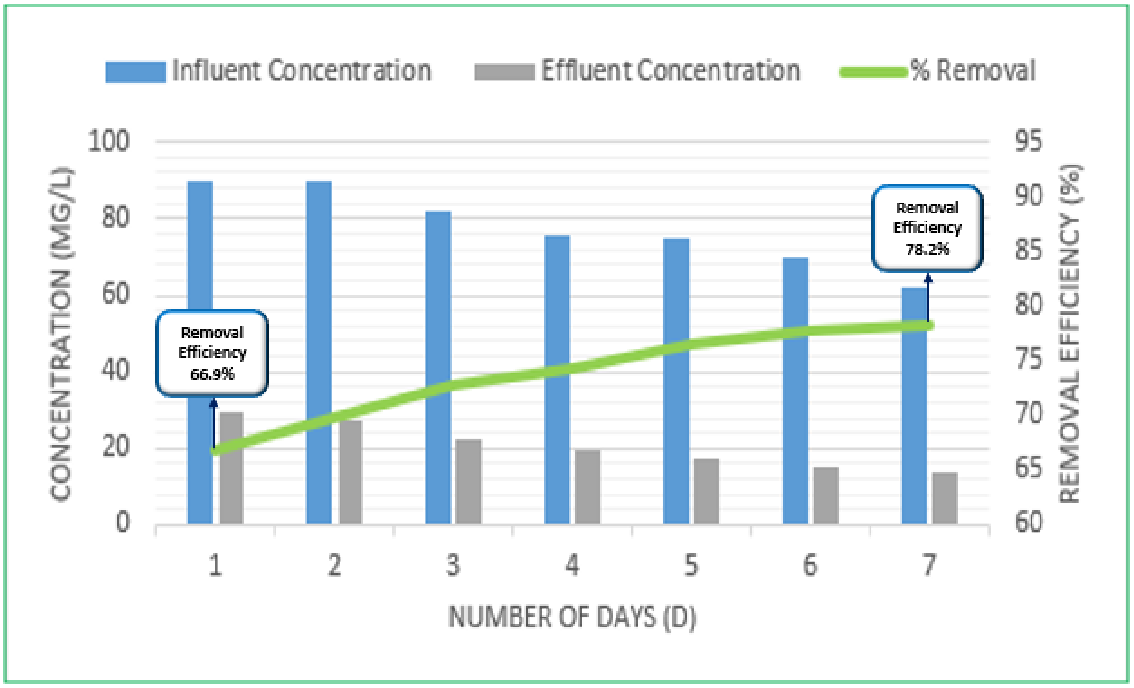

Figure 4.2.2 (a) TP Removal Efficiency at 16 Hour H.R.T.

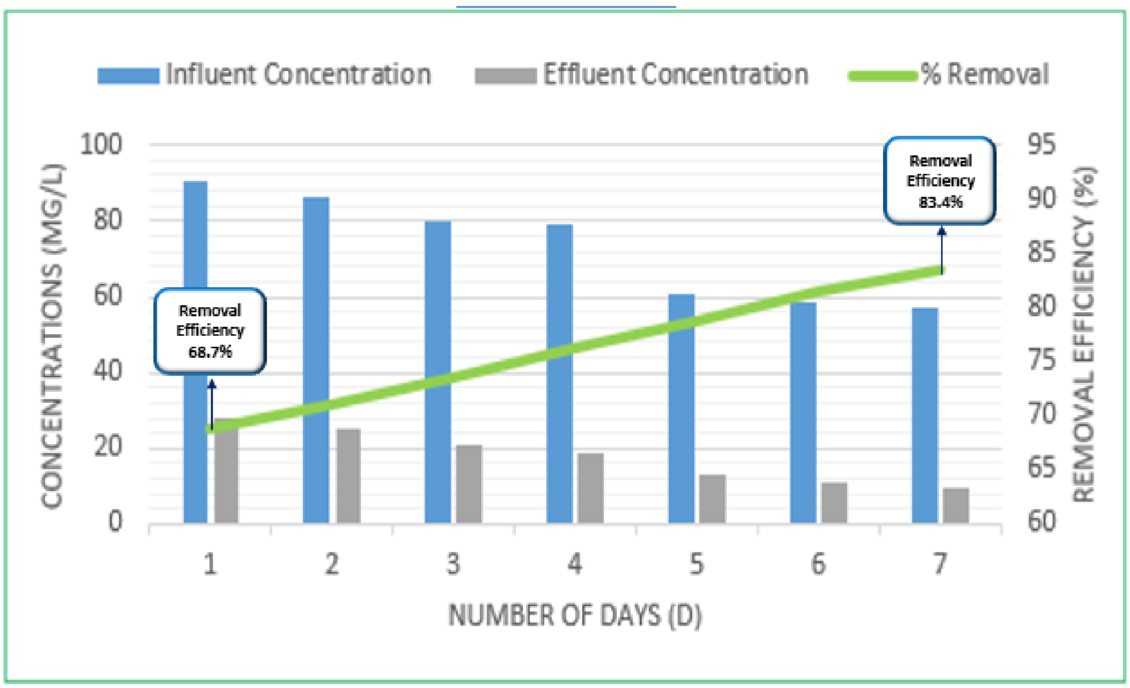

Figure 4.2.2 (b) TP Removal Efficiency at 20 Hour H.R.T.

Highest TP removal of (89.3%) was observed at 24 hours H.R.T.

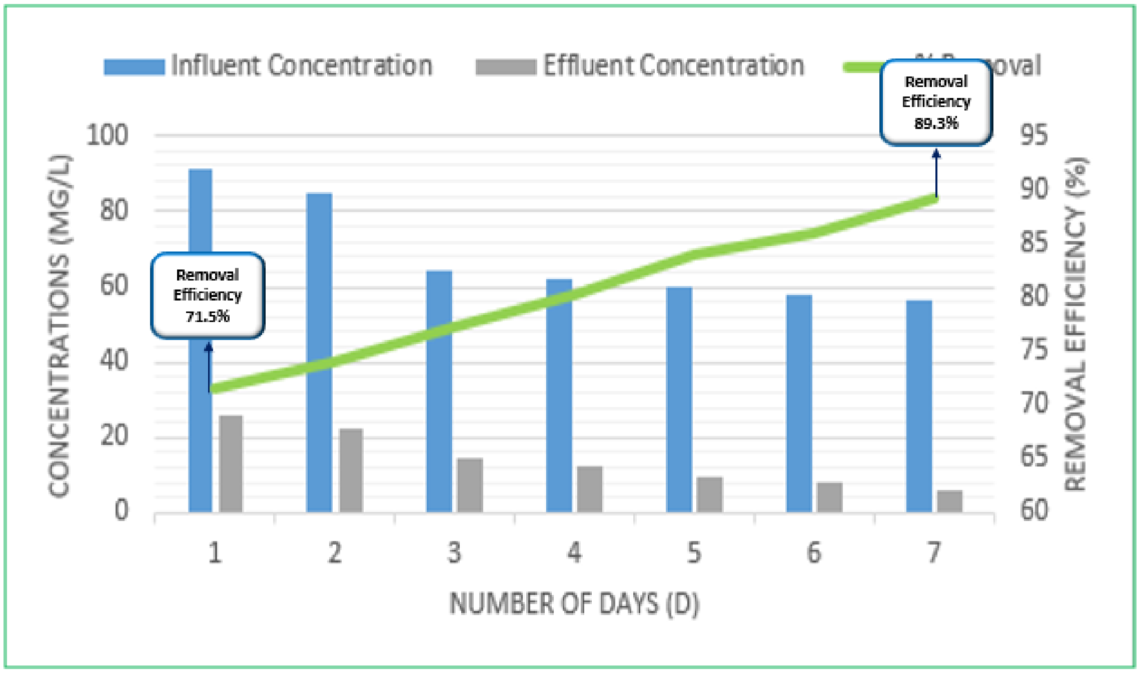

Figure 4.2.2 (c) TP Removal Efficiency at 24 Hour H.R.T.

4.2.3 Total Kjedahl Nitrogen (TKN)

The TKN removal over the course of 7 days at hydraulic retention time of 16, 20 and 24 hours are given in the following graphs. Initially the TKN removal was low (42.1%) at 16 hours H.R.T. but with time it increased to 55.1%. Changing H.R.T. also resulted in an increased in the removal rates of TKN.

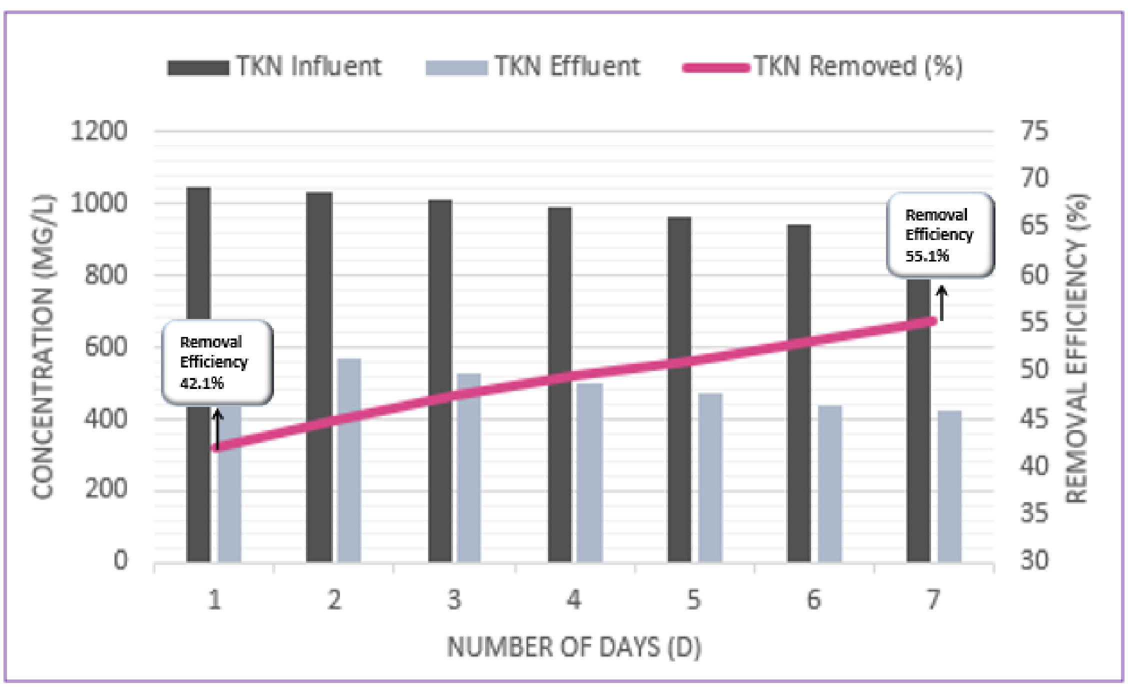

Figure 4.2.3 (a) TKN Removal Efficiency at 16 Hour H.R.T.

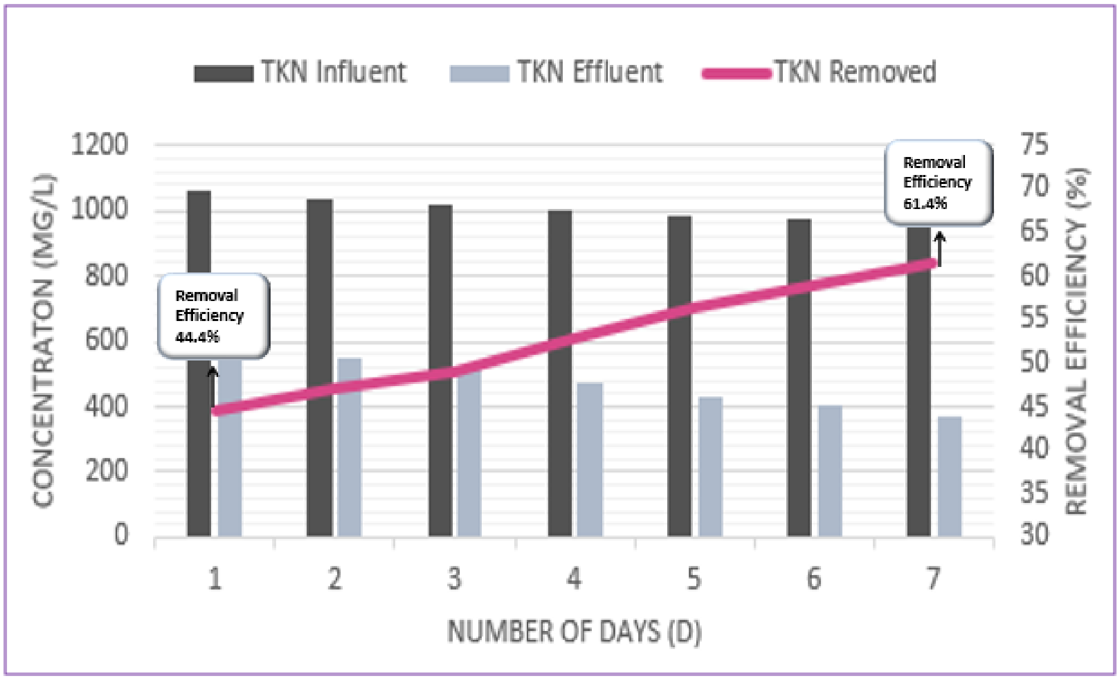

Figure 4.2.3 (b) TKN Removal Efficiency at 20 Hour H.R.T.

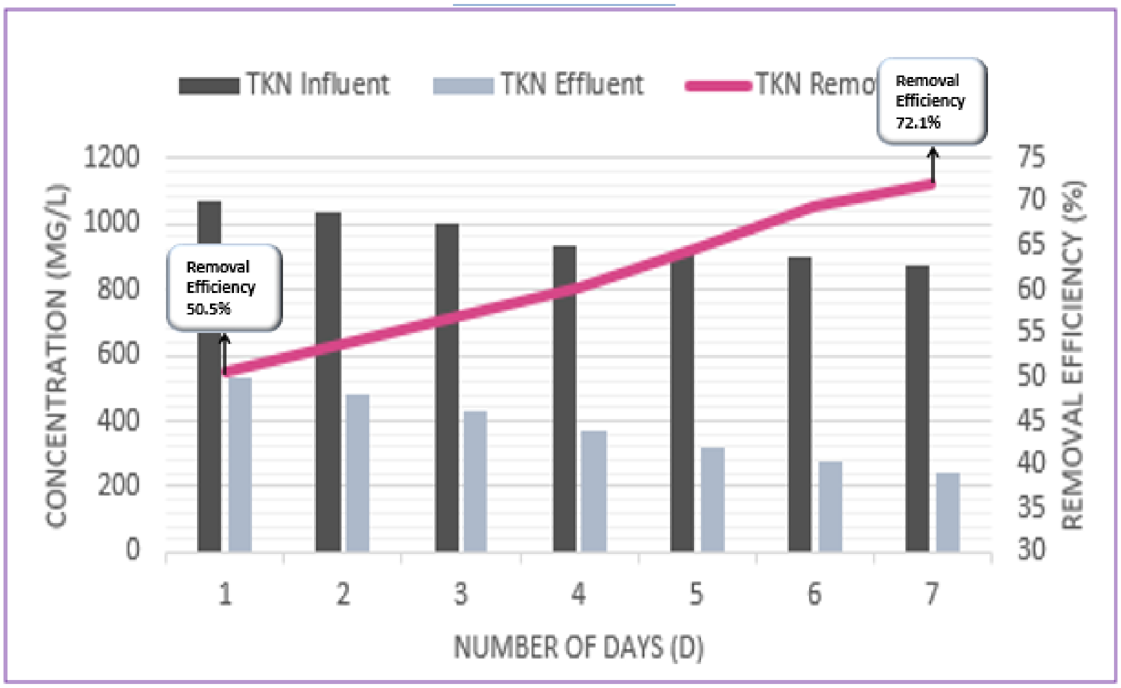

Figure 4.2.3 (c) TKN Removal Efficiency at 24 Hour H.R.T.

4.2.4 Ammonia Nitrogen

The graphical results for ammonia nitrogen over the course of 7 days at hydraulic retention time of 16, 20 and 24 hours are given in the following graphs. Highest removal efficiency was observed at 24 hours H.R.T. i.e. 68.2%.

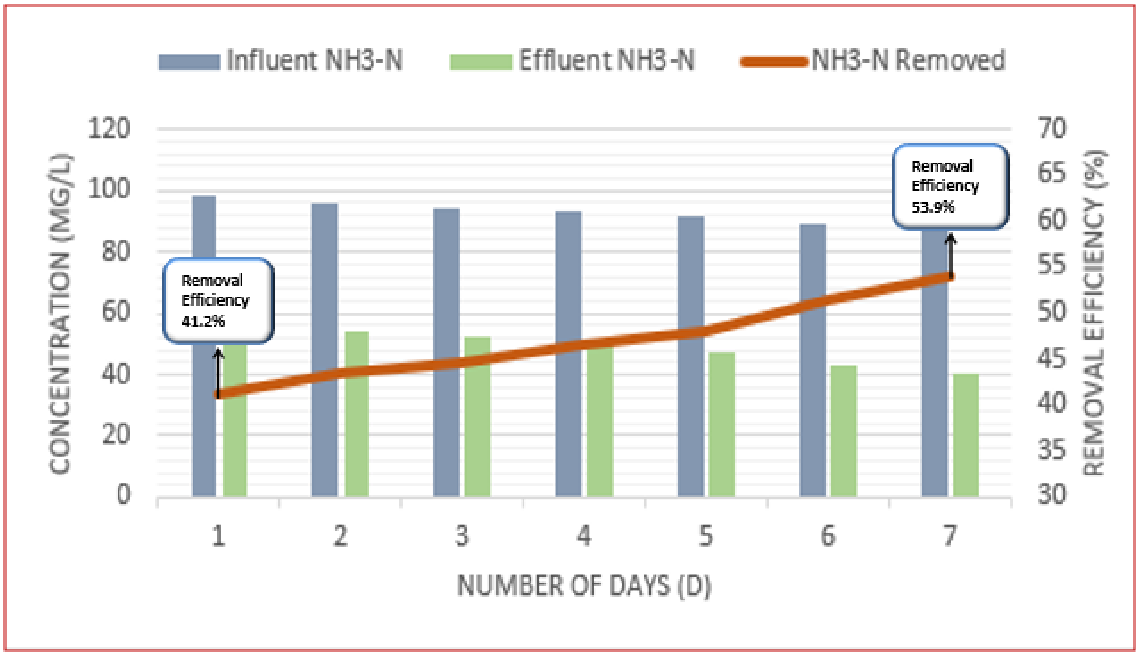

Figure 4.2.4 (a) AN Removal Efficiency at 16 Hour H.R.T.

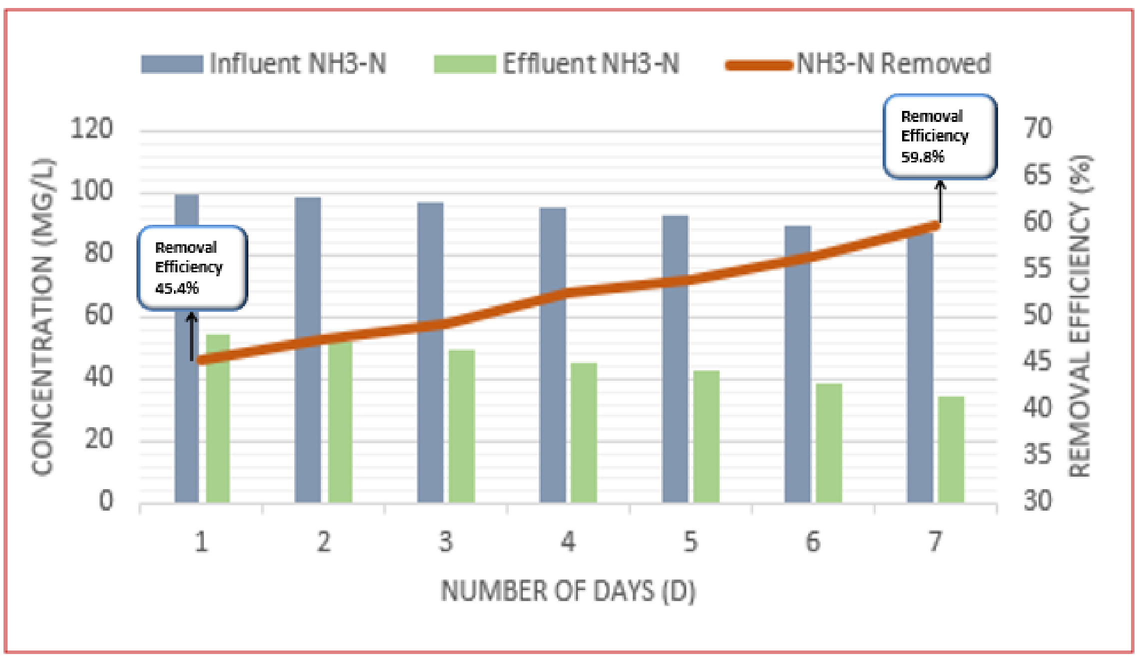

Figure 4.2.4 (b) AN Removal Efficiency at 20 Hour H.R.T.

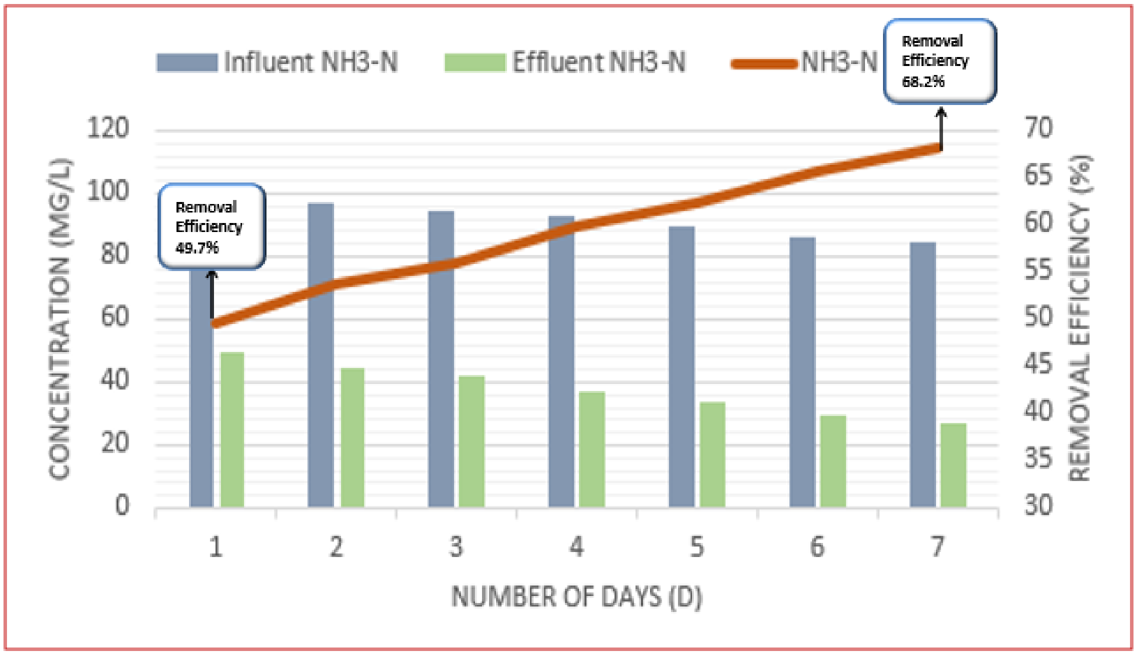

Figure 4.2.4 (c) AN Removal Efficiency at 24 Hour H.R.T.

4.2.5 Summary of Results for An-MBBR

The following table summarizes the results of the tests conducted on Anaerobic Moving Bed Bioreactor (An-MBBR). Values of ORP, VFA/Alkalinity ratio and pH are also given.

Parameters	Units	Hydraulic Retention Time (H.R.T.)		
		16 (Hours)	20 (Hours)	24 (Hours)
Chemical Oxygen Demand (COD)	mg/L	2367	1597	1011
Total Phosphate (TP)	mg/L	13.5	9.45	6.1
Total Nitrogen (TKN)	mg/L	421.4	372.4	243.1
Ammonia Nitrogen (NH_3–N)	mg/L	40.1	34.9	26.8
Oxidation Reduction Potential (ORP)	mV	-150.8	-156.4	-168.8
Volatile Fatty Acids/Alkalinity	-----	0.36	0.37	0.39
pH	-----	6.4	6.6	6.9

Table 4.2.5 Results Summary for An-MBBR

4.3 Comparison of Results for UASB and An-MBBR

The following table draws a comparison between the COD, TP, TKN and Ammonia Nitrogen removal efficiencies of both UASB and An-MBBR reactors at varying hydraulic retention times. Highest removal efficiencies are encircled.

Parameters	Units	Removal Efficiency (%)					
		Up flow Anaerobic Sludge Blanket Reactor (UASB)			Anaerobic Moving Bed Bioreactor (An-MBBR)		
		16 (Hours)	20 (Hours)	24 (Hours)	16 (Hours)	20 (Hours)	24 (Hours)
Chemical Oxygen Demand (COD)	**mg/L**	70.1	75.2	84.7	69.5	79.2	87.7
Total Phosphate (TP)	**mg/L**	74.2	82.9	84.8	78.2	83.4	89.3
Total Nitrogen (TKN)	**mg/L**	50.4	59.4	65.2	55.1	61.4	72.1
Ammonia Nitrogen (NH_3–N)	**mg/L**	52.1	56.5	63.1	53.9	59.8	68.2

Table 4.3 Removal Efficiencies of UASB & An-MBBR

5. CONCLUSIONS

This research was conducted on the treatment of textile (de-sizing) wastewater by utilizing two treatment technologies i.e. Up flow Anaerobic Sludge Blanket Reactor and Anaerobic Moving Bed Bioreactor (An-MBBR). The hydraulic retention times were varied at 16, 20 and 24 hours for both reactors. The most efficient treatment technology was identified and the following conclusions were drawn:

- Percentage removal for COD, TP, TKN and Ammonia Nitrogen is maximum at 24hrs Hydraulic Retention Time.
- An-MBBR shows higher removal efficiencies than UASB for COD, TP, TKN and Ammonia Nitrogen i.e. 87.7%, 89.3%, 72.1% and 68.2% respectively.
- An-MBBR is an efficient treatment technology for industrial wastewater treatment.

6. RECOMMENDATIONS

Based on the conclusions we recommend:

- Variation in operating parameters of An-MBBR to increase reactor efficiency i.e. media fill percentage, temperature, pH, recirculation etc.
- Up gradation of lab-scale unit of An-MBBR to pilot scale
- Utilization of An-MBBR for treatment of industrial and brewery wastewater

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