ROTATING BIOLOGICAL CONTACTORS FOR THE TREATMENT OF DOMESTIC WASTEWATER

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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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ABBREVIATIONS

BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
FAS	Ferrous Ammonium Sulphate
GDP	Gross Domestic Product
HLR	Hydraulic Loading Rate
HRT	Hydraulic Retention Time
MBR	Membrane Bioreactor
NEQs	National Environmental Quality Standards
RBC	Rotating Biological Contactors
SDG	Sustainable Development Goals
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
WHO	World Health Organization

ABSTRACT

Pakistan is a country with a population of 202.7 million, which produces massive amounts of wastewater each year and currently there is no reliable and sustainable wastewater treatment technology in place and only about 7.7% of the urban wastewater is treated. Open dumping of wastewater leads to high annual mortality rates due to water borne diseases and results in the loss of millions of dollars each year. Since Pakistan is also energy stressed; less complicated and efficient technologies are necessary for scaling up applications. This study shows an innovative approach towards the design and use of Rotating Biological Contactors (RBC); viewed as an effective and efficient biological growth process alternative of the conventional activated sludge. RBC is a compact, economical system owing to low energy consumption, less land area requirement and high removal efficiencies at low treatment times which are as low as 3 hours to meet the NEQs making them a perfect option for decentralized wastewater treatment systems. A three-stage lab-scale RBC was employed to treat synthetic wastewater of 520mg/L chemical oxygen demand (COD) at a hydraulic retention time of 8 hours. Removal efficiencies at different submergence level (30%, 40%, 70% and 100%) of the pall ring media was tested and a combination of varying submergence levels at consecutive stages was also tested. A highest removal rate of 95% and 71% of COD and Total Kjeldahl Nitrogen (TKN) were achieved at 40% submergence respectively. A run was also conducted for 40% submergence level with MBR media and it gave 0.62% and 2.41% more COD and TKN removal respectively than Pall Ring Media. A feasibility analysis was also discussed for a pilot scale-up of the same design considering its applications in Jatoi, Pakistan.

Keywords: Rotating Biological Contactor, domestic wastewater, submergence levels, media, pilot-scale design.

Chapter 1

INTRODUCTION

1.1 Background

Pakistan is on the verge of water scarcity and the most alarming indicator is that groundwater, which is considered to be the last resort of water supply is being rapidly depleted. And the worst part is authorities haven't conducted risk assessments or even have management plans that indicates they plan to do anything about any of this (Michael Kugelman, South Asia expert at the Washington-based Woodrow Wilson Center). Economy and public health is already suffering due to this negligence. Pakistan Council of Research in Water Resources reported that, over 80 percent of water supplied is considered unsafe, and water scarcity and water-borne diseases are resulting in a loss of up to 1.44 percent of GDP.

Along with this water crises issues, Pakistan is also facing the sanitation problems. Greater than half of the population do not have access to improved sanitation facilities. Due to this poor sanitation and hygiene practices the country is facing huge burden of diseases mainly like diarrhea that kills thousands of infants every year. According to WaterAid, 79 million people lack a decent toilet, while 37% have no system for wastewater disposal, which result in spread of diseases due to contamination of water and contact with human waste.

Focusing on the SDG 6 that states "Ensure access to water and sanitation for all" the main objective now is to improve water quality by reducing pollution, minimizing and eliminating the release of hazardous materials and chemicals and treating the wastewater significantly increasing the recycling and reuse of the water.

1.2 Magnitude of Problem

About 1.8 billion people across the globe are using the contaminated water as their source of drinking water and this source of drinking water is mainly fecal contamination. Due to the poor sanitation and hygiene issues different diseases are spread that are killing the world population. Each day, around 1000 children are dying due to the water and sanitation related diseases. Regardless of the significant improvements in the fraction of population using an improved water source and enhanced sanitation facility, still 27.2 million people of Pakistan do not have access to safe drinking water and almost 52.7 million do not have access to the adequate sanitation facilities.

According to WaterAid over 93 million people don't have access to adequate sanitation in Pakistan (WaterAid). Pakistan an under developed country has most of its population living in the semi-urban and rural areas don't have any water treatment or wastewater treatment facility. Due to the inadequate sanitation facility most of the wastewater is recklessly dumped in open area or into the other water bodies causing the environmental pollution. Thus, this present situation can be solved by employing a decentralized wastewater treatment system.

1.3 Environmental Effects

The effects of the water pollution are out of reach to the population. The contaminated water is affecting our ecosystem and not only we have to simply worry about the unhealthy material that is reaching our drinking water but also the animals, crops and the fresh water bodies that are seriously affected by this pollution. Most of the wastewater produced is discharged directly into the water bodies or is infiltrated thus contaminating the groundwater which leads to the spread of water borne diseases diarrhea, cholera, typhoid and hepatitis. About 1000 children die daily due to these water borne diseases. According to the world health organization, In Pakistan, every year 39,000 children under the age of five die due to diarrhea, out of which 88 percent is attributed to unsafe water supply, inadequate sanitation and hygiene (World Health Organization, Glass 2014). These waterborne diseases are causing about $1.3billion dollars every year to the Pakistan's economy and this contaminated water also results in 40% deaths in the country. WHO also reported that 25%-30% of all hospital admissions are connected to water borne bacterial and parasitic conditions with 60% of infant deaths caused by water borne infections.

1.4 Research Motivation

- Present situation of environmental pollution by wastewater
- Water borne diseases
- Absence of reliable and sustainable wastewater treatment technology
- Solution to the domestic wastewater produced

The wastewater produced in Pakistan is mostly discharged without any treatment into the environment. This wastewater produced is not treated due to lack of the resources and capital cost. Rotating Biological Contactors (RBCs) are biological treatment technology using suspended growth mechanism can be good method to treat the domestic wastewater produced.

1.5 Objectives

Our main objective is the successful treatment of domestic wastewater using RBCs without aerators to meet the NEQs. The oxygen required for the growth of the microorganisms is obtained by adsorption from the air as the biofilm on the media is rotated out of the wastewater.

The objectives of this study are:

1. Establishment of RBCs for the treatment of domestic wastewater
2. Optimization of the RBC parameters: Submergence level and RBC packing material
3. Full scale design of RBC treating wastewater for 250 households of tehsil Jatoi

1.6 Scope of Study

As in Pakistan there are a few wastewater treatment systems in operation and enormous amount of wastewater is recklessly disposed of without any treatment. This untreated wastewater is thus contaminating our living environment and the water bodies that we use for various purposes. This prevailing condition of the ecosystem needs our attention. This project aims to provide a cost effective and easy solution to the huge amount of wastewater produced. Keeping in mind the situation and living standards of the people living in semi-urban and rural areas, this will provide an effective solution to the wastewater using very limited energy resources.

1.7 Problem Statement

Currently no sustainable and reliable wastewater treatment technologies have been implemented in Pakistan to counteract against this situation and as an energy stressed nation, we need less complicated and efficient technologies for full scale application to treat vast amount of produced wastewater.

Thus,

“A water scarce country like Pakistan can treat extensively produced municipal wastewater by employing RBCs and reusing it instead of discharging it directly into the environment affecting various ecosystems and human health.”

1.8 Existing Solutions

The mostly used wastewater treatment technologies include the activated sludge process and packed bed reactors. Yet due to the complication of the process, unavailability to handle the varying loads, high operational cost and energy requirements these activated sludge process are not the effective solutions in case of Pakistan. Most of the wastewater treatment technologies require a high capital cost for the operation and maintenance of the treatment setup. While on the other hand rotating biological contactors offer a cost-effective wastewater treatment method with ease of operation and maintenance.

1.9 Hypothetical Solution

The solution to the huge amount of domestic wastewater produced is the use of rotating biological contactors consisting of rotating cage (that are submerged at varying levels into the wastewater) filled with the media upon which the biofilm grows and upon rotation the aeration requirement is fulfilled by the exposure of biofilm to the atmosphere. This RBCs are the best solution due to;

- Aerobic biological process
- Lower operational and maintenance cost
- High treatment efficiency
- Compact design and easy construction
- Resistance to shock and toxic loads
- Easy process control and monitoring
- Relatively less land requirement
- Less power requirement

1.10 Introduction to Rotating Biological Contactors

Rotating biological contactors are fixed bed biological contactors that consists of rotating disks filled with the media used for the treatment of wastewater without the use of aerators.

These rotating disks (drums) are partially submerged into the wastewater. The biofilm grows on the surface of media and upon the rotation of the disk, the microbes are alternately exposed to the atmosphere for the absorption of oxygen and to the wastewater for nutrients. In this research, the RBC system was sued to treat domestic wastewater.

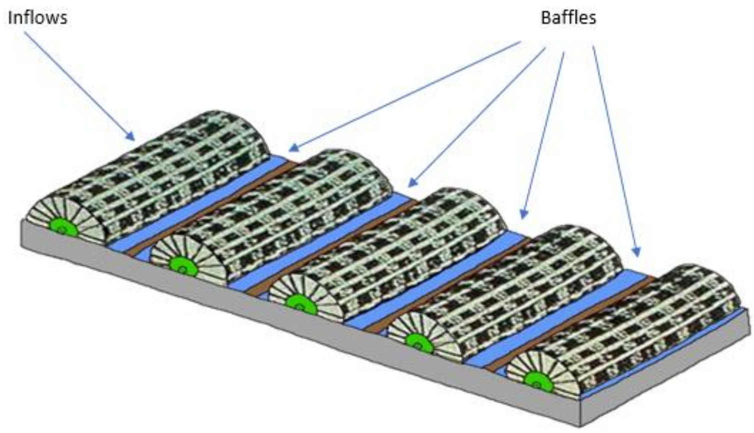

Figure 1.1: Conventional RBC with five stages

1.10.1 Conventional RBCs vs this RBC

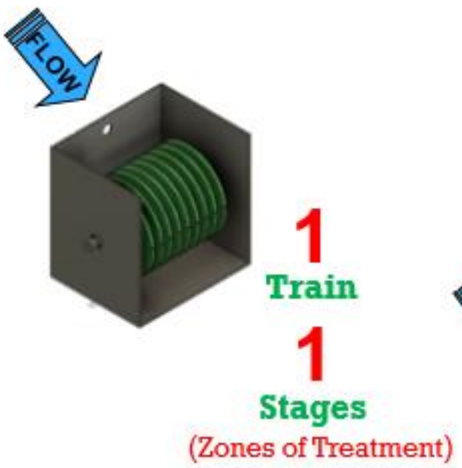

Figure 1.2: 1 stage in a single train of RBC

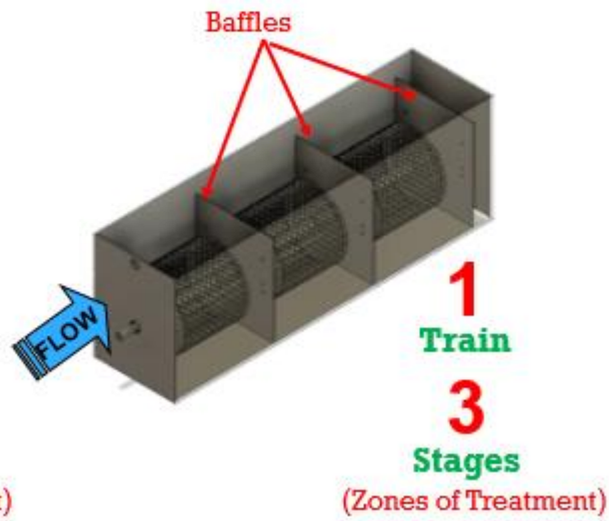

Figure 1.3: 3 stages in a single train of RBC

- Media

Support material on which the biofilm grows.

- Stages

The stages in RBC system are each zone of treatment that are separated by baffles. In each stage the wastewater is retained for a specific duration.

- Train

The train consist of two or more stages connected in series combination. The picture given below is a general diagram of RBC train with 5 stages in series separated by the baffles.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Rotating biological contactors is an efficient alternative biological process to the conventional activated sludge. This is an attached growth process. Rotating biological contactors have the following advantages over other conventional biological treatment processes, i.e. lower energy consumption, simple design and operation, low HRTs and quick start-up. As well as land requirement is low, operating and maintenance cost is less and these are shock loading resistant.

It is a well-suited option for decentralized wastewater treatment technologies due to its economical operation and the compactness of the overall system. The energy consumption of RBC is less than that of extended aeration activated sludge plant, also less maintenance and operational skills are required due to easy operation. RBC can more economically feasible as compared to activated sludge plant for treating the domestic wastewater of small communities.

2.2 Comparison Studies

Due to easy operation of RBC, it is less complicated as compared to activated sludge process. Also, this is a process more resistant to shock loadings (S. Cortez, P. Teixeira, R. Oliveira and M. Mota 2008).

According to Nasr (2007), the operational cost of Activated Sludge process is almost double the operational cost of RBC for the industrial wastewater treatment. (Nasr et al. 2007, Tawfik et al., 2006) observed the working of a RBC for the treatment of municipal wastewater on a pilot scale. The two-stage rotating biological contactor, working on a HRT of 5 h had a removal efficiency of 77%, 30% and 20% of COD, TKN and ammonia-nitrogen respectively. [4]

When compared to packed reactor, RBC energy requirement is only 70-80% (Rodgers and Zhan, 2003) and in comparison, to an activated sludge system its only 25% (US Filter, 1998).

Van Buuren (1991) compared the treatment efficiency of a conventional packed bed reactor with that of a RBC at an HRT of 3.3 h: RBC successfully removed 70% of the COD while the bed reactor removed 50%. Also, the RBC achieved 40–80% COD removal at a much shorter HRT of 0.24 h.

A comparison of the treatment efficiencies of a packed bed reactor with a RBC at a short HRT of 3.3 hours was made. The RBC gave a COD removal of about 70% whereas the packed bed reactor gave a COD removal of only 50%. The RBC gave a COD removal of 40-80% at a very short HRT of 0.24h (Van Buuren, 1991).

2.3 Case studies

Table 2.1 Shows different case studies using RBC

Sr. No.	Observation	Results	Reference
1	The removal rates of BOD, TSS and TKN for three different concentrations of municipal wastewater for a pilot scale RBC reactor were observed. The operating condition were: Average influent flowrate: 400/d RBC wastewater volume: 0.2 m3 Total surface area: 16.2 m2 Submergence: 40% Biofilm thickness: 0.001m MLSS: 2800 mg/l Hydraulic Loading Rate: 0.03 m3/m2.d	Refer to table 2.2	Abdel-Kader, A. M. (2013)
2	Domestic wastewater was treated in an RBC system consisting two stage system. It was optimized using varying combinations of hydraulic retention times and organic loading rates. The bottom of the RBC unit was an immhoff settling tank. It was operated for a time span of 3.5 years without any issues. The efficiency of one stage versus two stage system was also investigated at an OLR of 22 g COD/m2.d and HRT of 5.0 h.	The figure 2.5 shows the setup. The removal efficiencies of COD were observed to significantly decrease with decrease in HRT from 10 to 2.5 h and increasing the OLR from 11 to 47 g COD/m2.d. There was no effect on the effluent quality of soluble COD. Considering the results, a two stage RBC system at an OLR of 11 g COD/m2.d and a longer HRT of 10 h is recommended for domestic wastewater. The nitrification capacity of two stage RBC system was higher as compared to one stage RBC system. The results are displayed by table 2.3	A. Tawfik, H. T. (2006)
3	A full-scale RBC reactor with primary and secondary clarifiers were employed to evaluate the performance at varying organic loading rates ranging from 15 to 37 g COD/m2/d.	The removal rate achieved for COD and ammonia-nitrogen were 82-92% and 82-97% respectively. The organic removal percentages in both the clarifiers were 22.2-28% and 19.7-24.1% respectively. The tables 2.4a and 2.4b reflects the operating conditions and performance summary.	T. Panswad, C. P. (1988)
4	Net-like rotating biological contactor using three stages was employed to treat municipal-type synthetic wastewater. Advantages of such a system are fast start-up, high biomass concentration and higher OLR.	The removal rate of COD and total nitrogen for low municipal-type wastewater at HRTs ranging from 5 to 9 h were 78.8–89.7% and 40.2–61.4% respectively. For organic loading rates between 16 and 40 gCOD/m2 d, the COD removal percentage achieved was between 80–95%.	Zhiqiang Chen, Q. W. (2006)

	For the startup, the reactor was run on synthetic wastewater of COD 600 mg/L, rotating speed = 5 rpm and HRT = 3 h.	The results obtained are displayed in the table 2.5.	

Facts on significant parameters for successful operation

Sr. no.	Feature	Observations	Reference
1	BOD_5	In the first stage of RBC system, the design load shouldn't exceed a BOD5 loading of 30 g BOD5/m2 d or a soluble BOD5 loading of 12–20 g BOD5/m2 d to avoid oxygen transfer limitations. Rotating Biological Contactors can show a biological oxygen demand (BOD) removal of 80 to 90%.	WEF and ASCE 1998 Apilfinez, A. G. (1998)
2	Effluent ammonia concentration	The effluent ammonia concentration below 5mg/L can only be maintained when the surface loading doesn't surpass 2.5 g BOD5/m2, investigated for nitrification in full-scale RBCs. Design value of 5 g BOD5/m2 d is proposed by German ATV guideline in full-scale RBCs for the purpose of nitrification of domestic wastewater with four units run in series.	Nowak (2000) ATV (1989)
3	Hydraulic loading	Increase in hydraulic loading results in an increased biomass on the media surface of the RBC. For full scale, RBC manufactures recommend a hydraulic loading rate range of 1.292–6.833 dm3/m2 h.	(Alemzadeh and Vossoughi 2001) (Tchobanoglous and Burton 1991)
4	Packing	Randomly packed media contribute to higher mass transfer efficiency as they provide more area for biofilm attachment and due to increased turbulence as compared to discs at the laboratory and pilot-scale. They consume less energy and the fabrication cost is very less, nearly one third that of discs.	(Ware et al. 1990; Mathure and Patwardhan 2005)
5	Bio-media	Polypropylene rings used as a bio-media can give us a good performance. According to Jawahar Saud experimental setup, 36% of the circular disc is immersed in the wastewater. With the use of polypropylene as biomedia in RBC's, figure 2.6 and figure 2.7 results were generated. Activated carbon was the best for biofilm growth, reaching 10 mg DM/cm^2	Apilfinez, A. G. (1998) Martin K Jaison, M. K. (2017, March)
6	Reactor Covers	Individual covers over preferred to reduce heat loss, minimized algal growth and byproduct gases can be collected to prevent odor problems.	Tchobanoglous and Burton 1991
7	Rotational Speed	At the same rotational speed disc RBCs provide less oxygen than packed supports but packed supports have a higher energy consumption.	Hoccheimer and Wheaton 1998
8	Oxygen transfer efficiency	Oxygen transfer efficiency (OTE) per unit energy consumed decrease rapidly by increasing rotational speed and increase by decreasing hydraulic loading rate. OTE value for packing (2–5 kg/kWh) is higher than typical RBC disks (1–2 kg/kWh).	Israni et al. (2002) Mathure and Patwardhan (2005).

9	Submergence	Submergence of about 40% is typically observed in aerobic treatment of wastewater and 60% submergence can be attained for nutrient removal. Increased submergence for improved equipment reliability and to reduce load on bearings as well as on the shaft. Submergence of 70-90% provides the advantage of fewer units required and larger medium volume available.	Tchobanoglous and Burton 1991 Schwingle et al. 2005
10	Energy Consumption	For a full-scale RBC, the energy consumed is 1–1.5 kWh/kg of BOD5 removed is specified by the manufacturers. A full-scale RBC with a packing of cylindrical PVC had an energy consumption of 1.6 kWh/kg of BOD5 removed, In a pilot RBC, electrical power consumption of 0.005 kWh/m2 d at a rotational speed of 1 rpm.	MSE 2006 Wanner et al. (1990) Watanabe et al. (1994)
11	Clarifiers	RBCs require primary and secondary clarifiers.	S. Cortez, P. T. (2008)
12	Organic Surface Loading	It is advised to keep the organic surface loading less than 30 g BOD5/m2 d in the first stage.	S. Cortez, P. T. (2008)
13	Peripheral speed	It is advised to keep the ‘v’ within the range of 10-20 m/min kept independent of the disc diameter. For a higher power economy, the operating peripheral speed should be close to its minimum. At lower rotational speed, the power economy of RBC is way higher than AS.	Antonie, 1976
14	Staging	For same BOD removal, an increase in the hydraulic loading per unit disc surface can be achieved by introducing stages. This results in an increase in BOD loading per unit of the floor area of the RBC unit and thus the power economy increases. Influence of staging is useful and effective within the range of 3-5.	Koichi Fujie, H. E. (1983)
15	Cost	The overall construction cost of RBC is more than that of AS but the running cost is considerably low.	Koichi Fujie, H. E. (1983)
16	Flow equalization	The RBCs require a greater floor area for the same BOD loading per unit as compared to AS thus a flow equalization tank is preferred before the RBC unit to reduce the requirement of the floor area.	Koichi Fujie, H. E. (1983)

2.4 Figures

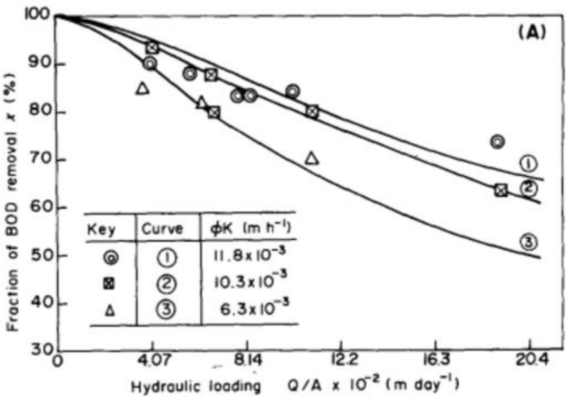

Figure 2.1: Shows the operational design and power economy of a RBC. Experimentally observed fractions of BOD removal in domestic wastewater treatment reported by U.S. EPA (1971) are shown in Fig. 2.1. Adapted from Koichi Fujie, H. E. (1983)

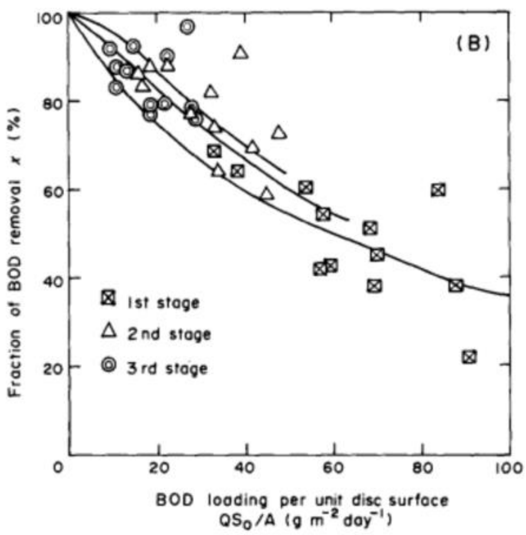

Figure 2.2: Experimental data obtained for wastewater from a wool-spinning mill. Experimental conditions: D = 3m, n = 3, N= 13rpm, average BaD in effluent Co = 160mgl -~ and t= 25-30°C. For calculated curves bK = 15 × 10-3mh -I is selected. Adapted from Koichi Fujie, H. E. (1983).

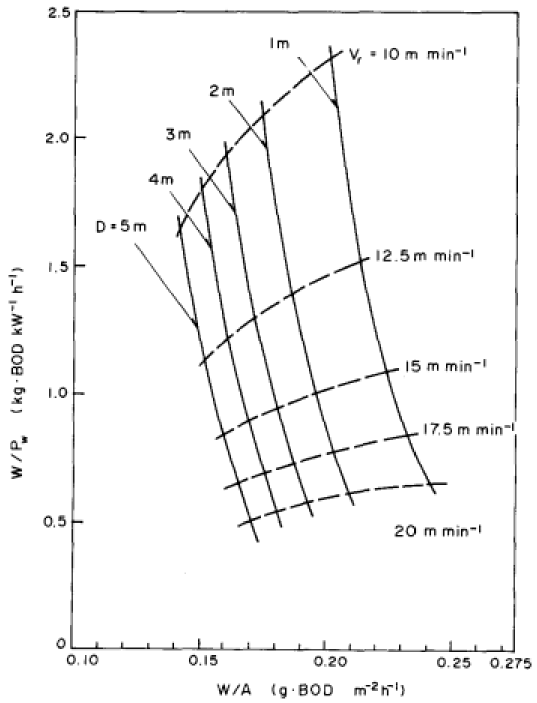

Figure 2.3: Relation between BOD removal rate per unit surface area of disc W/A and power economy W/P w under steady operation (So = 150 mg l- 1 S, = 20 mg]- 1) and number of stage n = I. With a decrease in the disc diameter, the removal rate of BOD per unit surface area of disc increases at a constant peripheral disc speed. Consequently, the reduction of disc diameter results as less removal rate of BOD per unit floor area of RBC. Adapted from Koichi Fujie, H. E. (1983).

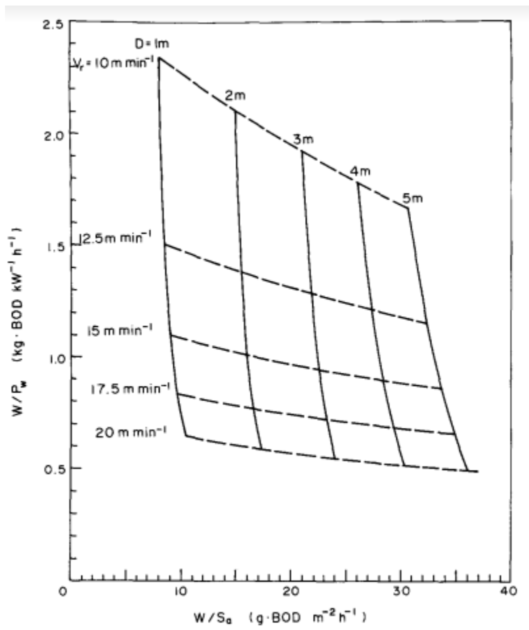

Figure 2.4: Relation between BOD removal rate per unit floor area of RBC W/S. and power economy W/Pw under steady state operation (So = 150 mg 1- i S. = 20 mg 1- ~) and number of stage n = 1. Power economy significantly decrease with increase in peripheral speed v. Adapted from Koichi Fujie, H. E. (1983).

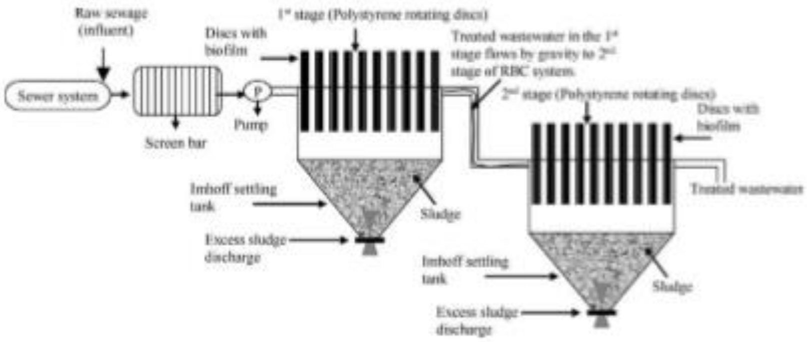

Figure 2.5: Two stage RBC system treating domestic wastewater. The bottom of the tank is immhoff settling tank. Adapted from A. TAWFIK, H. T. (2006).

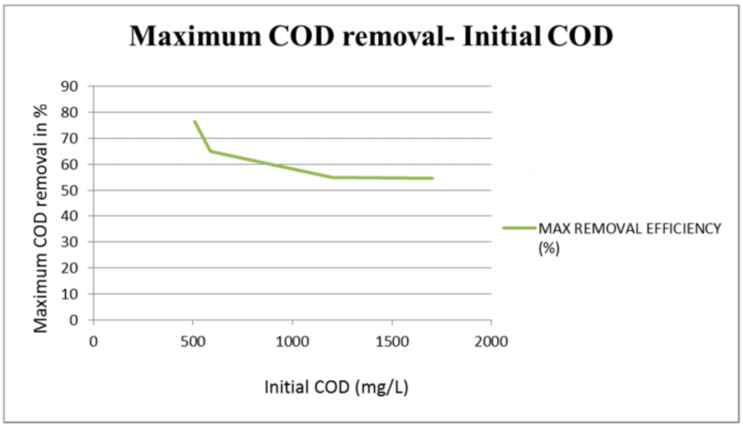

Figure 2.6: At less initial COD, the removal percentage is approximately 76%. As the initial COD is increasing, i.e. strength of the wastewater is increasing, the removal efficiency is reducing. Adapted from Martin K Jaison, M. K. (2017).

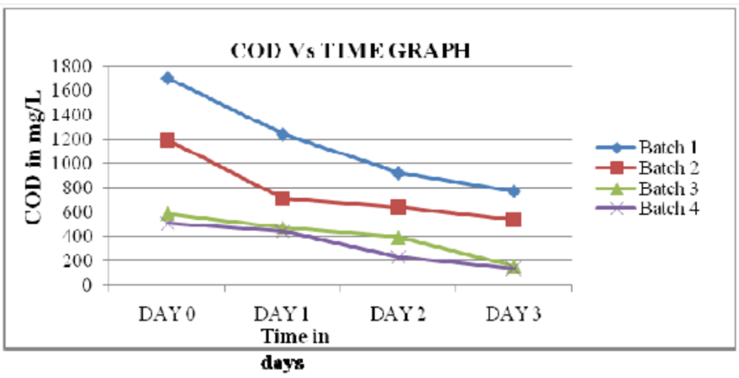

Figure 2.7: COD removal efficiency depends on the f/m ratio: as the f/m ratio decreases, efficiency increases. Adapted from Martin K Jaison, M. K. (2017).

2.5 Tables

Table 2.2: Summary results for the RBC experimental pilot plant. Adapted from Abdel-Kader, A. M. (2013).

Parameter	Low Concentration			Medium Concentration			High Concentration		
	Inlets mg/L	Outlet mg/L	Eff (%)	Inlet mg/L	Outlet mg/L	Eff (%)	Inlet mg/L	Outlet mg/L	Eff (%)
TSS	28	2	92.9	79	11	86.1	146	20	86.3
BOD	72	5	93.1	119	6.3	94.7	182	8	95.6
TKN	2	0.3	85	8	2.3	71.3	13	5.6	57

Table 2.3: Comparison between the overall removal efficiency (%R) of a single versus two stage RBC system at the same operational conditions (OLR=22gCOD/m2.dandHRT=5h.). Standard deviations are presented in brackets. Adopted from A. Tawfik, H. T. (2006).

Sample Parameter	Unit	Influent Raw wastewater	RBC effluents			
			Single stage	% R	Two stage	% R
COD_{Total}	mg/l	496 (137)	174 (46)	65 (12)	115 (28)	77 (11)
$COD_{Suspended}$	mg/l	231 (122)	60 (35)	74 (8)	39 (20)	83 (3)
$COD_{Colloidal}$	mg/l	107 (56)	40 (29)	63 (5)	21 (19)	80 (6)
$COD_{Soluble}$	mg/l	158 (27)	73 (18)	54 (3)	57 (57)	64 (4)
Ammonia	mg/l	50 (9.9)	43 (9.9)	14 (4)	40 (6)	20 (6)
Nitrate	mg/l	0.0	0.0		1.4 (0.6)	
TKN	mg/l	61 (9.7)	52 (12)	15 (4)	42 (5.0)	31 (5)
E.coli	/100 ml	7.1×10^6	2.9×10^6	59 (11)	2.8×10^5	96 (7)

Table 2.4a: Characteristics of various phases at varying organic loading rates ranging from 15 to 37 g COD/m2/d. Adopted from T. Panswad, C. P. (1988).

Parameters/ Phases	A	B	C	D
Flow rate (l/min)	1.0	1.2	1.0	1.2
Detention Time (min)	160.0	133.3	160.0	133.3
Organic Loading Rate (g COD/m/d)	27.80	25.60	17.63	13.10
Hydraulic loading Rate ($m^3/m^2/d$)	0.124	0.149	0.124	0.149

Table 2.4b: Summary of process performance of treatment plant in terms of COD. Adopted from T. Panswad, C. P. (1988).

Percentage removal in primary sedimentation		Organic load into RBC $gCOD/m^2/d$	1st stage RBC percentage removal		Overall RBC percentage removal		Percentage removal in final sedimentation	
Total	Filtered		Total	Filtered	Total	Filtered	Total	Filtered
28.0	5.2	27.8	78.8	73.2	82.2	85.7	24.1	3.1
26.2	3.1	25.6	79.9	68.0	78.0	72.1	21.6	2.2
22.7	4.8	17.6	79.4	70.4	77.2	71.8	18.8	4.8
22.2	4.2	13.1	51.5	64.8	80.2	69.3	19.7	3.6

Table 2.5: COD and nitrogen removal in NRBC under different HRTs. Adopted from Zhiqiang Chen, Q. W. (2006).

Sample	Flowrate (L/h)	HRT (h)	NH_4^+-N (mg/L)	NO_2^--N (mg/L)	NO_3^--N (mg/L)	TN (mg/L)	% TN removal	COD (mg/L)	% COD removal	DO (mg/L)
In*	13.8	5	31.2			33.6		315.3		
E1			19.4	1.5	5.2	27.2		165.8	47.4	2.8
E2			12.7	4.3	7.7	25.3		113.6		4.1
E3			7.4	3.7	8.8	20.1	40.2	66.9	78.8	5.7
In	11.5	6	32.4			32.6		316.5		
E1			16.7	1.6	7.2	25.2		150.6	52.4	3.9
E2			10.3	3.4	8.3	22.3		89.7		5.2
E3			5.3	3.6	9.2	18.4	43.6	47.9	84.9	6.0
1n	9.9	7	31.4			31.6		309.9		
E1			13.3	2.4	6.1	21.2		140.3	54.7	4.1
E2			7.5	4.5	7.9	19.0		61.4		5.7
E3			3.8	3.2	9.2	16.4	48.1	36.7	88.17	6.2
In	8.6	8	30.5			30.6		315.3		
E1			12.1	3.6	6.5	20.8		119.6	62.1	4.3
E2			5.5	4.2	8.8	17.3		56.7		6.0
E3			2.4	3.0	9.2	14.4	53	38.7	87.7	6.3
In	7.7	9	31.5			32.4		314.7		
E1			10.1	3.6	5.7	19.2		106.8	66.1	4.9
E2			5.9	3.7	6.4	15.7		51.1		6.1
E3			2.2	2.2	2.2	12.5	61.4	32.5	89.7	6.5

*In: influent: E1, E2, E3: effluent of three stages; each value was averaged by samples in steady-state days; HRT are based on the total reactor volume; shaft rotational speed was 5 rpm.

METHODOLOGY

3.1 Process flow diagram for experimental study

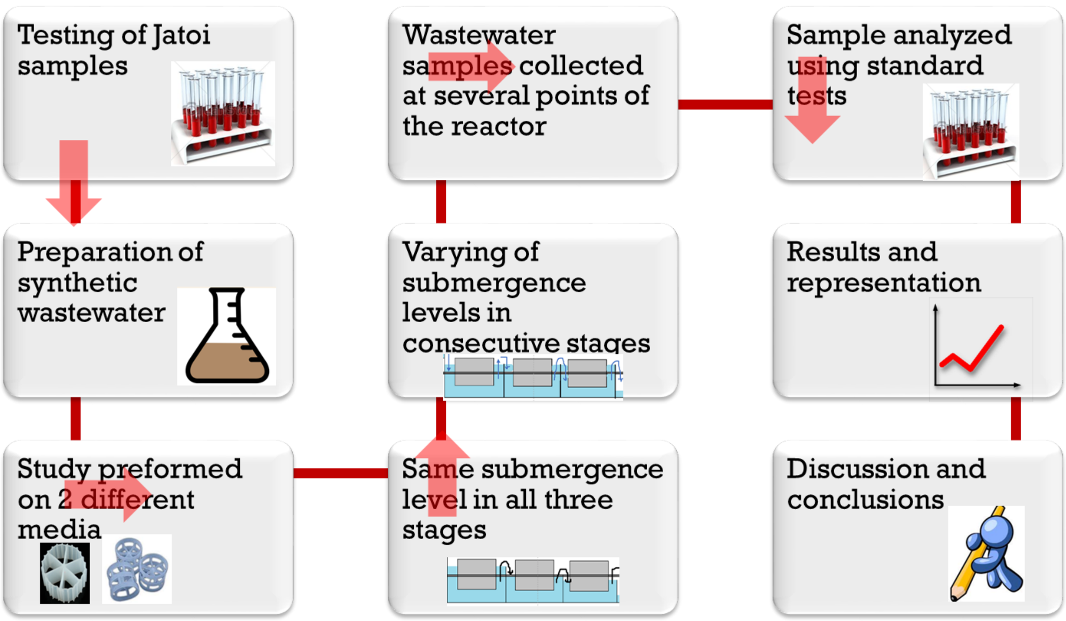

Figure 3.1: Summary figure of experimental study

3.2 Process flow diagram

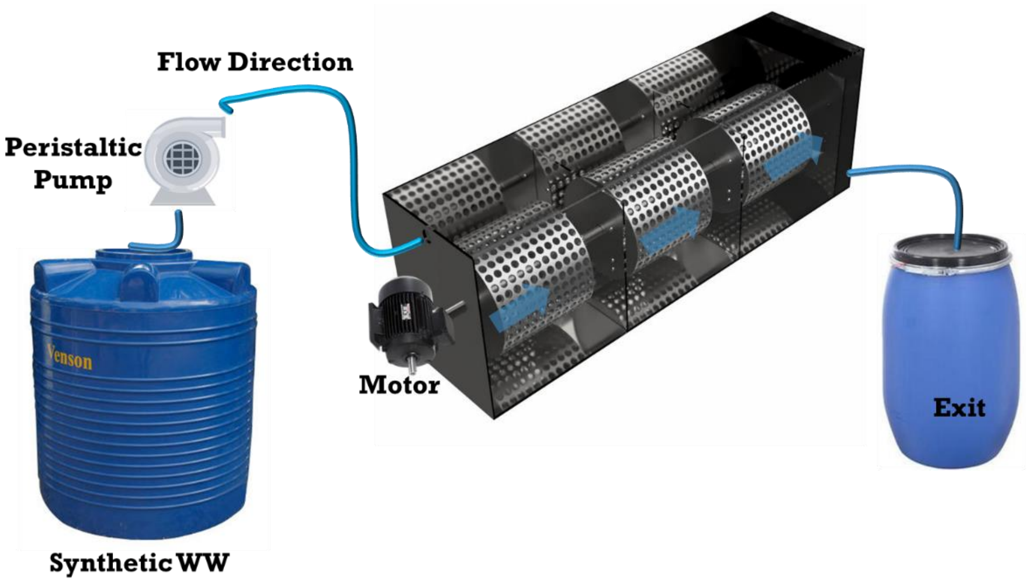

Figure 3.2: Process flow diagram of the experimental setup

3.3 Detailed Methodology

3.3.1 Testing of Jatoi samples

The composition of the synthetic wastewater was determined by sampling the wastewater samples of Jatoi. Synthetic wastewater was used to replicate the conditions observed at Jatoi.

3.3.2 Preparation of synthetic wastewater

The recipe of synthetic wastewater was used to prepare the replicate of Jatoi wastewater having a COD of 500mg/L.

3.3.3 Startup

As per literature review, the growth of biofilm was initiated using high strength wastewater having a COD of around 700 mg/L. The setup was run at a longer HRT of 24hrs. The test time for each varying parameter was set at 4 days and HRT was maintained at 8 hours.

3.3.4 Parameters

This research was performed by varying two parameters. One was media and the other was submergence levels.

- **Media**

Media is a support on which the biofilm grows. The two different types of media we used in the rotating biological contactors are the pall ring media and the MBR media. The comparison between two different media was performed, here are its specifications. The packing density is higher for MBR media as well as its surface Area. The porosity ratio is higher for MBR media than for pall ring. The specifications of both the media are given in table 3.1. The media can be seen from the figure 3.3.

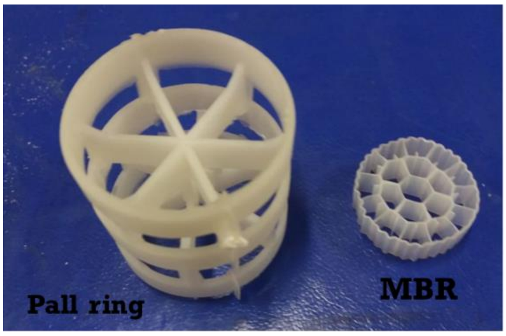

Figure 3.3: Media

Table 3.1: Comparison of specifications the two media

	Pall ring media	MBR media
Dimensions	Dia 25×25 mm	Dia 25x12 mm
Packing Density	175m2/m3	500m2/m3
Porosity	90%	>90%
Surface Area	0.00357m2	0.00515m2

- **Submergence**

Submergence is the percentage of the cage that is in contact with wastewater when the reactor is under operation Firstly, equal submergence levels in the consecutive stages were tested. Four different submergence levels were tested in separate runs and equal submergence was kept in all three stages. Submergence of 30%, 40%, 70% and 100% were tested for the removal efficiencies. Followed by that a run was also conducted for combination of submergence in which the submergence of media was varying among the consecutive stages. The combination run had the following submergence levels in respective stages: 70% in stage 1, 40% in stage 2 and 30% in stage 3.

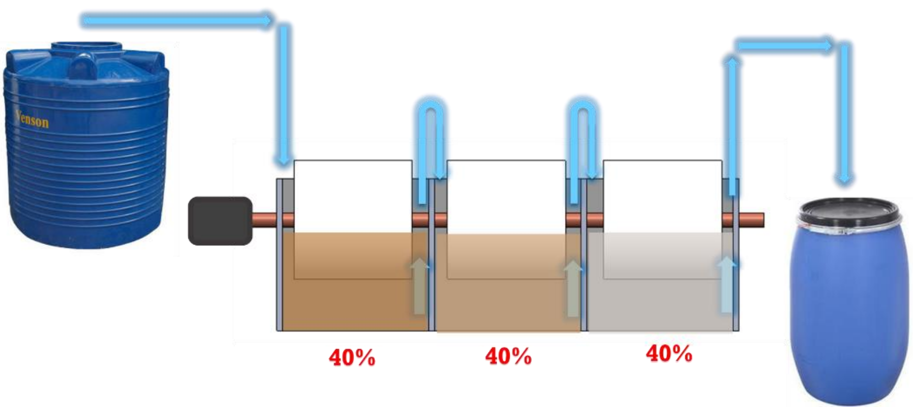

Figure 3.4: Equal submergence levels in the consecutive stages

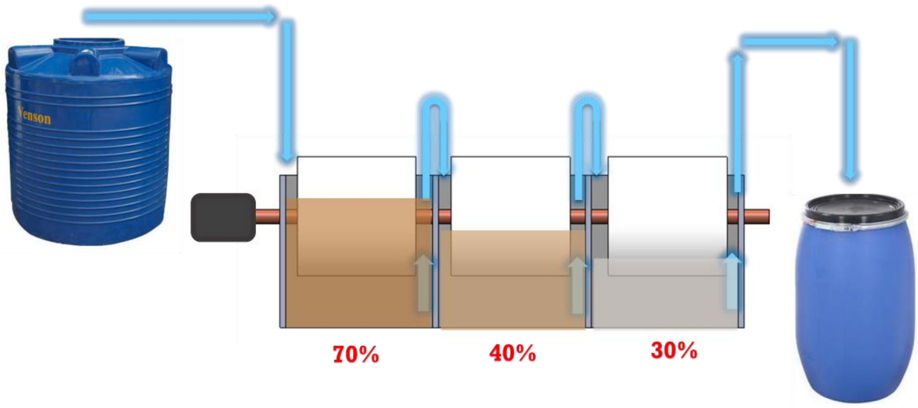

Figure 3.5: Different submergence levels in the consecutive stages

3.4 Lab-Scale experimental setup

A rotating biological contactor was designed to treat synthetic wastewater having an average COD of 520mg/L. The lab scale setup was of stainless steel. It had three stages in a single train. The three stages were separated by fixed baffles. Three cage-like structured units were mounted on a single shaft running through the three stages. A gear-motor assembly was attached to the shaft in order to rotate the media. The setup required three phase power connection to operate. The total volume of the reactor was 60 liters.

This system was designed to run at an HTR of 8 hours. The cages were filled with two different media (one at a time) on which the biofilm grew. The submergence levels were controlled by the openings provided in the baffles. The peristaltic pump was used to control/adjust the flow in the reactor as the volume varied with change in submergence level and the HRT was to be maintained at 8 hours. The wastewater entered the reactor from the inlet plate into the first stage. Later, it passed through the openings into the consecutive stages respectively. And finally, the treated wastewater left the reactor from the outlet. It was pumped from a storage container containing synthetic wastewater into the reactor. Where it flowed through all three stages one by one via gravity and it finally emptied the treated water in a storage vessel.

3.5 Design Calculations

The Rotating biological contactor was designed on the basis of example 9 from the book 'Wastewater Engineering by Metcalf and Eddy'.

The design calculations began with the average COD, BOD and sBOD values of the samples tested from Jatoi. The average COD of the wastewater was 560mg/L. The BOD was around

336mg/L. Since the ratio of sBOD/BOD was given as 0.64(Wastewater Engineering by Metcalf and Eddy, page 937), so the sBOD was calculated to be 216mg/L. The design calculations are given in the table 3.2.

Table 3.2: Design calculations for RBC

Average COD= 560 mg/L
Ratio of BOD/COD= 0.6 (Adapted from "Wastewater Engineering by Metcalf and Eddy", Table 2.18).
BOD= 336mg/L (using the approximate value from BOD/COD)
Ratio of sBOD/BOD= 0.64 (Adapted from Metcalf and Eddy, page 937)
sBOD = 216mg/L
Number of stages= 3
Number of trains= 1

The total volume of the reactor was 60L. after reviewing literature, the HRT was set to be 8hrs.

Volume= 60L = 0.06m^3
HRT= 8hrs = 0.33 days
Q=$\frac{0.06}{0.33}$ = $0.18m^3/d$

According to the example given the sBOD of the first stage was assumed to be 15g/m^2.d. further using the sBOD loading, the surface area was calculated for each stage. The sBOD for each stage was calculated using the formula. The diameter of the cage was set at 21cm. the dimensions of the reactor were calculated.

First stage sBOD is assumed to be $15g/m^2.d$. sBOD loading= $(216\ g/m^3)(0.18m^3/d)$ = 38.88 g/d
Surface Area Required= $\frac{38.88\ g/d}{15g/m^2.d}$ =2.592m^2 For a single stage Surface area required= $\frac{2.592\text{m2}}{3}$ = 0.864m^2
So $S_N = \frac{-1+\sqrt{1+4(0.00974)(^{A_s}/_{Q})(S_{N-1})}}{2(0.00974)(^{A_s}/_{Q})}$ Here,

A_s= Disc surface area on stage N Q= Flow rate S_N= SBOD in stage N For stage 1 $S_1 = \frac{-1+\sqrt{1+4(0.00974)(^{0.864}/_{0.18})(216)}}{2(0.00974)(^{0.864}/_{0.18})}$ = 58.11 g/m^3 For stage 2 S_2 = 26.15g/m^3 For stage 3 S_3 = 15.26g/m^3
Overall organic loading= $\frac{(0.18m^3/d)(336)}{2.592m^2}$=23.33g BOD/m²·d
HLR= $\frac{0.18m^3/d}{2.592m^2}$ = 0.069 m^3/m^2d
The diameter of the cage is set at 21cm Considering 100% submergence to calculate the maximum possible dimensions Depth= 21cm +3cm (from the bottom) +2cm (from water surface) Depth= 26cm Width= 21cm+ 4cm (safe distance from both sides) = 25cm Calculating the length (0.26m)(0.25m)(L)= 0.927m^3 Total length= 0.923m L per stage= 0.308m Recalculating the volume Volume= 0.26*0.25*0.92 = 0.0598 ≈ 0.06m^3
Cylindrical units in case of polypropylene Surface area of one cylinder= 24.88 cm^3 Volume of one cylinder= 6.28 cm^3 Number of cylinders required= 0.864/0.002488 = 347.3 ≈ 347 Volume of the mesh= (6.28cm²)(347) = 2179.16cm^3 Volume = $\pi r^2 h$ 2179.16= π*10.5²*H H= 6.29cm

For better removal more S.A. is incorporated Volume= π*10.5^2*17 Volume= 5888.13cm^3 Number of cylindrical units= 5888.13/6.28= 938
Overall organic loading= $\frac{(0.18m^3/d)(336)}{7.001232m^2}$=8.64g BOD/m^2.d
HLR= $\frac{0.18m^3/d}{7.001232}$ = 0.03 m^3/m^2d
Increase in water level due to a single mesh submergence (which is maximum for 100%) Volume of space to be filled with water in hollow cylinders Volume = πr^{2}h =π*(1-0.2)^2 *2 =4.021cm^3 Volume of polypropylene Volume= 6.28-4.021 =2.259cm^3 Number of cylindrical units= 938 Volume of water rise= 2.259*938= 2118.9cm^3 Total volume of water rise due to three mesh= 0.066357 m^3 Depth for water= 0.066357/0.25*0.924 = 28.7 ≈ 29cm

The number of cylindrical units were calculated by using the volume of the cage/cylinder and the surface area of the cylinder. Organic loading and Hydraulic loading rate values matched the table 3.3. This was done to estimate the number of units used for media.

Table 3.3: Design Considerations

		Treatment level		
Parameter	**Unit**	**BOD removal**	**BOD removal and nitrification**	**Separate nitrification**
Hydraulic loading	$m^3/m^2 \cdot d$	0.03-0.16	0.03-0.08	0.04-0.10
Organic loading	g $sBOD/m^2$.d	4-10	2.5-8	0.5-1.0
	g BOD/m^2.d	8-20	5-16	1-2
Maximum 1st stage organic loading	g $sBOD/m^2$.d	12-15	12-15	
	g BOD/m^2.d	24-30	24-30	
NH3 loading	g N/m^2.d		0.75-1.5	
Effluent BOD	mg/L	15-30	7-15	7-15
Effluent NH4-N	mg/L		<2	1-2

3.6 Startup

For the startup, the reactor was run at 40% submergence level at a longer HRT i.e. 24hrs to let the biofilm growth on the pall ring media. A high strength wastewater was used as a food for the micro-organisms. The MBR sludge was used as an inoculum. For this media, it was observed that the biofilm grew in 24 hours. Both media were tested for all four submergences and combination one after another. Test duration for each run was fixed at 4 days. Pall ring media was tested for all the parameters and then the MBR media was only tested for 40% submergence level in all three stages. The biofilm was grown in the same way as the pall ring media.

3.7 Troubleshooting

During the span of the thesis a few problems occurred and are discussed below:

1. For the startup, the MBR media was run at the HRT of 24hrs with high strength wastewater, but no biofilm was observed after 24 hrs. Thus, it additional 24hrs and synthetic wastewater was added in the same condition. The biofilm appeared after 48hrs.
2. When the reactor was shifted from the submergence level of 70% to 100%, the sludge changed its color from light brown to black. A lot of sludge sloughed off as well.

3.8 Analysis of Parameters

Table 3.4 shows the tests performed, the methods and their references. Using these test results comparisons were drawn to analyses parameters.

Table 3.4: Parametric Analysis for Wastewater

Parameters	Methods	Equipment/Material	References
Chemical Oxygen Demand COD (mg/l)	Close reflux method	Millipore Filtration Assembly, COD digester, Electronic filtration Unit	APHA, 2012
Total Suspended Solids TSS (mg/l)	Gravimetric method	Whatman filter papers, oven , Graduated cylinder, filtration assembly, china dishes, desiccator, analytical balance	APHA, 2012
Ammonium-Nitrogen Total Kjeldhal Nitrogen	Kjeldhal Method	Kjeldhal apparatus	

3.9 Total Suspended Solid Determination

For testing the total suspended solids, a filtration assembly with a Whatman filter papers with a pore size of 1.5 µm, were used. A sample of approximately 50mL volume was passed through the filter paper through the filtration assembly. The filter papers were placed in an oven at 103°C for 2 hours to remove any moisture present in the filter papers. The temperature of the filter papers is brought down to room temperature by placing them in a desiccator. the filter papers were again weighed after the oven drying. The total suspended solids were then determined by using the following formula

$$TSS\ (mg/L) = \frac{(A-B)\times 1000}{Volume\ of\ Sample\ in\ mL}$$

Where,

A = Initial weight of filter paper

B = Weight of filter paper after oven drying

3.10 Total Kjeldhal Nitrogen Determination

The Kjeldahl analysis was done for each run, it has three main steps:

Digestion:

Take 25mL sample and carefully add 12.5mL digestion reagent. Dilute it by adding 200mL of distilled water in a distillation flask. Now heat under the hood to remove the acid fumes. Let the solution boil until the volume is reduced to around 25 to 50mL and copious fumes are observed. Let the digestion continue for further 30 minutes. As the digestion progresses, the colored or turbid samples become pale green or transparent. Let the mixture cool.

pH adjustment:

Add Sodium hydroxide-sodium thiosulfate reagent drop by drop, until the pH reaches 7.

Distillation:

Place the mixture in a Kjeldahl flask and fix it on the stand. Make sure it is properly fixed. Now distill the solution. Collect 20mL from it. 50 mL indicating boric acid is used as absorbent solution.

Titration:

Titrate against 0.02 N NaOH until light pink end point is obtained.

$$TKN\ (\frac{mg}{L}) = \frac{A - B}{Sample\ Volume} * 100$$

Where,

A = Sample Concentration

B = Blank Concentration

3.11 COD Determination

A COD vial was prepared by adding 3.5 mL sulfuric acid reagent, 2.5 mL sample and 1.5 mL potassium dichromate. This vial was digested in COD digester for 2 hours. For the titration, 2 drops of orthophenanthroline ferrous complex (Ferroin) indicator were added to this mixture and titrated against ferrous ammonium sulfate (FAS) until red brown color appears.

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

Where,

A = Volume of FAS used to titrate blank mL

B = Volume of FAS used to titrate sample mL

N = Normality of FAS

3.12 Lab vs Pilot Scale Design:

Table 3.5: Design Calculations for Lab scale and Pilot scale plant

Parameters	Lab Scale	Pilot Scale
Volume (m^3)	0.06	71.87
HRT (Hrs)	8	8
Flowrate (m^3/day)	0.18	215.62
Surface Area Required (m^2)	2.592	3105
Overall Organic Loading (BOD/m^2.d)	8.64	8.64
Hydraulic Loading Rate (m^3/m^2.d)	0.03	0.03
Number of Units of Pall Ring	400	-
Number of Units of MBR Media	750	603000

3.13 Struvite formation

In addition to the treatment of the wastewater, we also formed a fertilizer (Struvite) out of the treated effluent. Since the treated wastewater had high TKN removal rates, therefore we decided to make a fertilizer out of the treated water. Struvite is a salt of Mg, phosphorous and nitrogen. It is made by increasing the pH of the water slightly and then adding $MgCl_2$. The pictures below show the settling of struvite, its texture after filtration followed by oven drying. Although this looks like a powder but they are small granules when formed. The samples were then weighted for further analysis. Figure 3.6 shows struvite.

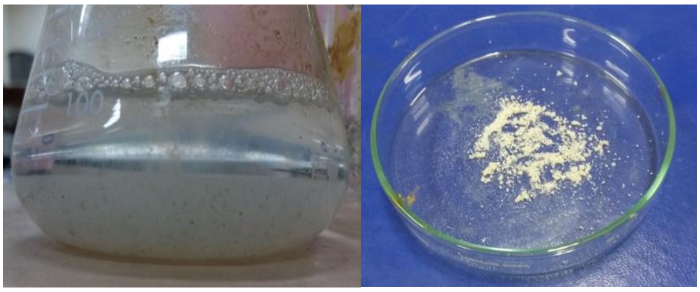

Figure 3.6: Struvite Formation

Chapter 4

Results and Discussion

In this chapter we will be discussing the removal rates of Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and Total Kjeldahl Nitrogen (TKN) for both of our media. A comparison of the two-different media is also performed. In the end we have the conclusions for the optimum submergence value and the type of media for which the setup performs more efficiently.

4.1 Pall ring Media

4.1.2 Chemical Oxygen Demand

The figure 4.1 shows the result for Chemical Oxygen Demand at all three stages for different submergence levels using Pall Ring Media. The error bars are only displayed for 30%, 40%, 70% and combination of 70%, 40%, 40% as the test was repeated for these submergences. The test was performed once for 100% submergence. The red line at 150 mg/l reflects the limit as given by the National Environmental Quality Standards.

The common trend shows that the COD removal is the maximum in third stage but the value of the COD concentration drop is maximum between the first and the second stage. The maximum overall removal of 95% was achieved in 40 % submergence where the COD dropped to 25mg/L from an average of 520 mg/L initial COD. The combination and 70 % have the second and third highest removal following 40 % with removals up to 94 and 91 % respectively.

The results for 40% submergence overall and combination of 70%, 40% ,40% shows that 40% submergence has the most suitable food to microbe to oxygen ratio.

For 100% submergence, removal percentages were the lowest and the trend of highest drop between first and the second stage was also different. In this the max drop is between second and the third stage. Low removal rates achieved were possible low as the sludge turned black (anoxic) from brown (oxic) as submergence was changed from 70 to 100% and a running time of four days might not be enough for the sludge to show effectiveness. Also, the HRT of 8 hours might be less for anoxic conditions.

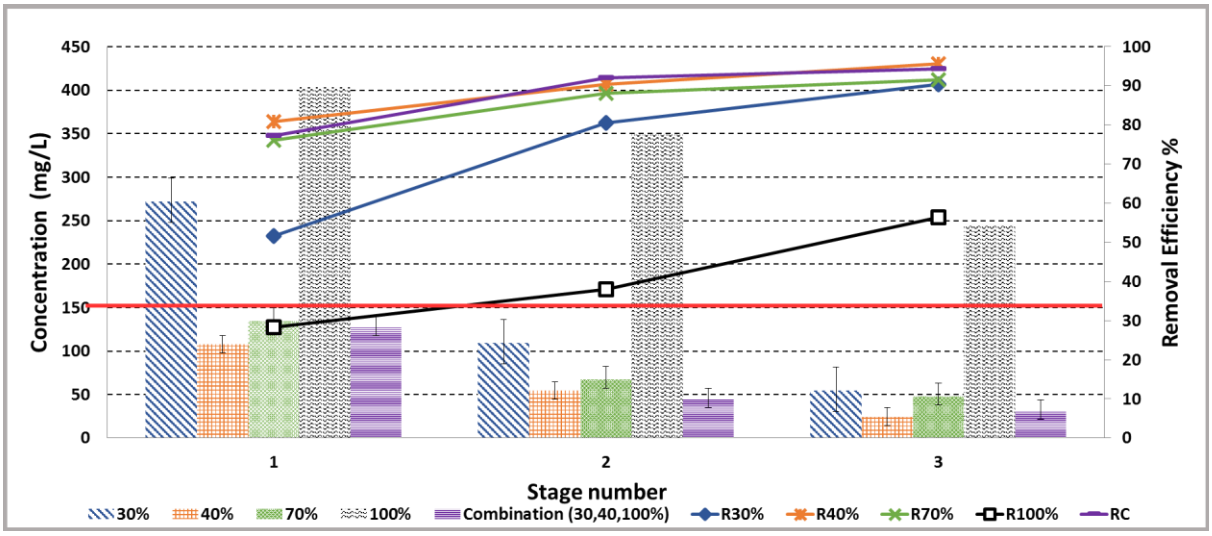

Figure 4.1: COD Removal for different submergence levels using Pall Ring Media

4.1.3 Total Kjheldal Nitrogen

In figure 4.2 the common trend shows that the removal increases considerably between the second and the third stage. This might be due to the reason that as the COD removal decreases, nitrification increases. 70% submergence has the highest removal for the second stage, whereas 40% submergence for third stage.

The maximum overall removal of 71% was achieved in 40 % submergence where the TKN dropped to 13mg/L from an average of 32 mg/L initial TKN. The combinations are also competing with similar percentages, and lies between the 40 and 70% submergence removal rates, acting as their average.

The results for 100% were the lowest as previously discussed under the COD results. Due to the change in submergence from 70 to 100%, efficiency is as low as 19%. Also, the TKN has increased in the third stage as compared to the second stage.

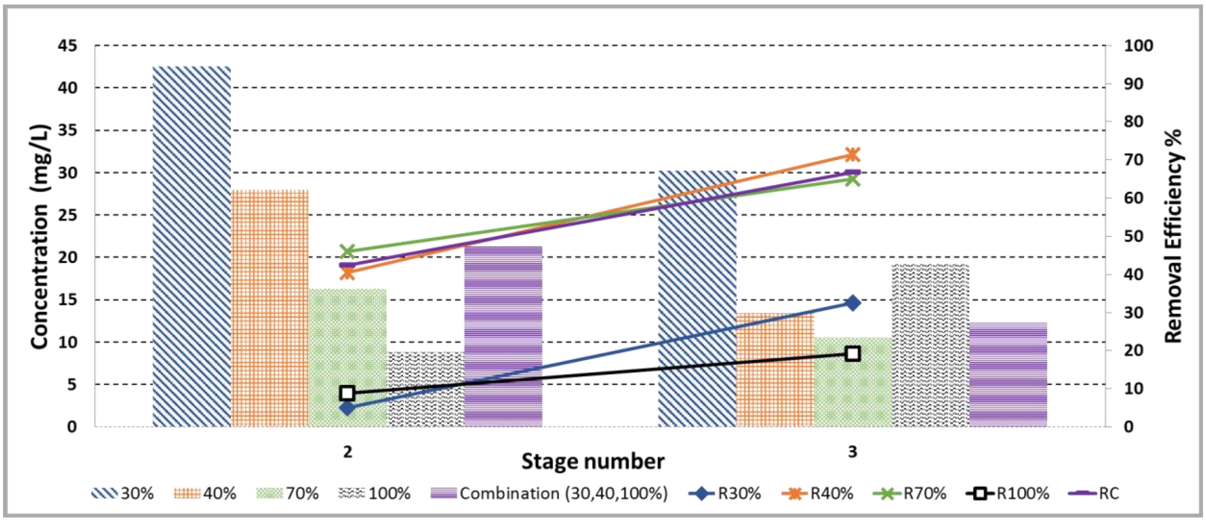

Figure 4.2: TKN Removal for different submergence levels using Pall Ring Media

4.1.4 Total Suspended Solids

The figure 4.3 shows that the TSS concentration varies for various stages in the same submergence level. It is although the least in third stage for all submergence reflecting the process of sedimentation throughout the system. Although the values are very low for most of the submergence and stages, justifying that RBCs are less sludge producers. Also for 100% submergence, it is the highest showing that due to the formation of anoxic conditions, aerobic sludge sloughed off which was replaced by anaerobic sludge. The red line shows the NEQs limit for TSS.

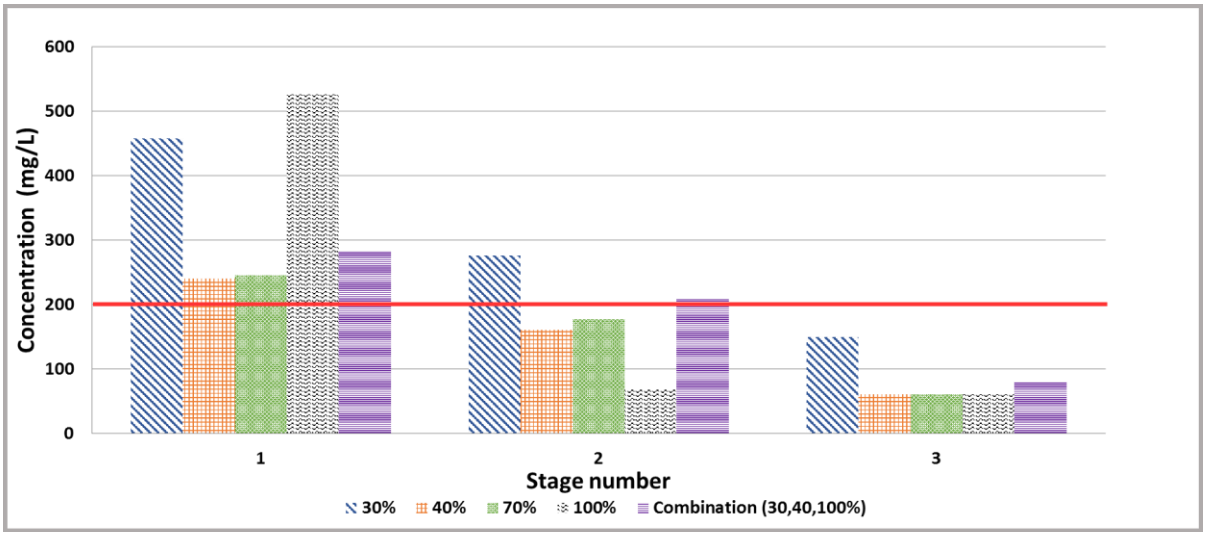

Figure 4.3: TSS Removal for different submergence levels using Pall Ring Media

4.2 MBR Media

4.2.1 Chemical Oxygen Demand

The figure 4.4 shows that the highest removal of 96% was observed in the third stage where the COD dropped to 21 mg/l and the highest COD removal drop can be observed between the first and the second stage.

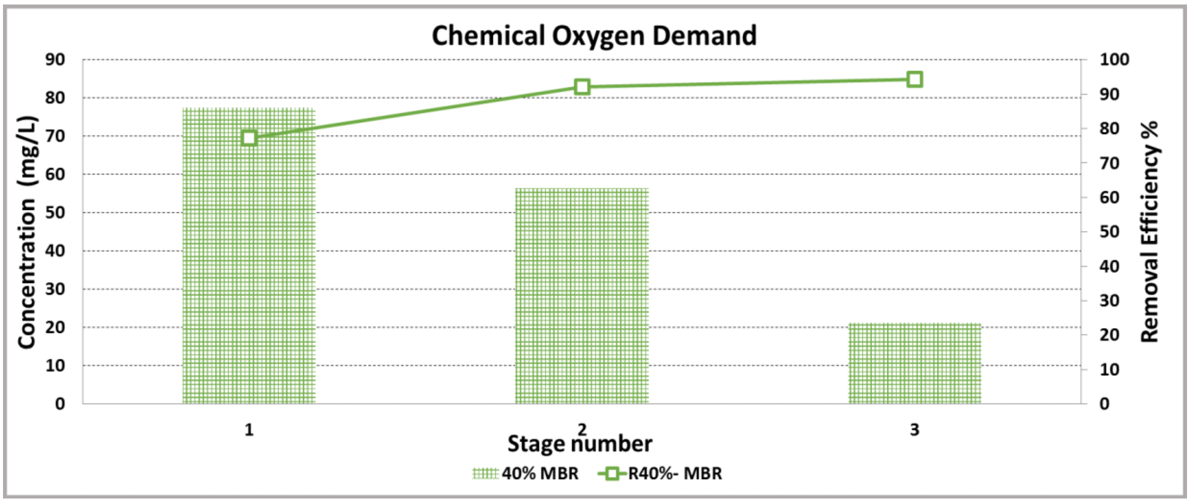

Figure 4.4: COD Removal for 40% submergence level using MBR Media

4.2.2 Total Kjheldal Nitrogen

The figure 4.5 shows that the maximum removal of 73.9% is observed in the third stage where the TKN dropped to 11.2 mg/l from an initial of 32 mg/l.

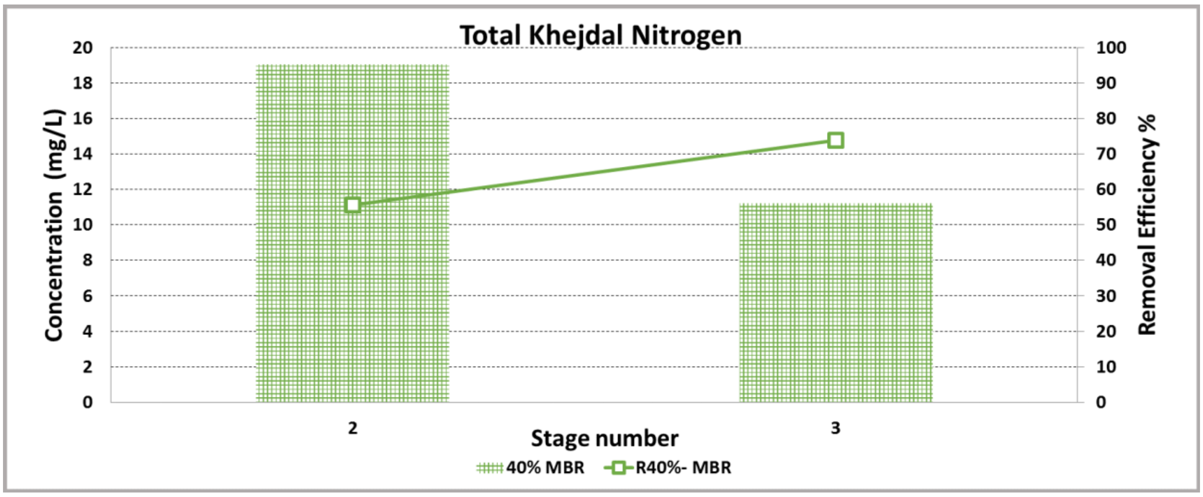

Figure 4.5: TKN Removal for 40% submergence level using MBR Media

4.3 Pall ring vs MBR Media

4.3.1 Chemical Oxygen Demand

Figure 4.6 clearly shows that the removal efficiency for MBR media is higher than Pall ring media at the submergence of 40%. The maximum overall efficiency for Pall ring media is 95% and for MBR media its 96%. Although the Pall ring media performed slightly better at the second stage as the observed removals were 89.9% and 90.3% for Pall ring and MBR media respectively. Although these slight fluctuations reflect that they are very competitive and further runs at varying submergence are required to draw a robust conclusion about the efficiencies of the media.

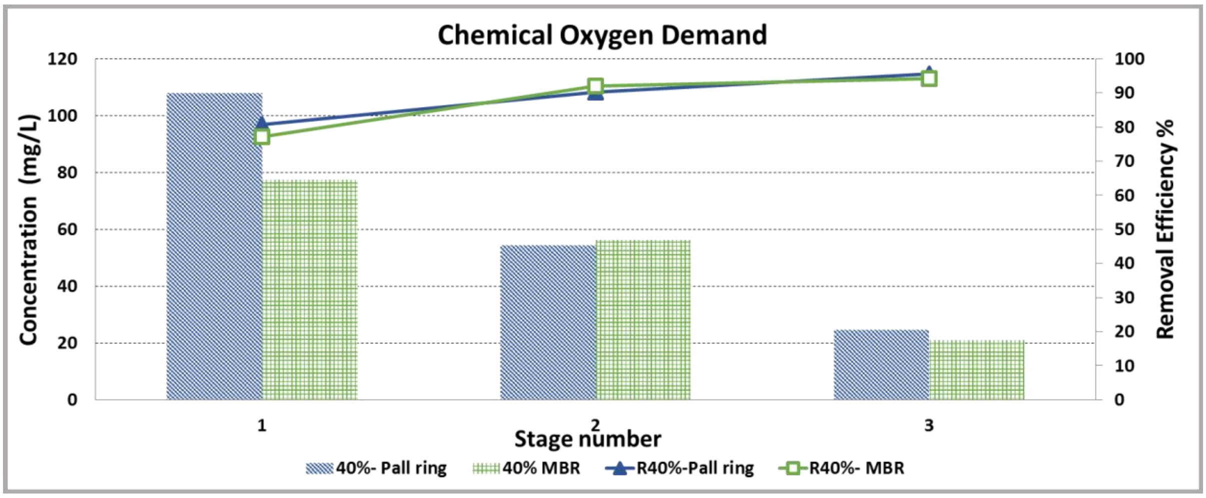

Figure 4.6: Comparison of COD Removal efficiencies for two different media

4.3.2 Total Kjheldal Nitrogen

As far as TKN removal is observed, figure 4.7 shows that the medias differ by a greater percentage as compared to the COD removal. A bigger difference of 15% is observed between the two medias for second stage than for third which is around 2%. Overall efficiency of 74% for MBR media is still greater than the Pall ring media for which it is 71%.

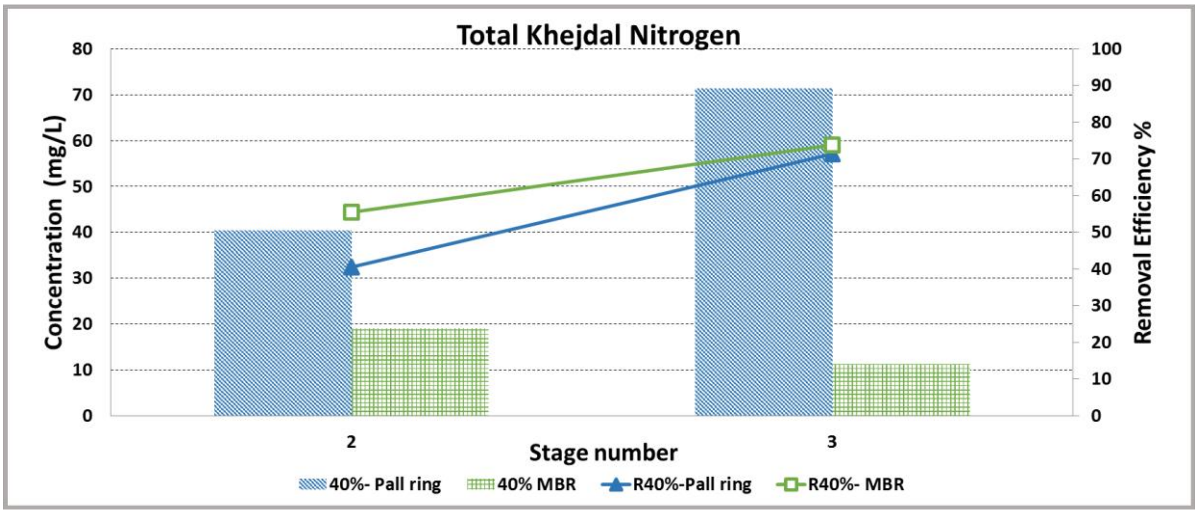

Figure 4.7: Comparison of TKN Removal efficiencies for two different media

Chapter 5

COST AND BENEFIT ANALYSIS

Decision to select a mechanical technology like RBC is always questioned as it is assumed to have high energy requirements. Feasibility of a technology like RBC can't be justified by only looking at its requirements. Any system without the quantification of the benefits is a burden. To pass a verdict on RBC's feasibility, a cost and benefit analysis was performed.

Since this study was conducted particularly for Jatoi, three scenarios related to that area were considered in order to compute the costs and benefits. Keeping in mind the minimum flows, only 90% of the total product water produced annually is used in calculations. Also, a maintenance cost of 5000 Rupees per month is assumed.

The first scenario labelled as do nothing reflects the current situation of the peri urban region where extensive dumping of wastewater into adjacent empty plots with no effort to isolate it from the public is the norm. For the second and the third case RBC is installed and the product water after tertiary treatment is used to extract struvite and irrigate cotton. In the second study the cotton is quantified in terms of the selling price whereas for the third study it is used extract bioethanol.

5.1 Cost Discussion

Since the RBC setup has a motor installed which is far beyond its actual requirement, several papers were reviewed and value for an average of kilowatts per cubic meter of wastewater treated was estimated and it came out to be 0.2kWh/m3. For the pilot scale plant at Jatoi, the total cubic meters of raw wastewater are equal to 215.6m3 per day. The commercial cost per unit of kWh is 4 Pakistani rupees. Thus,

Total electricity consumption cost= 215.6*4*365= 314776 Rs

To estimate the cost of the stainless-steel body, the following dimensions are assumed:

If height and width is assumed to be 4 meters, then length equals 13.475 meters

Total surface area equals= (4*4*2) + (13.475*3) = 72.425m2 * 4mm thickness= 0.2897m3 volume

Mass= 0.2897 * 7700= 2230.7 kg, assuming the density of the steel equals 7700 kg/m^3

Price of stainless-steel is 155Rs/kg thus cost of stainless steel body= 345758.5 Rs

According to the dimensions stated above a single Marla of land is enough to install the RBC unit and land cost in Jatoi is as follows:

One Marla cost= 50,000 rupees

Considering the rising concerns about the health effects of micropollutants and the inability of the secondary biological treatment system to remove these, a tertiary treatment system using carbon nanotubes is proposed.

200 cubic meters of water is treated using 1 square meter of CNTs surface produce this surface area and to produce this surface area 8 grams of CNTs are required. 1 sq. meter membrane of CNTs should cost $ 7.2. Thus,

CNTs tertiary treatment cost= 60,000 rupees

To produce bioethanol, its water footprint is 1981L water/1L bioethanol

Since, biofuel production energy requirement is half the output generation= 999124 Rupees

5.2 Benefits Discussion

Due to the open dumping of the wastewater, Pakistan's economy faces huge losses due to water borne diseases like Diarrhea. Installing a wastewater treatment plant at Jatoi, will save these costs. According to the literature, 719 Pakistani rupees per person annually can be saved if diarrhea related expenditures are mitigated. Thus for 250 households of Jatoi, the total number of people equals 1250 assuming 5 people per house.

Diarrhea related savings= (1.3*10^9*115)/207774520= 719.5 rupees/person/annually

Total savings= 719.5*1250=899375 Rupees

As one ton of high quality struvite costs $1380, it is assumed that the produced struvite from product water is only 50% good in quality compared to this.

Since, 100ml produced 275mg of struvite, 90% of the total generated of treated wastewater which is 70832.8 cubic meters will produce 214.72 tons of struvite.

Struvite earnings = 690*115*214.72= 34569992 Rs

Harvested seed cotton is sold for 4000 Pakistani rupees per 40 kg of seed cotton. Water footprint for seed cotton is 4029m3 of water used per ton and thus 17.6 tons of cotton can be produced per year.

Earnings= (15948*4000)/40 = 1594800 Rs

353 litres of bioethanol is produced from a ton of seed cotton and that makes a total of 6205.74 liters of ethanol in total that can be extracted. The cost of bioethanol per liters is $2.8. Thus,

Earnings= 1998248 Rs

Table 5.1 shows the results of the feasibility analysis. The cost and benefit ratio for scenario one and scenario two is 0.19 and 0.33 respectively. The Cost-Benefit ratios shows that it is practicable to install RBC as the value is less than 1. Although this analysis not very detailed, out of the three scenarios the most profitable one is when cotton is harvested and sold out, that saves about 48 lacs per year. The DN scenario shows that 8.9 lacs per year are lost in a peri urban region due to poor sanitation.

Table 5.1: Cost and Benefit Analysis

Costs		**Do Nothing**	**Scenario 1**	**Scenario 2**
		Price in rupees		
Operating Costs	314776	0	314776	314776
Capital costs (Motor, Gear, Stainless steel)	7,00,000	0	700000	700000
Maintenance Cost	60,000	0	60,000	60,000
Production of Bioethanol	9,99,124	0	0	9,99,124
Poor Sanitation for ALL	89,8750	89,8750		
CNTs for Tertiary Treatment	60,000		60,000	60,000
Sum		89,8750	11,34,776	21,33,900
		Benefits		
Irrigation of Cotton	15,94,800	0	1594800	0
Bioethanol	19,98,284	0	0	19,98,284

Struvite	34,56,992	0	34,56,992	34,56,992
Good Sanitation	9,28,155	0	9,28,155	9,28,155
Sum		0	59,79,947	63,83,395

Chapter 6

Conclusions and Recommendations

From all the results discussed earlier it is concluded that:

- The percentage removal rates for COD and TKN is maximum at a submergence of 40%, followed by 70% for the Pall Ring Media.
- The MBR Media gives 0.62% and 2.41% more COD and TKN removal respectively than Pall Ring Media at 40% submergence, although further studies can be conducted for a fair comparison.
- Lab scale removal efficiencies and feasibility calculations encourage upscale of the system.
- The overall removal efficiency of the rotating biological contactors came out to be 93.4%.
- The Rotating Biological Contactors are energy efficient treatment systems than other treatment technologies and can be implemented in peri-urban regions like tehsil Jatoi.
- The treated wastewater from the RBCs can be re-used for agriculture purposes.

In the future, further research can be conducted on lab scale RBC by testing for changes in the composition of product water by achieving the effect of nitrification and denitrification. This can be achieved by varying the submergence level in consecutive stages and recycling the water from the third stage to the first.

More media material can be tested to find the most effective product in terms of removal efficiency, life time and power consumption. Also, a lot of other RBC parameters discussed in the literature review can be tested.

References

A. Tawfik, H. T. (2006). Sewage Treatment In A Rotating Biological Contactor (Rbc) System. Water, Air, And Soil Pollution, 275–289.

Abdel-Kader, A. M. (2013). Studying The Efficiency Of Grey Water Treatment By Using Rotating Biological Contactors System. Journal Of King Saud University – Engineering Sciences, 89-95.

Apilfinez, A. G. (1998). Effect Of Surface Materials On Initial Biofilm Development. (E. S. Ltd., Ed.) Bioresource Technology, 225-230.

Aiyuk, S., Forrez, I., Lieven, D.K., Van Haandel, A., Verstraete, W., (2006). Anaerobic And Complementary Treatment Of Domestic Sewage In Regions With Hot Climates — A Review. Bioresour. Technol. 97, 2225–2241

J.L. Clayton And J.D. King U.S. Effects Of Weathering On Biological Marker And Aromatic Hydrocarbon Composition Of Organic Matter In Phosphoria Shale Outcrop: Geological Survey, Box 25046, Ms 977, Denver Federal Center, Denver, Co 80225, U.S.A

Jonathan Parkinson, Kevin Tayler. Decentralized Wastewater Management In Peri-Urban Areas In Low-Income Countries.

Koichi Fujie, H. E. (1983). Operational Design And Power Economy Of A Rotating Biological Contactor. Water Res., 17, 1153-1162.

Martin K Jaison, M. K. (2017, March). Performance Analysis Of Rotating Biological Contactor With Polypropylene And Wool Media. International Journal Of Civil Engineering And Technology (Ijciet), 8, 771–777.

M. Starkl, M. Phansalkar, R.K. Srinivasan, E. Roma, T.A. Stenström, Evaluation Of Sanitation And Wastewater Treatment Technologies. Centre For Environmental Management And Decision Support (Cemds) And University Of Natural Resources And Applied Life Sciences, Vienna, Austria

S. Cortez, P. T. (2008, January 24). Rotating Biological Contactors: A Review On Main Factors Affecting Preformance . Rev Environ Sci Biotechnol, 155–172.

Susan M. Parten, P.E.. Analysis Of Existing Community-Sized Decentralized Wastewater Treatment Systems: Community Environmental Services, Inc. (Ces) 2008

T. Panswad, C. P. (1988). Water Pollution Control In Asia. International Association Of Water Pollution Research And Control.

Zhiqiang Chen, Q. W. (2006). Simultaneous Removal Of Carbon And Nitrogen From Municipal-Type Synthetic Wastewater Using Net-Like Rotating Biological Contactor (Nrbc). Process Biochemistry, 2468–2472.