DOWN HANGING SPONGE SYSTEM FOR WASTEWATER TREATMENT

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DOWN HANGING SPONGE SYSTEM FOR WASTEWATER TREATMENT

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Chemical Engineering with Honours

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DECLARATION

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

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APPROVAL FOR SUBMISSION

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ABSTRACT

In September 2015, the Sustainable Development Goals (SDGs) were established to address global challenges, including ensuring access to clean water and sanitation (SDG 6). Despite this, water scarcity remains a significant issue worldwide, exacerbated by factors such as population growth and uneven development. The water crisis and pollution in Malaysia, particularly in the state of Selangor, present significant challenges to both urban and rural populations. This study investigated the efficacy of the Down Hanging Sponge (DHS) system as an alternative to conventional wastewater treatment methods in addressing these pressing issues. After existing water crisis scenario and conventional biological wastewater treatment methods were reviewed, the study focused on the design and evaluation of a laboratory-scale DHS-G3 reactor for wastewater treatment. The DHS-G3 reactor designed utilized easily accessible materials such as plastic containers, bioballs, and straws as well as featuring a two-segment design. Notably, the DHS-G3 reactor demonstrated remarkable performance in COD removal efficiency and nitrification efficiency. The reactor exhibited efficient nutrient removal, with COD removal efficiency ranging from 68.84 % to 98.37 % and nitrification efficiency ranging from 16.08 % to 62.71 %. Despite encountering challenges related to limited denitrification activities of 4.44 % to 30.0 %, the DHS-G3 reactor’s performance underscored its potential as a cost-effective and sustainable solution to Malaysia's water treatment challenges, as external aeration systems were not needed. This research highlighted the promise of the DHS system in providing cleaner water for all Malaysians while promoting environmental sustainability.

TABLE OF CONTENTS

DECLARATION		**i**
APPROVAL FOR SUBMISSION		**ii**
ACKNOWLEDGEMENTS		**iv**
ABSTRACT		**v**
TABLE OF CONTENTS		**vi**
LIST OF TABLES		**ix**
LIST OF FIGURES		**x**
LIST OF SYMBOLS / ABBREVIATIONS		**xi**
LIST OF APPENDICES		**xii**

CHAPTER

1	**INTRODUCTION**	**1**
	1.1 Importance of Water in Human Activities	1
	1.2 Water Crisis and Water Pollution in Malaysia	2
	1.3 Wastewater and Nutrients	3
	1.4 Wastewater Treatment	4
	1.5 Conventional Biological Wastewater Treatment	5
	1.6 Down Hanging Sponge (DHS) System	6
	1.7 Problem Statement	7
	1.8 Objectives	8
	1.9 Scope of Study	8
	1.10 Structure of Dissertation	9
2	**LITERATURE REVIEW**	**10**
	2.1 Water Pollution	10
	2.2 Wastewater Treatment in Malaysia	12
	2.2.1 Individual Septic Tank (IST)	12
	2.2.2 Conventional Activated Sludge Process (ASP)	13
	2.2.3 Membrane Bioreactor (MBR)	13

		2.2.4 Moving Bed Biofilm Reactor (MBBR)	14
	2.3	Malaysia's Wastewater Treatment Regulation	15
	2.4	Different Configuration of DHS System	16
	2.5	Factors Affecting the Performance of DHS	21
		2.5.1 Effect of Sponge Media Design	22
		2.5.2 Effect of Hydraulic Retention Time	24
		2.5.3 Effect of Organic Loading Rate	26
		2.5.4 Ventilation	27
	2.6	Application of DHS Reactor in Other Countries	28
3	**METHODOLOGY AND WORK PLAN**		**31**
	3.1	Introduction	31
	3.2	Experimental Setup	32
	3.3	Procedure	33
		3.3.1 Synthetic Wastewater Preparation	34
		3.3.2 Biofilm Formation on Sponge Media	34
	3.4	DHS-G3 Reactor Performance Analysis	36
		3.4.1 COD Analysis	36
		3.4.2 Nitrogen and Ammoniacal Component Analysis	38
4	**DESIGN DETAILS OF DHS REACTOR**		**39**
	4.1	Introduction	39
	4.2	DHS Reactor Design	39
	4.3	Operation Conditions	42
5	**NUTRIENT REMOVAL AND COD REMOVAL WITHIN DHS-G3 SYSTEM**		**45**
	5.1	Introduction	45
	5.2	Optimum Condition for Phase 1	45
	5.3	Concentration Profiles	46
	5.4	Nitrogen Removal	48
	5.5	COD Removal	53
6	**CONCLUSIONS AND RECOMMENDATIONS**		**58**
	6.1	Conclusions	58
	6.2	Recommendations for future work	59
REFERENCES			**61**

APPENDICES **66**

LIST OF TABLES

Table 2.1: DOE Water Quality Index Classification (Goi, 2020). 11

Table 2.2: Existing Sewage Treatment System (approved after January 1999). 15

Table 2.3: New Sewage Treatment System (approved after October 2009). 16

Table 2.4: Removal Performance of Six Generation of DHS (Nurmiyanto and Ohashi, 2019). 18

Table 2.5: Set Up and Drawbacks of Different Generation of DHS (Adapted from Nurmiyanto and Ohashi (2019); Tyagi et al. (2021)). 19

Table 2.6: Selected DHS Performance Data at Different Countries. 29

Table 3.1: Concentrated Synthetic Wastewater Contents and Concentrations. 34

LIST OF FIGURES

Figure 1.1: Status of Pipe Water Access in Each State for 2014 and 2016 (Adapted from Sarbatly, Lahin and Chiam, 2020). 3

Figure 2.1: River Water Quality from 2008 to 2017 (Adapted from Goi, 2020). 12

Figure 2.2: Operational Principle of DHS-G3 Sponge (Adapted from Tyagi et al. (2021)). 22

Figure 2.3: Different Sponge Media Designs (Tyagi et al., 2021). 24

Figure 2.4: Oxygen Concentration in DHS and DO Concentration in Wastewater at Various Height of DHS (Onodera et al., 2014). 28

Figure 3.1: Sponge Medium Encased in Spherical Support Structure. 32

Figure 3.2: Schematic Diagram of DHS-G3 Reactor with Sponge Media Encased in Spherical Structure. 32

Figure 3.3: Flowchart of the Experiment Procedure of DHS-G3 Reactor. 33

Figure 3.4: Cultivation of Activated Sludge on Sponge Media. 36

Figure 3.5: Digital Reader Block, DRB 200. 37

Figure 3.6: HACH DR 3900 Sectrophotometer. 37

Figure 4.1: Design of DHS-G3 Reactor: (a) Schematic Diagram of DHS-G3 Reactor, (b) Laboratory Set-up of DHS-G3 Reactor. 39

Figure 4.2: Distribution Design: (a) Straw Distributor, (b) Bottle Cap. 40

Figure 5.1: Nitrate Nitrogen ($NO_3{}^{-}-N$) Concentration Profile on Different Days during Phase 1. 47

Figure 5.2: Chemical Oxygen Demand (COD) Concentration Profile on Different Days during Phase 1. 48

Figure 5.3: COD Removal, Nitrification and Denitrification Efficiency of DHS-G3 Reactor. 51

Figure 5.4: COD Removal Efficiency of DHS-G3 Reactor. 54

LIST OF SYMBOLS / ABBREVIATIONS

SDG	Sustainable Development Goals
TSS	Total Suspended Solids
COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
TN	Total Nitrogen
DHS	Down Hanging Sponge
DHS-G3	Third Generation Down Hanging Sponge
ASP	Activated Sludge Process
MBR	Membrane Bioreactor
MBBR	Moving Bed Biofilm Reactor
TF	Trickling Filter
ISP	Individual Septic Tank
UASB	Upflow Anaerobic Sludge Blanket
WWTP	Wastewater Treatment Plant
SRT	Sludge Retention Time
HRT	Hydraulic Retention Time
OLR	Organic Loading Rate
DO	Dissolved Oxygen
WQI	Water Quality Index
DOE	Department of Environment
EQA	Environmental Quality Act 1974

LIST OF APPENDICES

Appendix A: Results Table 66

CHAPTER 1

INTRODUCTION

1.1 Importance of Water in Human Activities

In September 2015, a significant milestone was reached when a collection of interlinked global goals was created to address some of the world's most pressing challenges. These goals aimed to end all forms of poverty, combat inequalities, and confront the impacts of climate change. Over the past 8 years, these goals, known as the Sustainable Development Goals (SDGs), have been adopted by all 193 countries to serve as a comprehensive framework guiding countries towards sustainable development. Among the 17 SDGs, SDG 6 focuses on ensuring easy access to clean water, sustainable management of water sources, and sanitation for all.

It comes as no surprise that the world heavily relies on water, as most human activities are dependent on access to clean water. However, it's easy to assume that water is readily available, when in reality, usable freshwater is incredibly scarce. Water scarcity refers to the insufficiency of water to meet the needs of humans, the economy, and the environment. According to WWF (2023), an estimated 2.7 billion people experience water scarcity for at least one month each year, highlighting the occurrence of water scarcity when water withdrawals surpass its availability. This indicates that water stress is happening when the demand for water exceeds its supply.

In an article by Salehi (2022), it was highlighted that the issue of water shortage is rapidly escalating, affecting a growing number of residential, commercial, industrial, and agricultural consumers worldwide. United Nation (2017) reported that the world population is projected to increase to 8.6 billion by 2030, 9.8 billion by 2050, and 11.2 billion by 2100, indicating a significant rise in global water demand. Presently, it is predicted that global water demand will surpass the anticipated supply by 40% by 2030 (World Economic Forum, 2023), underscoring the concerning pattern of a water crisis.

In low-income countries, the availability of clean water is severely restricted, resulting in people of all ages and genders having to walk long distances under the scorching sun to fetch drinkable water (Tan, 2021).

Consequently, to achieve the aforementioned SDG 6 of the UN2030 agenda, there is an urgent need to develop affordable and efficient technology for wastewater treatment in these developing nations. Such advancements would ensure a safer and improved quality of life for the residents in developing countries.

1.2 Water Crisis and Water Pollution in Malaysia

Over the past few decades, water crisis has become a pressing national concern in Malaysia, with a particular focus on the state of Selangor (Loi et al., 2022). Selangor, including the Federal Territories of Kuala Lumpur and Putrajaya, is home to 9.08 million citizens (Department of Statistics Malaysia, 2020). As a result, any water disruption in the region would have a significant impact, affecting 28 % of Malaysia's population. Given that Selangor is one of the most populous and developed states in the country, the issue of water scarcity in Selangor holds even greater importance. According to a news article by Tuan (2021), in the year 2020, alone, there were a total of 24 cases of water disruption recorded in Selangor and the Federal Territories of Kuala Lumpur. Among these cases, 5 were attributed to water pollution, while the remaining disruptions were caused by incidents such as pipe bursts, maintenance work, low water pressure, and power outages in the water treatment plants. Unfortunately, although it is common sense that dumping chemicals into rivers will definitely pollute the water, industrial waste dumping remains a recurring issue that needs to be addressed in Malaysia. For example, in 2022, 472 areas in Selangor and Putrajaya were affected by the illegal dumping of perfume essence into the river, leaving most homeowners without access to clean water on Christmas Eve (Chan, 2022). As the people of Selangor rely on 3 main river basins (Selangor River basins, Klang River basins, and Langat River basins), proper treatment for these river basins is important.

On the other hand, uneven development across Malaysia has led to disparities in water distribution networks. Water distribution networks in Malaysia are primarily managed centrally in major towns and cities, while regional water networks cater to smaller towns (Sarbatly, Lahin and Chiam, 2020). However, this setup casts shadows on rural areas, where rural populations continue to face difficulties in accessing treated water supply.

Figure 1.1 highlights that in less developed states such as Kelantan, Sabah, and Sarawak, obtaining clean pipe water remains a significant issue, leading many to seek alternative water sources on their own. For instance, a community project manager, Yeoh (2021), reported that in Kg. Orang Asli Tibang Ulu, untreated water is currently sourced from a makeshift gravity-fed dam. Tragically, villagers also shared that it is common for them to suffer from diarrhoea after drinking the water, indicating the severe consequences of relying on unsafe water sources. Hence, addressing these challenges necessitates implementing a solution that is cost-effective and easy to maintain for efficient removal of nutrients, ensuring access to clean and safe water for everyone.

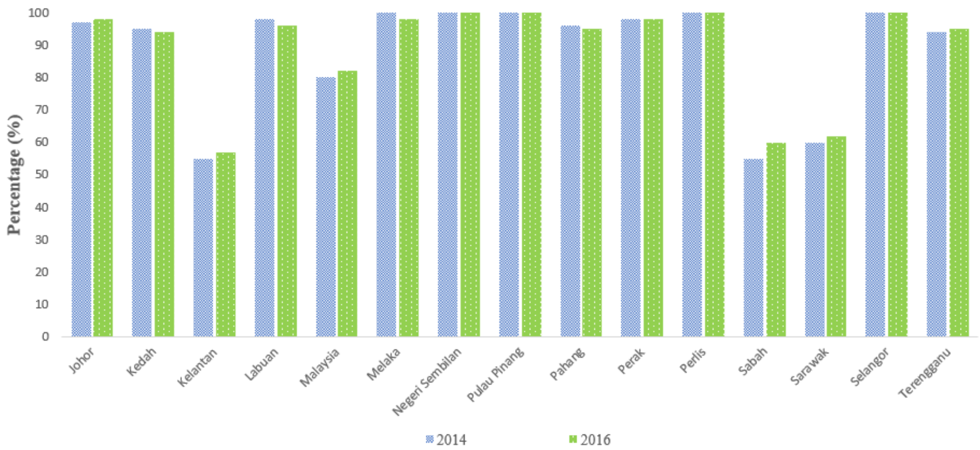


Figure 1.1: Status of Pipe Water Access in Each State for 2014 and 2016 (Adapted from Sarbatly, Lahin and Chiam, 2020).

1.3 Wastewater and Nutrients

In simple terms, the primary cause of water pollution is wastewater. Wastewater, also called sewage or effluent, is water that has been used and affected by various activities in homes, industries, and businesses. Generally, there are 3 main types of wastewaters. Firstly, domestic wastewater comes from residential areas, including water used in toilets, bathrooms, and kitchens in households. Secondly, commercial wastewater comes from non-domestic sources like beauty salons or vehicle repair shops, where water is used in their operations. Thirdly, industrial wastewater is discharged from manufacturing processes in industries such as petrochemical, textile, electroplating, pharmaceutical, and food production. When wastewater is not treated or disposed of in a proper manner, it will contaminate any water bodies, leading to water pollution and posing a threat to both human health and mother nature.

The composition of wastewater can vary depending on its sources, but typically, it contains organic matter, nutrients (including nitrogen and phosphorus), suspended solids, pathogens, and chemical pollutants. While some of these nutrients, like nitrogen and phosphorus, are essential for plant growth, an excessive amount of them can lead to environmental issues. The main forms of nitrogen in wastewater are ammonium ($NH_4{}^+$), nitrite ($NO_2{}^-$), and nitrate ($NO_3{}^-$), which become more toxic when it transforms into ammonia (NH_3) (Kotcharoen et al., 2023). Phosphorus is found in wastewater mainly as phosphate. To regulate the discharge of treated water into inland waters or Malaysian waters, the Environmental Quality (Sewage) Regulations 2009 specify the accepted levels of certain parameters. For example, by following the existing sewage treatment system guidelines approved after January 1999, the accepted level of Ammoniacal Nitrogen in treated sewage is 50 mg/L, while total suspended solids (TSS) and Chemical Oxygen Demand (COD) are acceptable at 100 mg/L and 200 mg/L, respectively.

When wastewater containing an abundance of nitrogen and phosphorus is discharged into water bodies, it can lead to a phenomenon called eutrophication. Eutrophication occurs when these nutrients increase primary productivity, promoting the growth of algae, nuisance plants, and weeds (NIWA, n.d.). As a consequence, the water body becomes excessively enriched with organic matter, resulting in a decrease in oxygen levels through the process of decomposition. This reduced oxygen content in water leads to the degradation of water quality and can harm aquatic life (Tuser, 2021).

1.4 Wastewater Treatment

Wastewater treatment is a crucial process that plays a vital role in safeguarding our environment and public health. It involves the removal of pollutants and contaminants from wastewater, transforming it into a state that is safe enough for discharge back into natural water bodies or even for potential reuse. The treatment process typically comprises three essential stages: primary treatment, secondary treatment, and tertiary treatment.

During the primary treatment of wastewater, physical processes take place where large debris, such as sticks, plastics, and other solid materials, are removed through screening and grit chambers. The wastewater then flows into primary clarifiers, where heavier particles settle to the bottom, forming a sludge layer, while the relatively clearer water moves on to the secondary treatment phase.

In the secondary treatment stage, the focus shifts to transforming dissolved and fine suspended organic materials that cannot be effectively removed by physical means. This is where biological treatment takes the spotlight. During this stage, microorganisms, such as algae, fungi, or bacteria, play a pivotal role in breaking down the organic matter (in the wastewater) under aerobic or anaerobic conditions (Samer, 2015). These microorganisms digest the organic matter, converting it into harmless byproducts like carbon dioxide, water, and more sludge. The resulting mixture, known as activated sludge, is then separated from the treated water using secondary clarifiers.

Finally, the tertiary treatment, also known as chemical treatment, is employed to further polish the wastewater to meet stringent water quality standards. This advanced treatment stage utilizes the addition of specific chemicals to target and remove the remaining contaminants. However, according to Samer (2015), due to the environmental problem of disposing large amounts of chemical sludge and the cost of chemical additives, the chemical treatment of wastewater is seldom used. As an alternative, biological treatment is utilized to further treat the wastewater, such as the Down Hanging Sponge (DHS) System, which will be further discussed in this paper.

1.5 Conventional Biological Wastewater Treatment

Biological wastewater treatment relies on bacteria, nematodes, and other small organisms to break down organic waste (Fluence News Team, 2020). One primary example of conventional biological wastewater treatment is the activated sludge process (ASP). This widely used aerobic wastewater treatment method is employed for both domestic and industrial wastewater. In this process, an aerobic stirred tank bioreactor is seeded with an inoculum of microbial sludge (Narayanan and Narayan, 2019). To prevent the microbes from remaining in suspension, air is introduced under high pressure using a large compressor, which can result in higher operational costs.

Furthermore, anaerobic biological treatment is another example of biological wastewater treatment that occurs in the absence of oxygen. A notable application of this method is anaerobic digestion, which not only breaks down organic matter but also repurposes and converts the organic matter into valuable products such as biogas and biofertilizers. This sustainable approach significantly contributes to waste-to-energy initiatives. However, this treatment method may have a slower pathogen elimination rate (Narayanan and Narayan, 2019). To accelerate the digestion rate, a heating utility can be employed which would introduce additional installation and operational costs.

Additionally, trickling filter (TF) system is an example of a biological treatment method where rocks or plastic media are utilized to treat wastewater. The substantial specific surface area of these media allows for a significant attachment area for the formation of biofilm. These biofilms play a crucial role in breaking down organic waste, converting it into carbon dioxide and water, and simultaneously generating new biomass.

1.6 Down Hanging Sponge (DHS) System

DHS system for wastewater treatment is employed to address many of the drawbacks associated with conventional biological wastewater treatment systems. According to Nurmiyanto and Ohashi (2019), DHS system bears a close resemblance to TF system. However, the key difference lies in the selection of supporting media. The TF system typically utilizes rocks and hard plastic materials, while the DHS system utilizes sponges as its supporting media. In simple terms, wastewater is supplied at the top of the supporting media, and as it flows through the DHS reactor via gravity, it comes in contact with the prokaryotes within and on the sponge media. These prokaryotes actively oxidize the waste present in the wastewater, effectively breaking it down during its passage through the DHS system.

The use of DHS system offers several advantages over conventional wastewater treatment plant (WWTPs). Firstly, the high porosity of sponges allows for the proliferation of biomass, both inside and outside the sponge. This leads to a better biomass concentration and longer sludge retention time (SRT).

As a result, the extended SRT and longer food chains within the biofilm have resulted in the reduction of excess sludge production (Kobayashi et al., 2017). Furthermore, the extended exposure of the sponge media to the atmosphere in the open setup of the DHS system naturally allows oxygen to dissolve into the wastewater as it flows through the system. This eliminates the need for an external aeration system, reducing energy consumption. Additionally, the porous sponge in the DHS system allows for a higher hydraulic retention time (HRT) for the wastewater being treated. This means that the DHS system requires a smaller area compared to a conventional WWTP, making it a space-efficient option for wastewater treatment. Additionally, the DHS system utilizes minimal energy, as the only energy needed is for pumping the wastewater for distribution. This low-energy consumption contributes to the system's cost-effectiveness and sustainability. In conclusion, the DHS system, with its cheap, easy-to-set-up, and widely available sponge media, offers an attractive alternative to conventional WWTPs.

1.7 Problem Statement

The escalating concerns regarding water pollution and the impending water crisis in both rural and urban regions of Malaysia constitute a critical national issue, especially as the nation strives to achieve sustainable development in alignment with the United Nations' SDGs. This mounting challenge is primarily rooted in the existing regional developmental disparities within the country. The increase in the urban population, particularly in Selangor and Kuala Lumpur, worsen water pollution in these areas. Unfortunately, this phenomenon inadvertently diverts attention from crucial rural water treatment efforts. Therefore, there is a pressing need to establish affordable and easily accessible biological wastewater treatment solutions across Malaysia.

The uncontrolled release of hazardous chemicals and toxins from industrial and agricultural activities fosters the growth of algae. This, in turn, leads to eutrophication, a major contributor to the degradation of water quality. To mitigate this phenomenon, biological wastewater treatment is employed. However, conventional WWTPs such as the activated sludge process, anaerobic digestion, and trickling filter system present several disadvantages. These approaches are only available at a higher cost and are also challenging to construct and operate. Besides, external utilities such as heating, and aeration systems are required for the operation of conventional WWTPs. Hence, the DHS system emerges as an attractive alternative to address these problems, given its simplicity, cost-effectiveness, and high nutrient removal efficiency.

1.8 Objectives

The DHS system for wastewater treatment is considered an emerging technology that has not yet gained widespread adoption. Due to its potential in the wastewater treatment industry, extensive studies are being conducted to gather sufficient information for enhancing the performance of the DHS system. The objectives of the present study in this report are:

(i) To design a laboratory scale DHS system for the treatment of wastewater.

(ii) To evaluate the effectiveness and treatment performance of the DHS system for COD and nutrient removal.

(iii) To highlight the targeted pollutant the DHS system is designed to treat.

1.9 Scope of Study

A brief overview of the importance of water, water crisis and water pollution in Malaysia, wastewater and its treatment, conventional biological wastewater treatment, and DHS system are given in Chapter 1. In Chapter 2, a review on DHS system including different generations of configuration, comparative analysis of removal performances of conventional WWTPs and DHS system, and applications of DHS system in other countries will be performed. In Chapter 3, a detailed outline of the experimental procedure, including the setup, biofilm formation from sludge cultivation, effluent collection method, and analytical techniques is given. In Chapter 4, the study's findings are presented and compared to previous experimental results. The focus is on identifying factors influencing the performance of the DHS reactor, such as sponge shape and sizes, ventilation, and climate changes. Finally, Chapter 5 summarizes the main findings from the results and discussions, ensuring that the report's objectives are met. Additionally, this chapter addresses recommendations and limitations associated with the research.

1.10 Structure of Dissertation

The structure of the dissertation is outlined as follows:

(i) A brief introduction of water, wastewater and its treatment system as well as DHS system.

(ii) Literature review on the effectiveness and efficiency of different DHS systems.

(iii) Methodology for the set-up of DHS reactor design and data collection method.

(iv) Design details of the DHS reactor for COD and nutrient removal.

(v) Experimental results obtained and discussion on the significance and implications of the research findings.

(vi) A summary of the main findings of the study as well as limitation and recommendation for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Water Pollution

In this section of the report, an analysis is conducted regarding the global and local water pollution status. The adverse impact of rapid urbanization and development in developing countries on water quality is evident, as contaminants from development activities tend to accumulate in water sources, leading to pollution. Given the universal importance of water, there is a growing competition for water resources among municipalities, businesses, and the agricultural sector (Zhu et al., 2023). According to the World Health Organization (2023), as of 2022, a staggering 2.2 billion people lacked access to safely managed drinking water treatment services. These groups are categorized as follows:

(i) 1.5 billion people with basic services.

(ii) 292 million people with limited services.

(iii) 296 million people collecting water from unprotected wells and springs.

(iv) 115 million people collecting untreated surface water from lakes, ponds, rivers and stream.

Moreover, Filipenco (2022) highlights that a significant 44 % of all wastewaters on Earth is returned to the environment with inadequate or no treatment at all. The situation underscores the urgency of finding wastewater treatment solutions to protect and preserve water quality. This is particularly crucial as numerous individuals currently drinking water from sources that are dangerously contaminated and chemically polluted from agricultural and industrial activities.

In addition, 98 % of water utilized is sourced from rivers; thus, to identify the water quality status of Malaysia, a review on the river water quality in the country is performed. The escalating pace of urbanization in Malaysia has contributed to a decline in river water quality, thereby worsen the issue of river water pollution within the country. By referencing Table 2.1, the Water Quality

Index (WQI), as established by the Department of Environment (DOE), employs a five-class classification system to assess water quality. To elaborate, Class I indicates clean water, and no treatment is required, while Class V is the most severe category where the water is highly polluted and unsuitable for any use.

Table 2.1: DOE Water Quality Index Classification (Goi, 2020).

Parameter	Unit	Class				
		I	II	III	IV	V
Ammoniacal Nitrogen	mg/L	<0.1	0.1–0.3	0.3–0.9	0.9–2.7	>2.7
Biochemical Oxygen Demand	mg/L	<1	1–3	3–6	6–12	>12
Chemical Oxygen Demand	mg/L	<10	10–25	25–50	50–100	>100
Dissolved Oxygen	mg/L	>7	5–7	3–5	1–3	<1
pH	mg/L	>7	6–7	5–6	<5	>5
Total Suspended Solid	mg/L	<25	25–50	50–150	150–300	>300
Water Quality Index (WQI)	mg/L	<92.7	76.5–92.7	51.9–76.5	31.0–51.9	<31.0

In a study conducted by Goi (2020), it was observed that the proportion of clean rivers in Malaysia is declining. In 2017, among the 477 monitored rivers, 219 (46 %) were classified as clean, 207 (43 %) were deemed slightly polluted, and 51 (11 %) were categorized as polluted. These trends in river water quality data, spanning from 2008 to 2017, have been visually represented in Figure 2.1. To provide more specific insights, contamination sources primarily stem from five main sectors: manufacturing industries, agricultural-based industries, sewage treatment plants, piggeries, and wet markets. Notably, Goi (2020) highlights that in 2018, a cumulative BOD pollution load of 653 tonnes/day, suspended solid pollution load of 835 tonnes/day, and Ammoniacal nitrogen load of 205.3 tonnes/day were recorded. To counteract the pollutants, implementation of a biological wastewater treatment becomes imperative. Such measures are necessary to mitigate the detrimental effects of pollution on river ecosystems.

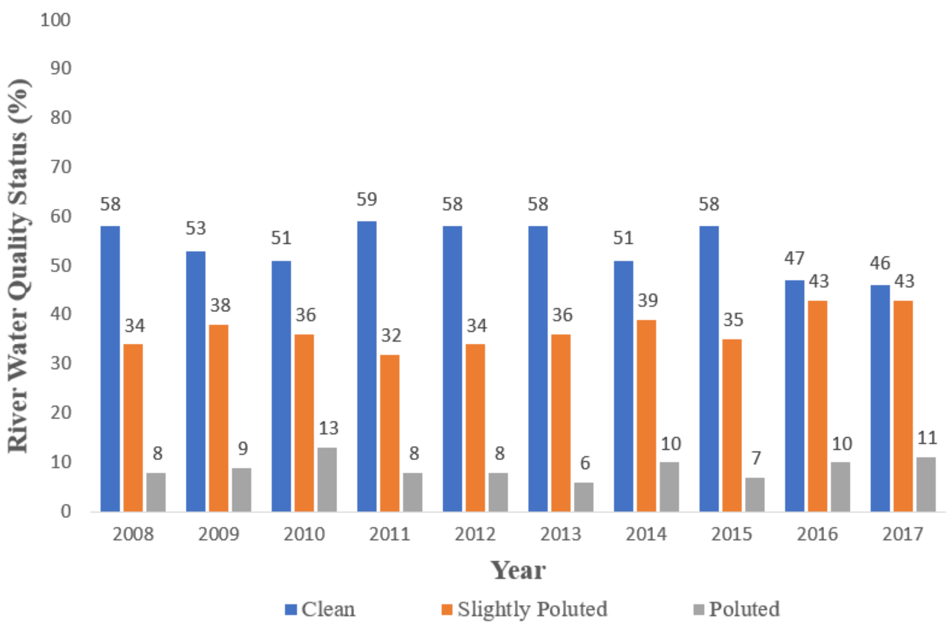


Figure 2.1: River Water Quality from 2008 to 2017 (Adapted from Goi, 2020).

2.2 Wastewater Treatment in Malaysia

As a developing country, Malaysia faces a growing need to manage the diverse and often complex pollutants present in its wastewater. To mitigate the environmental and public health risks posed by untreated wastewater, Malaysia has been investing in wastewater treatment infrastructure and technology. In this section of the report, some of the most commonly used municipal wastewater treatment technologies in Malaysia such as septic tanks, Activated Sludge Process (ASP), Membrane Bioreactor (MBR), and Moving Bed Biofilm Reactor (MBBR) will be discussed.

2.2.1 Individual Septic Tank (IST)

In the country, individual septic tanks (IST) are the most common form of wastewater treatment system. According to (Indah Water, 2023), there are approximately 1.2 million premises in Malaysia equipped with IST. IST represent a simple and cost-effective system that offers basic treatment by separating solids from wastewater. Subsequently, within an anaerobic environment, microbial degradation takes place. However, one of the limitations of this system is the requirement for regular maintenance and proper emptying to prevent groundwater contamination.

2.2.2 Conventional Activated Sludge Process (ASP)

Conventional Activated Sludge Process (ASP) is a widely used biological wastewater treatment process that relies on microorganisms to break down organic matter and nutrients. Despite its numerous variations, the general steps of ASP remain consistent, containing two stages: biological stage and settling stage. In the biological stage, wastewater is fed to the aeration tank from the primary treatment phase. Within the aeration tank, microorganism consume the organic matter in wastewater producing carbon dioxide, water and new microbial cells (Kristanti et al., 2023). The duration of the process depends on the quality of wastewater desired and system efficiency, typically spanning several hours. Following the biological stage, the treated wastewater is transferred to a settling tank where suspended solids and microbial cell are allowed to settle and separated from treated water. The treated water is then release back to the environment.

While conventional ASP can remove a wide range of pollutants from wastewater, the aeration process involved in ASP can be energy intensive. The operating costs associated with maintaining proper aeration level can be substantial. The energy consumption associated with ASP typically ranges between 0.2 to 0.4 kWh/m^3 of treated water, which is approximately 1 to 3 % of the overall electricity utilization of developed countries (Sophia and Gohil, 2018). Hence, the high energy consumption limits the adoption of ASP by developing countries. This underscores the need to establish affordable and effective treatment technologies capable of replacing conventional ASP.

2.2.3 Membrane Bioreactor (MBR)

Membrane Bioreactor (MBR) process constitutes an advanced tertiary wastewater treatment technology that combines biological treatment with membrane filtration (Kristanti et al., 2023). In this method, wastewater undergoes initial biological treatment such as a conventional ASP. Then, the treated effluent from ASP is directed to a membrane barrier made of microfiltration or ultrafiltration membranes. This barrier effectively eliminates suspended solids and other impurities.

According to Kristanti et al. (2023), MBR process boasts an impressive removal rate, with the potential to eliminate up to 99 % of suspended solids and BOD, along with up to 90 % removal of nitrogen and phosphorus, making it suitable for wide range of uses. However, despite the remarkable removal rate, MBR has its share of disadvantages. Notably, it involves higher capital and operational costs due to membrane cost and antifouling strategies. Moreover, in certain times, MBR consumes twice the energy of conventional ASP during operation (Al-Asheh, Bagheri and Aidan, 2021). The energy consumption of a simple aerobic and anaerobic MBR varies in the range of 0.25 to 7.3 kWh/m^3 (Al-Asheh, Bagheri and Aidan, 2021). While MBR offers undeniable advantages, it is a relatively new emergence in wastewater treatment, coupled with high energy demands, raises the possibility of seeking alternatives to support the sustainable development of Malaysia.

2.2.4 Moving Bed Biofilm Reactor (MBBR)

The Moving Bed Biofilm Reactor (MBBR) represents an evolution from the traditional TF system, introducing enhanced efficiency and controlled biofilm growth. It functions as a stirred tank bioreactor, employing mobile plastic carriers that move freely within the bioreactor. These plastic carriers facilitate the establishment of a diverse microbial community crucial for pollutant removal from wastewater. As noted by (Narayanan and Narayan, 2019), compressed air is sparged into the bioreactor to induce movement of the plastic carriers within the wastewater. Within the bioreactor, the biofilm attached to the carriers actively breaks down the organic matter present in the wastewater. Then, the resulting biomass is separated from treated water through a sedimentation tank. Similarly, MBBR is also high in energy cost as aeration is needed to promote the carriers' movement.

2.3 Malaysia's Wastewater Treatment Regulation

Malaysia follows several regulations and guidelines related to wastewater treatment. Two of the important regulatory frameworks in Malaysia for wastewater treatment are the Environmental Quality Act 1974 (EQA) and Environmental Quality (Sewage) Regulations 2009. EQA is an important guide for all stakeholders to ensure that the environment is clean, safe, healthy and productive, while the country is developing rapidly. Under this act, the Department of Environment (DOE) of Malaysia has the authority to manage and regulate various environmental aspects, including wastewater treatment. Next, the Environmental Quality (Sewage) Regulations 2009 set out guidelines for effluent quality, discharge standards, and procedures for obtaining permits for wastewater discharge. Table 2.2 and 2.3 below show the standards of water discharge from existing and new sewage treatment plant before and after amendment of Environmental Quality (Sewage) Regulations 2009. Standard A, as listed in Table 2.2 and 2.3, pertains to treated water that is suitable for discharge into any inland waters within the catchment areas outlined in the Third Schedule. Meanwhile, Standard B is applicable to treated water intended for discharge into any other inland waters or Malaysian waters.

Table 2.2: Existing Sewage Treatment System (approved after January 1999).

Parameter	**Unit**	**Standards**	
		A	**B**
BOD_5 at 20 ℃	mg/L	20	50
COD	mg/L	120	200
Suspended Solids	mg/L	50	100
Oil and Grease	mg/L	20	20
Ammoniacal Nitrogen	mg/L	50	50

Table 2.3: New Sewage Treatment System (approved after October 2009).

Parameter	Unit	Standards	
		A	B
Temperature	℃	40	40
pH Value	-	6.0 – 9.0	5.5 – 9.0
BOD_5 at 20 ℃	mg/L	20	50
COD	mg/L	120	200
Suspended Solids	mg/L	50	100
Oil and Grease	mg/L	5.0	10.0
Ammonical Nitrogen (enclosed water body)	mg/L	5.0	5.0
Ammonical Nitrogen (river)	mg/L	10.0	20.0
Nitrate – Nitrogen (river)	mg/L	20.0	50.0
Nitrate – Nitrogen (enclosed water body)	mg/L	10.0	10.0
Phosphorus (enclosed water body)	mg/L	5.0	10.0

2.4 Different Configuration of DHS System

DHS system made its debut in Japan during the late 1990s, introduced by a research group from the Nagaoka Institute of Technology. Led by Prof. Hideki Harada, the team developed the first generation of DHS. According to Tyagi et al. (2021), over the past few decades, initiatives were taken to enhance the wastewater treatment efficiency of DHS through the introduction of six different variants of sponge materials and a range of configurations. However, various variants of sponge material and their impact on wastewater treatment efficiency will be discussed in the subsequent section.

There are a total of six generations for a DHS system, and an overview of these DHS systems based on their removal performance as well as the drawbacks will be summarized in Table 2.4 and Table 2.5, respectively. Initially, DHS system was developed as a post-treatment process for an upflow anaerobic sludge blanket (UASB) that operates with minimal energy requirements. The first generation (DHS-G1) is a modification of a hanging tube process, where a series of cube-shaped polyurethane sponges were connected via nylon strings (Nurmiyanto and Ohashi, 2019). Despite the excellent treatment efficiency of the UASB-DHS system, a drawback of the system became apparent at a larger scale, where the stability of nylon strings and sponge cubes was insufficient to handle a large amount and potentially high flow rate of wastewater. This limitation led to the development of the DHS-G2 system. DHS-G2 system is a curtain-type design where triangular-shaped polyurethane sponges are affixed to a polyvinyl sheet (Tyagi et al., 2021). This second generation of DHS serves as a post-treatment for UASB reactors. However, DHS-G2 has its limitations; achieving uniform wastewater distribution is challenging, and the system is susceptible to sudden loss of microbial biomass due to washout. These drawbacks have driven the development of the third generation. DHS-G3 system closely resembles the TF system but employs a different filtering medium. In the DHS-G3 configuration, polyurethane sponges are randomly packed within the reactor. This arrangement allows for simpler construction and easier up scale. Besides that, a net-like polypropylene material encloses the sponge in G3 configuration to prevent sponge deformation and maximizing contact area to encourage the attachment and growth of beneficial microbial communities. Importantly, DHS-G3 does not rely on external aeration; natural air diffusion through the reactor's ventilation points reduces energy consumption during operation. However, there is a concern where declining of DO concentration followed by a reduction of nitrification activity might occur after months of operation (Nurmiyanto and Ohashi, 2019).

Further down the line, DHS-G4 represents an arrayed type of DHS configuration. In this improved setup (from DHS-G3), multiple sponges are arranged in a linear arrangement and stacked vertically. In between the stacking, there will be a 7 – 10 mm gap to enhance the air transfer into the system. This set up provide better air transfer and prevent clogging sludge buildup (Nurmiyanto and Ohashi, 2019). Similar to DHS-G2, the subsequent DHS-G5 reactor is a curtain-type model that employs a continuous sheet with an undulating surface instead of a single sponge module sheet (Tyagi et al., 2021). However, the holder of the sponge module in DHS-G5 is prone to bending and tearing over time due to its weak mechanical strength. This limitation stems from the holder's inability to withstand the accumulated biomass load in the DHS curtain.

Lastly, the latest configuration of the DHS system is the G6 system, which follows the same general concept as the G3 configuration. The primary distinction is that DHS-G6 utilizes a rigid sponge medium made with epoxy resin. The utilization of a rigid sponge enables the filter medium to attain a larger contact surface for wastewater treatment, while trading off biomass retention capacity.

Table 2.4: Removal Performance of Six Generation of DHS (Nurmiyanto and Ohashi, 2019).

	DHS Generation					
	G1	**G2**	**G3**	**G4**	**G5**	**G6**
Removal Performances (%):						
COD	94	83	83	91	88	91
BOD	99	94	89	95	94	96
SS	100	67	82	94	95	91
TN	17	40	22	23	56	43
F. Coliform	-	98	-	3.3 log	4.0 log	3.1 log

Table 2.5: Set Up and Drawbacks of Different Generation of DHS (Adapted from Nurmiyanto and Ohashi (2019); Tyagi et al. (2021)).

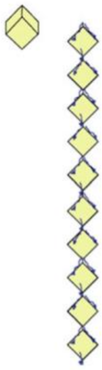
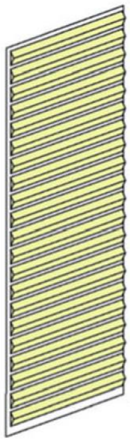
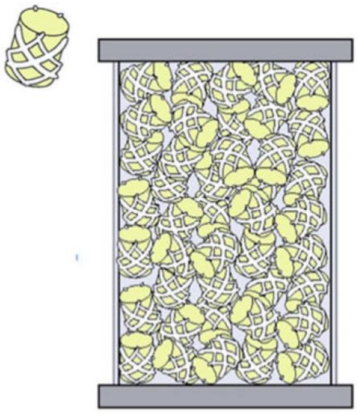
DHS Generation	Set Up	Drawbacks
G1		1. Difficult upscaling. 2. Unstable for high wastewater flowrate.
G2		1. Difficult to achieve uniform wastewater distribution. 2. Expensive. 3. Easy biomass washout.
G3		1. Decreased DO concentration and nitrification activity.

Table 2.5 (Continued)

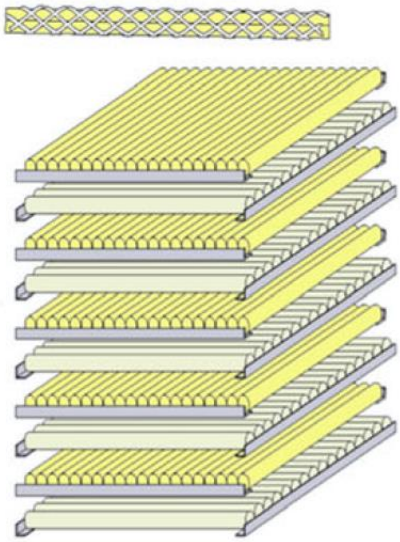
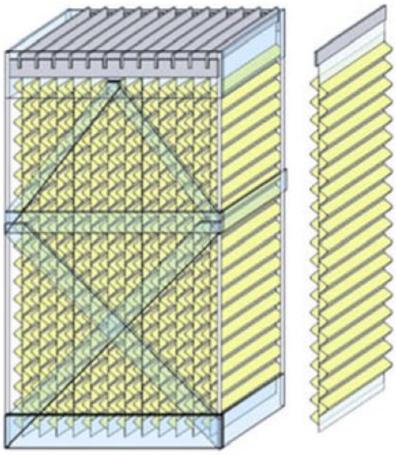
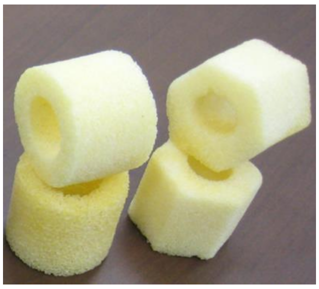
G4		1. Deformation of sponge module due to heavy biomass load.
G5		1. Sponge holder prone to bending and tearing after few months of operation.
G6		1. Reduced biomass retention capability attributed to a smaller void volume.

Table 2.4 and 2.5 summarized the different configuration of DHS that are developed. From Table 2.4, it is observed that all six DHS are showing promising removal performances. Among the six DHS configurations, DHS-G1,

DHS-G4 and DHS-G6 demonstrated outstanding organic removal efficiencies, exceeding 90 % for BOD, COD and SS. However, the nitrification activity for DHS-G4 and DHS-G1 is fairly low as the nitrogen removal is 17 % and 23 % respectively. The low nitrogen removal in DHS-G4 is due to its drawbacks where accumulation of biomass inside the sponge will occur over time. Similarly, DHS-G3 system also exhibits low nitrification activity where the removal is only 22 %. The low nitrification might be caused by the random arrangement of sponge media in the system causing a lack of air transfer between sponge media (Nurmiyanto and Ohashi, 2019). Nevertheless, the factors and parameters that affects the removal performances of DHS system will be discussed in Section 2.5.

In summary, DHS system remains a relatively new technology that holds unexplored potential. Each iteration of the DHS system configuration presents its own limitations, prompting the development of different generations to address these issues. Notably, DHS technology boasts several advantages, including a simple design with fewer mechanical components, resulting in benefits such as reduced capital, operational, and maintenance costs. Another significant advantage is its minimal energy consumption due to the absence of external aeration, positioning DHS technology as a more economically efficient alternative to conventional WWTPs. With full-scale DHS system adoption evident in countries like India, Egypt, Japan and Thailand, the viability of this technology becomes apparent. The stable performance of full-scale DHS showcases that Malaysia has the opportunity to delve into and embrace this innovative technology.

2.5 Factors Affecting the Performance of DHS

As mentioned earlier in Section 2.4, DHS system closely resembles a conventional TF system, but it operates on distinct principles. For instance, in the DHS system, biomass becomes immobilized within the interstitial matrix of the polyurethane sponge media. Taking advantage of the sponge's 90 % void space, a substantial quantity of active biomass can be trap both within and outside the sponge structure. Referring to Figure 2.2, the fundamental operational principles of the DHS sponge are illustrated. The active immobilized biomass engages in the consumption of organic matter from wastewater for metabolic process of biomass (Tyagi et al., 2021). The metabolic process utilizes dissolved oxygen (DO). Furthermore, from Figure 2.2, the outer region of the sponge is recognized as the aerobic zone and it is suitable for nitrification activities, given the presence of ammonium oxidizing bacteria dominating in this zone. Following this, denitrification activities occur within the anoxic zone, where the biomass will serve as a carbon source. The DHS technology is efficient for organic degradation and nitrification activity; however, effectiveness of DHS relies on several factors. These factors include sponge material, HRT, OLR and ventilation. These elements will be comprehensively discussed in Section 2.5.

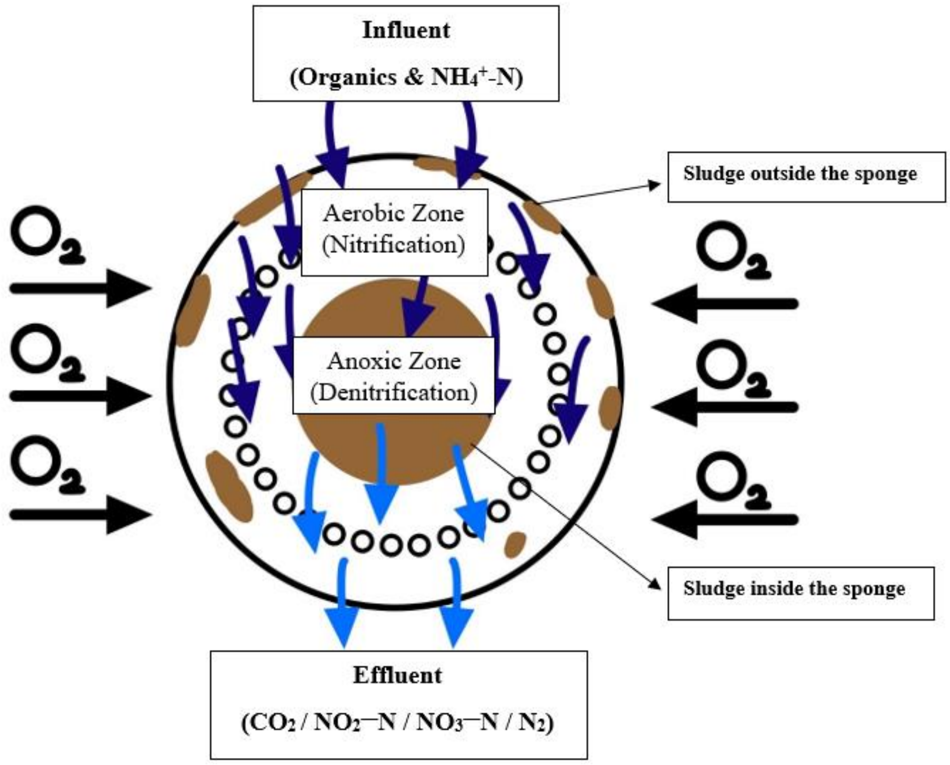


Figure 2.2: Operational Principle of DHS-G3 Sponge (Adapted from Tyagi et al. (2021)).

2.5.1 Effect of Sponge Media Design

As discussed in Section 2.4, the history of DHS reactor comprises six variants of sponge media design. Notably, the third generation (DHS-G3) and the sixth generation (DHS-G6) share the same configuration (TF method). Comparing the differences in sponge media between these two generations can provide insights for the DHS reactor design. Figure 2.3 visually presents six distinct variants of sponge media. Referring to the figure, G3 features four variants while G6 features two variants. Notably, the sponge media used in the sixth generation typically employs a more rigid sponge material (polyethylene sponge with epoxy resin). Conversely, the third generation utilizes a softer sponge encased with a plastic casing to prevent clogging of DHS system (Tawfik et al., 2008). A study by Okubo et al. (2016) revealed that the porosity of the G3 sponge medium stands notably high at 98 %, whereas the porosity of the G6 sponge medium is slightly reduced to 70 % due to the implementation of epoxy coating. Despite the lower porosity percentage, the absence of a plastic casing around the sponge medium in G6 exposes it to more air, aiding in maintaining favourable aerobic conditions.

In an experiment performed by Onodera et al. (2014), it was found that the rigid sponge media in DHS-G6 configuration provide satisfactory result for nitrification. This is because DHS-G6 configuration provide more aeration which is essential for maintaining a higher DO concentration in wastewater. The higher DO concentration is crucial for an efficient nitrification activity to occur. Besides, it is also concluded that the low porosity of DHS-G6 sponge media retain less biomass than any other soft sponge media. Despite that, Onodera et al. (2014) noted that higher removal activities and less amount of excess sludge were found in DHS-G6 configurations.

Conversely, a comparative study carried out by Okubo et al. (2016), focusing on DHS-G3 and DHS-G6 reactors operating under fluctuating temperatures between 14 °C and 33 °C, yielded slightly different results. The analysis of effluent quality variance between DHS-G3 and DHS-G6 did not uncover any significant difference, implying comparable treatment performances for both reactor configurations (Okubo et al., 2016). However, despite similar treatment performance, each variant of sponge design possesses distinct advantages. The rigid sponge in the G6 configuration may offer enhanced aeration quality, but it also comes with higher associated costs. In contrast, the soft sponge in the G3 configuration introduces the possibility of the plastic casing undergoing wear and tear over time. To summarize, both rigid and soft sponge designs exhibit their respective merits and limitations. The choice of sponge variant should be guided by a comprehensive assessment of factors, including sponge availability and material costs, among others.

Figure 2.3: Different Sponge Media Designs (Tyagi et al., 2021).

2.5.2 Effect of Hydraulic Retention Time

HRT refers to the average amount of time that wastewater remains within a treatment system. It is a crucial factor in wastewater treatment process for reasons such as treatment efficiency and energy efficiency. HRT are most commonly express in unit hour. In the case of DHS reactor, HRT is an important parameter as wastewater requires a minimal period of time in the reactor to be treated (Tan, 2020). Increased retention time of wastewater within a reactor leads to extended contact between microbes and wastewater, thereby enhancing organic removal efficiency. The porosity of the sponge media utilized in a DHS reactor plays a pivotal role in influencing HRT and the efficacy of two crucial microbial processes: organic matter degradation and the conversion of ammonia to nitrate. In other words, higher porosity within the sponge media corresponds to increased void space, resulting in an extended HRT, and vice versa. Besides that, flowrate will also affect the HRT of a DHS reactor. An increase in wastewater discharge flowrate will result in a decrease in HRT. Hence, based on theoretical factors, longer HRT will provide better removal efficiency.

Despite this, achieving an infinite HRT is impractical in reality, particularly when WWTPs are tasked with processing vast quantities of wastewater daily. Thus, determining the optimal HRT to attain desired effluent qualities that meet discharge standards set by the EQA becomes paramount for the effective performance of a DHS reactor. A study conducted by Machdar et al. (2018) indicated that the removal efficiency of a DHS reactor increases as the sponge pore size decreases. Smaller pore sizes result in longer HRT, aligning closely with theoretical expectations. Similarly, a study by Takemura et al., (2022), operating DHS reactors at ambient temperatures (ranging from 26 to 32 °C) with a HRT maintained at 1 to 2 hours, supports this theory, showing consistent findings. The design proposed by Takemura et al. (2022) consistently generates superior water quality, exemplified by TSS levels below 10 mg/L, BOD below 10 mg/L, NH_4-N below 5 mg/L, E. coli counts below 10^3 CFU/mL, and a reduction of pathogenic bacterial groups by over 2-$\log_{10}$.

Next, in a study conducted by Yoochatchaval et al. (2014), which investigated the performance of a DHS reactor at varying HRT ranging from 4 hours to 1 hour, it was observed that nitrification activity remained notably high across all HRT conditions. Specifically, at a 4-hour HRT, ammonium removal reached 98.6 %, at 2-hour HRT, it was 98.5 %, and even at 1-hour HRT, ammonium removal still reached a substantial 95.8 %. However, concerning total and soluble nitrogen removal, the removal efficiency displayed an interesting trend, increasing from 28.3 % to 38.2 % and from 15.1 % to 32.9 %, respectively, as the HRT decreased from 4 hours to 2 hours. This phenomenon suggests that the DHS reactor can effectively remove nitrogen through denitrification processes within the anoxic zone present inside the sponge media. The anoxic zone within the sponge media is capable of utilizing a carbon source to convert nitrate into nitrogen, even under aerobic conditions with a DO concentration of 5.2 mg/L (Tyagi et al., 2021).

In summary, different HRT will result in a different DHS reactor performance in treatment of wastewater. In general, longer HRT present better contact time between biomass and wastewater, which provide enough time for the decomposition of organic components (Tan, 2020). However, there is no such thing as universal or best HRT as different configuration of DHS require different HRT. In certain cases, an excessively long HRT will lead to longer operation, necessitating more time for wastewater treatment. Hence, the perfect HRT is only available through continuous research and experimentation.

2.5.3 Effect of Organic Loading Rate

Organic Loading Rate (OLR) quantifies the amount of organic material or pollutants applied to a WWTPs per unit time. The OLR stands as a pivotal design factor that significantly impacts the efficiency of the DHS module utilized for the degradation of organic compounds, ammonia oxidation, and the removal of pathogens (Tyagi et al., 2021). According to Tawfik et al. (2011), it is found that an increase in OLR will have a negative result on the performance of DHS system. In the result obtained, it was revealed that increasing OLR from 1.9 to 3.6 $\mathrm{kgCOD/m^3}$ day significantly declined the ammonia removal efficiency due to the decrease in sludge residence time (SRT). At an OLR of 1.9 $\mathrm{kgCOD/m^3}$ day the ammonia removal is at 91 %; at an OLR of 3.6 $\mathrm{kgCOD/m^3}$ day ammonia removal is at 58.5 %. The reduction in nitrification efficiency is affected by the competition between heterotrophs and nitrifiers for DO and site space. The DO concentration in high OLR system is lower as it is utilized by bacteria for organic degradation. In most cases, the high OLR will enhance the heterotrophs activities making it harder for denitrifying bacteria to compete for oxygen and space; thus, there it results in a reduction in ammonia removal performance.

In terms of pathogen removal, Beas et al. (2015) discovered that the treated effluent showed an increase in the number of Fecal Coliforms (F. coliform) as OLR increased. Specifically, the F. coliform count escalated from 2.1 x 10^2 / 100 mL (at OLR = 1.96 $\mathrm{kgCOD/m^3}$ day) to 5 x 10^6 / 100 mL (at OLR = 2.69 $\mathrm{kgCOD/m^3}$ day). This observation signifies that higher OLR values correspond to increased pathogen loading rates. Elevated pathogen loads have a detrimental impact on the efficiency of pathogen removal within the DHS reactor. As a result, a lower OLR is generally preferred to achieve better ammonia and F. coliform removal rates. In line with this, Tyagi et al. (2021) suggest that an OLR of 1.6 $\mathrm{kgCOD/m^3}$ day represents an optimal point for achieving effective removal of organics, ammonia oxidation, and pathogens within a DHS reactor.

2.5.4 Ventilation

According to (Tan, 2020), the sole source of oxygen for the microorganism to carry out work in DHS reactor is through a ventilation point. External aeration is not needed. The system capitalizes on the difference between the external and interior environment of DHS, thus creating a concentration gradient that are essential for natural draft ventilation. The difference in concentration gradient generates requisite force that draws oxygen into the DHS system for aeration.

Figure 2.4 illustrates the experimental data gathered from Onodera et al. (2014). This data showcases the oxygen content within the DHS reactor and the DO concentration in the wastewater stream at various heights within the reactor. In the study, three distinct phases were observed. In phase 1, the ventilation window within the DHS reactor remained closed across all three segments. Moving to phase 2, the ventilation window was open for all three segments. Lastly, phase 3 saw the ventilation window open for the first segment and closed for the other two segments.

The DHS reactor comprises three segments, each with a specific role. Segment 1 is the initial stage where wastewater enters, facilitating the removal of organic matter and nitrogenous components through the activity of heterotrophic bacteria. Moving to segment 2, the middle section, it addresses residual matter from segment 1 and also facilitates ammonia removal. The final segment, segment 3, is dedicated to the elimination of the majority of ammonia and nitrogenous compounds. To summarize, segment 1 primarily manages organic matter removal, while segments 2 and 3 focus on ammonia and nitrogen removal, supported by a high concentration of dissolved oxygen (DO) that fosters the nitrification process.

The experimental results unveiled in phase 2, where the oxygen concentrations inside and outside the DHS reactor closely matched, exhibited notably improved DO concentrations within the wastewater stream. Consequently, this enhancement in DO concentration translated to superior removal efficiency of BOD and TN (87 % and 32 %), as compared to the outcomes observed in both phase 1 (78 % and 31 %) and phase 3 (78 % and 18 %) (Onodera et al., 2014).

Hence, natural ventilation is sufficient to provide satisfactory removal efficiency. Besides that, adequate ventilation is necessary to have a high DO concentration in the wastewater stream. With sufficient ventilation point to provide adequate amount of oxygen, mechanical pumping or aeration equipment is not needed for the DHS system.

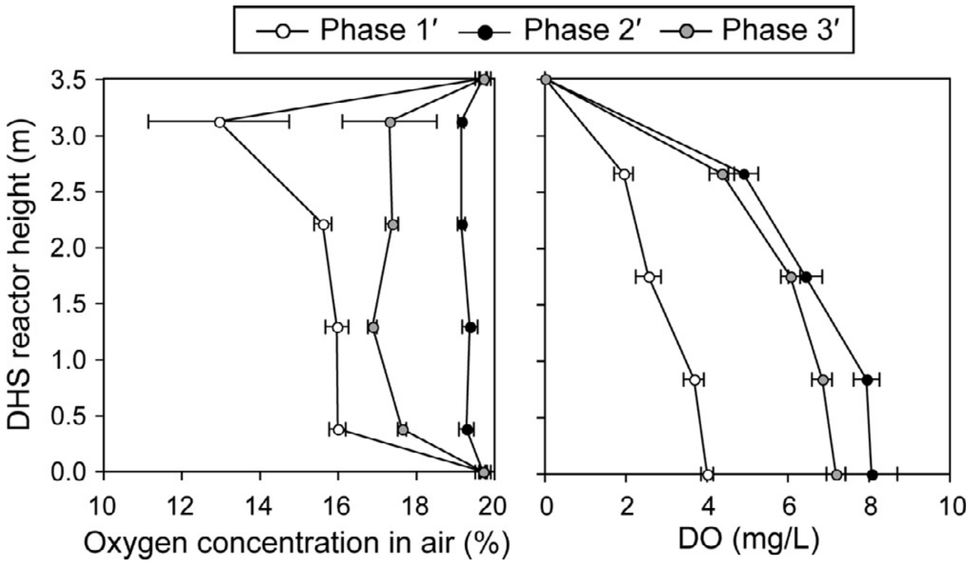


Figure 2.4: Oxygen Concentration in DHS and DO Concentration in Wastewater at Various Height of DHS (Onodera et al., 2014).

2.6 Application of DHS Reactor in Other Countries

Throughout its existence, the DHS technology has consistently demonstrated strong performance as a post-treatment solution for UASB effluent. Table 2.6 compiles a collection of studies underscoring the stable operational performance of DHS reactors, both in full-scale and pilot-scale implementations. The successful incorporation of DHS technology in various countries, including Japan, Egypt, India, and Thailand, serves as a promising testament that can instil confidence among government authorities and potential investors, paving the way for significant investments in DHS projects. This is particularly relevant in the context of Thailand, given its geographical proximity and climatic similarities to Malaysia. With comparable year-round temperature and humidity conditions, the experimental data obtained from DHS studies conducted in Thailand holds valuable potential as a guiding framework for the continued advancement of DHS technology in Malaysia.

The influence of temperature was highlighted by Tandukar, Ohashi and Harada (2007), revealing that the efficiency of the DHS system experienced a slight decrease during the winter season. Notably, the DHS system demonstrated more noteworthy outcomes at warmer temperatures, particularly around 20 °C and above. These findings hold valuable implications for Malaysia, suggesting that the DHS system is likely to perform optimally in tropical or sub-tropical climates prevalent in such countries.

Table 2.6: Selected DHS Performance Data at Different Countries.

Location	**India**	**Thailand**	**Japan**	**Egypt**
DHS Type	G2	G3	G5	G3
Scale	Large	Pilot	Pilot	Pilot
Flowrate ($\frac{m^3}{day}$)	500	0.806	-	0.288
Reactor Volume (m^3)	125	0.18	0.48	0.13
Sponge Occupancy (%)	24.7	27.8	55	53
Operational Condition				
Temperature (°C)	30	32	9 - 32	33
Duration (days)	1800	167	300	140
HRT (h)	1.5	3.0	2.5	2
OLR ($\frac{kgCOD}{m^3\ day}$)	2.84	1.3	2.40	1.84
Wastewater Quality ($\frac{mg}{L}$)				
COD	430	158	599	536

Table 2.6 (Continued)

BOD	151	60	290	250
TSS	228	39	333	220
TN	29	55	40.6	48
Removal Performance (%)				
COD	94	85	89.7	90
BOD	96	91	94.3	95
TSS	93	93	94.8	96
TN	65	56	55.9	72
Reference	(Onodera et al., 2016)	(Miyaoka et al., 2017)	(Tandukar, Ohashi and Harada, 2007)	(Mahmoud, Tawfik and El-Gohary, 2011)

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

In this section of the report, the experimental setup and work plan for a laboratory-scale DHS-G3 system were discussed. The primary objective of this experiment was to investigate the effectiveness and treatment performance of the DHS reactor in removing COD and nutrients. Additionally, the experiment aimed to produce treated wastewater that complies with the standards outlined in the Environmental Quality (Sewage) Regulations of 2009 for new sewage treatment plants.

Referring to Figure 2.3, the DHS-G3 sponge typically utilized a net-like plastic casing to encase the sponge material. However, in this experiment, a spherical casing was employed to enhance the mechanical strength and surface area of the filter media. Each sponge medium was individually encased within a spherical support structure, as illustrated in Figure 3.1. This spherical filter design was inspired by bioballs commonly used in fish tanks for ammonia removal. However, the biochemical filter foam inside the bioball was replaced with conventional sponge material. The spherical casing not only improved the mechanical stability of the sponge media, making it more robust against physical stresses, but also widely available in the market, simplifying the procurement process. Subsequently, these sponge media elements were randomly packed within the DHS reactor, enhancing the packing density and ensuring a more uniform flow distribution, which reduced the risk of channeling and maximized contact between the wastewater and the biofilm. Furthermore, adequate ventilation was ensured in the DHS reactor to maintain sufficient DO concentrations within the system, promoting efficient aerobic biological activity essential for the degradation of organic pollutants.

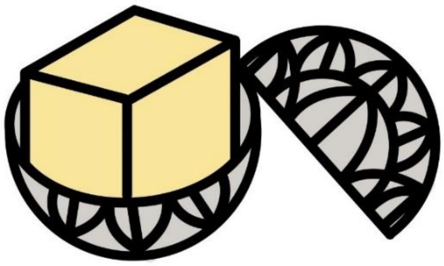


Figure 3.1: Sponge Medium Encased in Spherical Support Structure.

3.2 Experimental Setup

The DHS-G3 reactor was modelled using a 4 L plastic container. The lid of the container was removed, and the lid opening was facing downwards. A pump wias installed to pump the wastewater from the sewage tank into the system. At the inlet section of the DHS reactor, a perforated sheet was placed to evenly distribute the wastewater. Furthermore, another pump was installed to recycle the wastewater from the sedimentation tank into the system. Next, the sponge media seeded with biomass were placed into the spherical casing individually followed by randomly packed the media in the 4 L plastic container. The seeded spherical casings were placed at different heights of the reactor. Several ventilation points were added into the system to ensure sufficient DO concentration. The illustration of the DHS-G3 set up was shown in Figure 3.2.

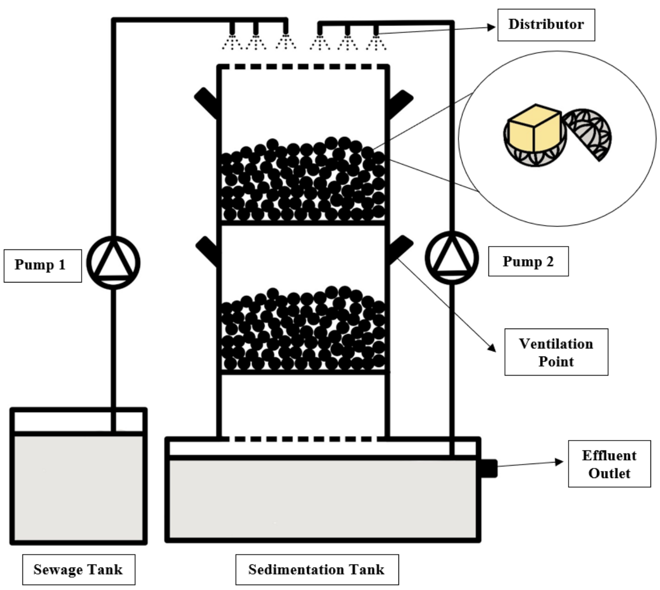


Figure 3.2: Schematic Diagram of DHS-G3 Reactor with Sponge Media Encased in Spherical Structure.

3.3 Procedure

The experiments and studies were expected to last for a total of 50 days, and it would be separated into phase 0 and phase 1. In phase 0, the cultivation of sponge media was performed which will last for 14 days. Next, in phase 1, the experiment was carried out over 36 days where the suitable operating conditions for nutrients and COD removal in DHS reactor were studied. The study also touched on the start-up process of a laboratory DHS-G3 reactor, which included growing biofilm on the sponge media and developing synthetic wastewater. Figure 3.3 presented the flowchart of the experimental procedure discussed.

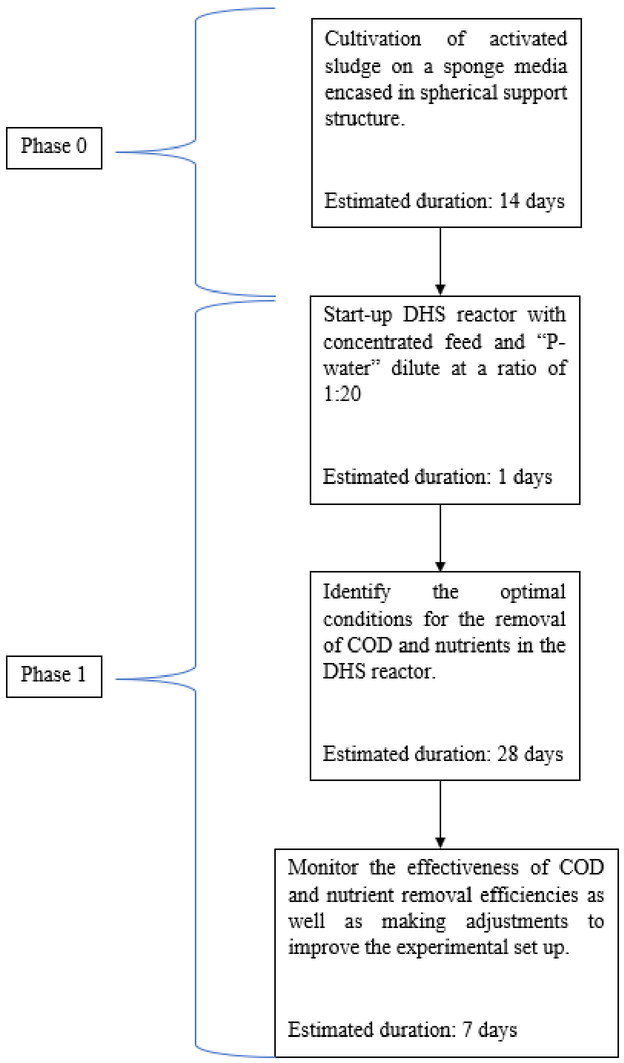


Figure 3.3: Flowchart of the Experiment Procedure of DHS-G3 Reactor.

3.3.1 Synthetic Wastewater Preparation

In the preparation of synthetic wastewater for this experiment, a combination of various laboratory chemicals was synthesized. The glassware and apparatus employed during the synthetic wastewater preparation included a spatula, weighing paper, and a 1 L Scott bottle. The synthetic wastewater used in the study was augmented with chemical substances, including sodium acetate, iron (III) chloride, ammonium chloride, magnesium sulfate heptahydrate, calcium chloride, yeast extract, and monopotassium phosphate. Given that these chemical substances were used in small quantities, a weighing tray was not selected to prevent any impact on the final concentration of the synthetic wastewater. This was to prevent the small chemical substance from sticking onto the weighing tray during preparation. In addition, a higher concentration of synthetic wastewater (ten times the desired concentration) was initially prepared and then diluted as needed during the experiment. This approach was adopted because the chemical substances required for the synthetic wastewater were difficult to prepare at lower concentrations. The chemical substances and their corresponding concentrations used for the concentrated synthetic wastewater are outlined in Table 3.1.

Table 3.1: Concentrated Synthetic Wastewater Contents and Concentrations.

Chemical Substances	Concentration (g/L)
Sodium Acetate	0.7
Iron (III) Chloride	0.49
Ammonium Chloride	19
Magnesium Sulfate Heptahydrate	30.8
Calcium Chloride	34
Yeast Extract	0.1
Monopotassium Phosphate	0.09

3.3.2 Biofilm Formation on Sponge Media

In the DHS system, the treatment of wastewater was carried out by microorganisms or biomass. These microorganisms were sourced from activated sludge obtained from the Indah Water wastewater treatment plant in Selangor, Malaysia. The choice of using activated sludge was primarily due to its high microbial populations and diversity, which contributed to enhanced treatment efficiency. As noted by Theobald (2014), activated sludge typically comprised five major groups of microorganisms: bacteria, protozoa, metazoan, filamentous bacteria, as well as algae and fungi.

Furthermore, the experiment aimed to assess whether the activated sludge commonly employed in conventional ASP was equally effective or potentially even more efficient when used in a DHS reactor. In scenarios where the DHS reactor demonstrated superior performance in terms of nutrient and COD removal efficiency, the DHS-G3 reactor under investigation could be considered for incorporation into existing WWTPs in Malaysia, potentially enhancing their treatment capabilities.

To establish a biofilm around the sponge media, following the encasement of the sponge within the spherical structure, the sponge media were immersed in the activated sludge, as depicted in Figure 3.4. The sponge media remained submerged in the activated sludge for an estimated duration of 14 days, allowing ample time for the microbial community to colonize the sponge media. It was essential to ensure that the activated sludge adequately covered all the sponge media, and aeration was provided throughout this process to prevent the microbial community from dying. This precautionary measure is crucial to guarantee the formation of a biofilm that comprehensively covered the entire surface area of the sponge media. Once the spherical structure containing the sponge media was entirely covered by the biofilm, it will be introduced into the DHS-G3 reactor, as depicted in Figure 3.2.

Figure 3.4: Cultivation of Activated Sludge on Sponge Media.

3.4 DHS-G3 Reactor Performance Analysis

In the sample collection process, a composite sampling technique was employed, with samples taken at 2-hour intervals. For instance, on a sampling day commencing at 8 a.m., sample collections occurred at 10 a.m., 12 p.m., 2 p.m., and 4 p.m. In this experiment, each sampling day was considered a complete cycle, and fresh artificial wastewater was prepared to replace any remaining artificial wastewater in the sewage tank. This precautionary measure was taken to prevent the degradation of the artificial wastewater after prolonged exposure to room temperature.

To ensure the accuracy of both COD and nitrogen concentration analysis, a 50 mL sample was extracted from the DHS-G3 effluent tank for every collection. Additionally, the 50 mL sample collected served as a backup. The HACH method was employed to analyse the COD concentration in the treated wastewater, while HACH nitrate analysis was used for the analysis of nitrogen concentration in the treated wastewater.

3.4.1 COD Analysis

To prepare the samples, the reactor digestion method was employed. Vials were selected based on the COD range of 3 to 150 mg/L. A 2 mL sample was carefully pipetted into each vial at a 45° angle to minimize the introduction of air bubbles and enhance the precision of the analysis. Subsequently, the sample preparation procedure was repeated to create a blank sample using distilled water. The closed vials were then rinsed with distilled water and lightly wiped with a clean paper towel. This step was crucial to ensure the accuracy of the COD analysis by eliminating any potential contaminants on the vials.

Next, the digital reactor block (DRB 200) was preheated to 150°C. The prepared vials were gently inverted before being placed into the preheated DRB. A 2-hour heating period was allocated for digestion. Afterward, the vials were cooled down to approximately 120°C, which took approximately 20 minutes. Following this, the vials were removed from the DRB 200 and gently inverted to ensure thorough mixing.

The collected vials were allowed to cool further in a tube rack. Finally, a colorimeter procedure was employed to measure the COD concentration in the treated wastewater using the HACH DR 3900 Spectrophotometer. The 430 COD LR method with a measurement range of 30 to 150 mg/L was chosen for this analysis. The procedure began with preparing a blank sample to establish an initial COD reading of 0.0 mg/L. Then, the collected sample was measured, and the results obtained were tabulated and discussed in Chapter 5 of the report.

Figure 3.5: Digital Reader Block, DRB 200.

Figure 3.6: HACH DR 3900 Sectrophotometer.

3.4.2 Nitrogen and Ammoniacal Component Analysis

As mentioned earlier, the concentration of nitrogen and ammoniacal components in the treated wastewater was analysed using the HACH nitrate analysis. The procedure of this analysis begins by preparing the samples for the nitrate ion test. The samples were transferred into centrifuge tubes, followed by filtration of sample using a 0.2 µm syringe filter. After that, a sample cell was filled up with 10 mL of wastewater sample. The nitrate reagent (NitraVer 5 Nitrate Reagent Powder Pillow) was then added to the sample cell with 10 mL of wastewater sample. The sample cell was shaken for 1 minute. After shaking, the sample cell was let sit for 5 minutes. While waiting, a blank sample was prepared by adding 10 mL of wastewater sample into another sample cell. Then, after the 5-minute wait, both sample cells were wiped clean with tissue paper. Finally, a colorimeter procedure was employed to measure the concentration of nitrogen within the nitrate molecule, $NO_3{}^{-} - N$ in the treated wastewater using the HACH DR 3900 Spectrophotometer. The 355 N Nitrate HR method with a measurement range of 0.3 to 30 mg/L was chosen for this analysis. The procedure began with a blank sample to establish an initial $NO_3{}^{-} - N$ reading of 0.0 mg/L. Then, the collected sample was measured. Similarly, the outcomes obtained were tabulated and discussed in Chapter 5.

CHAPTER 4

DESIGN DETAILS OF DHS REACTOR

4.1 Introduction

This chapter explores the design details of the DHS-G3 reactor for COD and nutrient removal. It covers the materials used in its construction, the functionality, operational timeline, encountered setbacks, and reactor dimensions, all of which will be comprehensively discussed.

4.2 DHS Reactor Design

A laboratory scale DHS-G3 reactor was set up for the study of COD removal and nutrient removal in wastewater treatment. The schematic diagram and the actual laboratory set-up of the DHS-G3 reactor were shown in Figure 4.1.

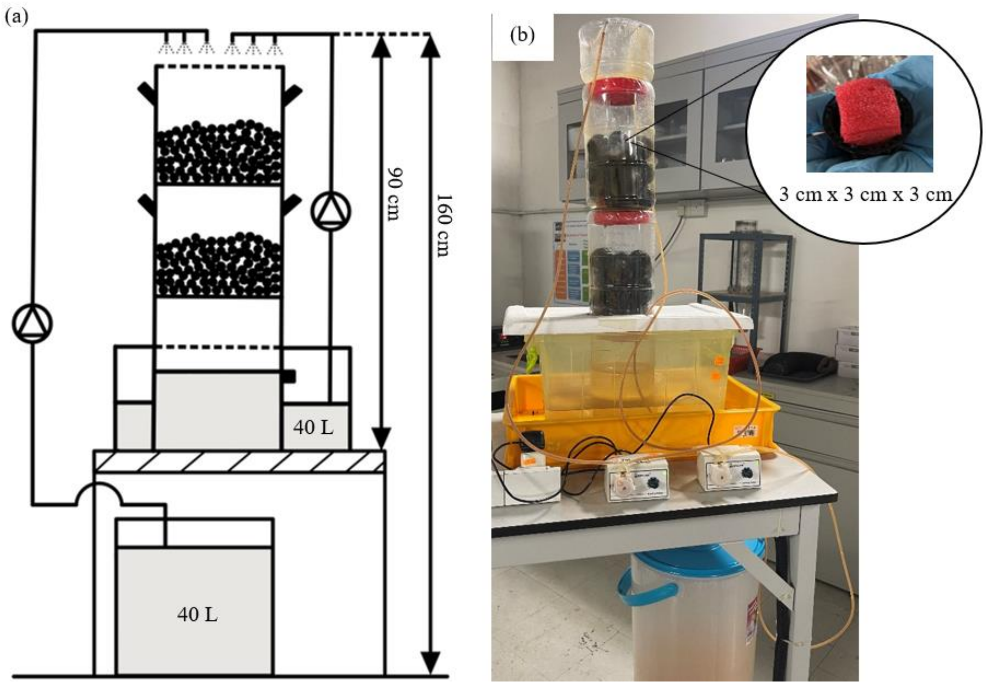


Figure 4.1: Design of DHS-G3 Reactor: (a) Schematic Diagram of DHS-G3 Reactor, (b) Laboratory Set-up of DHS-G3 Reactor.

The total height of the DHS-G3 reactor was approximately 160 cm, comprising three main components: the influent tank, the DHS reactor, and the effluent tank. As illustrated in Figure 4.1(b), the influent tank was a 40 L container positioned at the base of the table due to space constraints in the laboratory. This tank served to store freshly prepared synthetic wastewater, which was then pumped to the top of the DHS reactor using a peristaltic pump. To ensure even distribution of the wastewater, a perforated straw was utilized as a spray-like distributor. The straw featured 10 small holes, while the bottle cap had 24 holes to facilitate distribution. An illustration of the bottle cap and distributor was provided in Figure 4.2. The piping system connecting the straw distributor and peristaltic pump utilized silicone tubing with a 3 mm inner diameter and 5 mm outer diameter. Additionally, to prevent leaks, the connection between the silicone tubing and straw distributor was wrapped with PTFE seal tape.

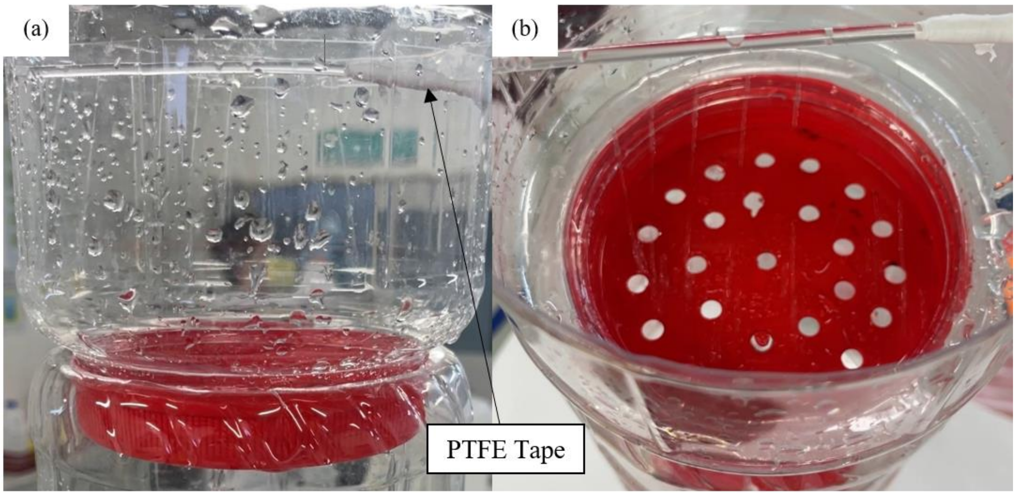


Figure 4.2: Distribution Design: (a) Straw Distributor, (b) Bottle Cap.

As for the DHS-G3 reactor, the central component of the entire system was constructed with sponge media housed within spherical casings. Each spherical casing contained cube-shaped polyurethane sponges as the media, with dimensions of 3 cm × 3 cm × 3 cm. Encasing the sponge within a spherical casing enhanced contact surface area and promoted microbial growth, crucial for biological wastewater treatment. Sponge compaction within the casing optimized available space, increasing surface area for microbial attachment and ensuring uniform distribution throughout the sponge matrix. This synergistic approach created an environment conducive to efficient wastewater treatment by maximizing microbial activity.

Additionally, the DHS system comprises two interconnected segments operated in series. Each segment was made with a 4 L plastic container. Within each segment, a total of 22 sponge media were randomly packed. This design choice was made to optimize treatment efficiency by allowing for sequential treatment processes. To support this statement, Onodera et al. (2014) highlighted the presence of distinct regions within DHS reactors. They found that the upper portion of the reactor was primarily dedicated to removing solids and organic matter, while the lower portion was mainly responsible for the removal of ammonia and nitrogen oxides. Furthermore, each segment featured ventilation holes to facilitate adequate airflow, promoting a high DO concentration. This high DO concentration was crucial for enhancing removal efficiency, contributing to the overall effectiveness of the treatment process.

The third and final component of the DHS-G3 system was the effluent tank. Treated effluent was collected using another 4 L plastic container, which serves as a sedimentation tank. A hole is punctured in the container for the separated effluent to drain out. The entire system is housed within a 40 L container (as illustrated in Figure 4.1(b)), providing additional protection to prevent effluent leakage. Connected to the effluent tank was a silicone tube, through which a recirculation stream was established with the aid of another peristaltic pump. Throughout the operation of the DHS-G3 reactor, the recirculation stream operates continuously, running 24 hours a day. This ensures continuous treatment of the synthetic wastewater while providing nutrients for the growth and survival of microbial communities within the sponge media.

On sampling days, the 4 L plastic container was replaced with a new one to prevent cross-contamination and maintain result accuracy. A 40 mL sample was withdrawn using a syringe and transferred to a 50 mL centrifuge tube. For sample preparation, a 0.2 μm syringe filter was employed to remove large particles during transfer. The collected samples were then stored in a refrigerator at 10 ℃ prior to analysis for COD and nitrate ion concentration, aiming to deactivate microbial activities. Finally, any remaining effluent or waste is disposed of in a dedicated waste bottle for proper disposal.

4.3 Operation Conditions

The experiment was conducted in a laboratory setting under ambient temperature and pressure conditions. Since the DHS-G3 reactor was designed for laboratory-scale operations, the working volume of the reactor was fixed at 20 L of fresh synthetic wastewater per day. This volume allowed for a moderate flow rate, effectively increasing the retention time of the synthetic wastewater within the sponge media. Consequently, it enhanced the contact time between the sewage and the microbial community. Additionally, the HRT for the DHS-G3 reactor was maintained at 2 hours. Observations made during operation under low HRT conditions revealed a tendency for the carbon source to concentrate in the lower segments. This suggests that the nitrifiers and denitrifiers were capable of utilizing the carbon source for both nitrification and denitrification processes. A study performed by Yoochatchaval et al. (2014) supported this statement as it demonstrated that the nitrogen removal efficiency increased at an HRT of 2 hours.

During phase 0 of the experiment, the sponge media was inoculated with activated sludge solution sourced from the Indah Water wastewater treatment plant in Selangor, Malaysia. The inoculation process spanned 10 days to provide sufficient time for microbial colonization and adaptation to the new environment. This period allowed the microbial community to establish and acclimate. In this experiment, the hypothesis posited that the microbial community attached to the media will consist of autotrophic and heterotrophic organisms capable of utilizing nutrients and organic matter as energy sources or food.

Next, freshly prepared synthetic wastewater was added to the influent tank. From there, it was pumped to the distributor, where it trickles down onto the sponge media under the influence of gravitational force. The operation of the DHS-G3 reactor commenced on 31st January 2024, and concluded on 7th March 2024. The operating period involved feeding fresh synthetic wastewater into the system from 8 a.m. to 5 p.m., Monday to Friday. Meanwhile, the recycle stream from the effluent tank ran continuously throughout the entire experiment. This operational schedule was implemented due to the laboratory's closure on Saturdays and Sundays, during which access to the DHS-G3 model was restricted and routine refilling of the influent tank with fresh synthetic wastewater was not feasible. As a result, fresh synthetic wastewater was not fed to the reactor on Saturdays and Sundays. However, the recycle stream was left running to prevent microbial die-off. A continuous flow of recycled stream prevented starvation of microbes, allowing microbial community to remain active and sustained even in the absence of new influent wastewater.

Furthermore, a special circumstance arose where the DHS-G3 system had to be shut down due to public holidays for Chinese New Year. Consequently, from 8th March 2024, to 13th March 2024, the DHS system was dismantled, and the sponge media used was stored in a refrigerator at approximately 10 ℃ to prevent microbial die-off. The low temperature conditions allowed the microbial activity to slow down significantly, reducing their energy requirements (Tan, 2020). As a result, the microbial inside the sponge media were able to survive during the shutdown period. During the startup of the DHS system, the sponge media were removed from the refrigerator and allowed to sit for a few hours before reintroducing it to the DHS-G3 reactor. This precaution was taken to avoid exposing the microbes directly to synthetic wastewater at a very low temperature. Rapidly increasing the temperature could potentially cause the microbial cell walls to break down, leading to cell lysis. Besides that, the system was allowed to run for a few days after startup before sample collection was continued. This action was taken to allow the microbes to stabilize and readapt to the environment.

In accordance with Section 3.3, the experiment comprises two phases: Phase 0 and Phase 1. Phase 0 entailed the inoculation of activated sludge onto the sponge media, whereas Phase 1 concentrated on determining optimal conditions for COD and nutrient removal. Throughout Phase 1, the performance of the DHS-G3 reactor was continuously monitored on an hourly basis, with adjustments being made based on results obtained from COD and nitrogen analysis. Additionally, the method of preparing synthetic wastewater was modified midway through the experiment. To distinguish between the two methods, Phase 1 was divided into two phases: Phase 1a for the first half and Phase 1b for the second half. In Phase 1a, synthetic wastewater was prepared using distilled water, whereas in Phase 1b, tap water was utilized. This decision was prompted by the unavailability of distilled water in the laboratory due to a malfunction in the machine. Despite this setback, it provided a valuable opportunity to test the effectiveness of tap water, which contains bacteria and microbes that cannot be replicated with chemicals. A study by Biplob et al. (2011) supported this change in preparation method, as they prepared synthetic wastewater with tap water, considering consistent organic substrate loadings and nutritional requirements for microbial growth. Besides, this adjustment provided insights into the robustness and adaptability of microbial community under varying conditions.

CHAPTER 5

NUTRIENT REMOVAL AND COD REMOVAL WITHIN DHS-G3 SYSTEM

5.1 Introduction

After the initial setup of the laboratory-scale DHS-G3 reactor, Phase 1 of the experiment, spanning 36 days, commenced. Phase 1a was scheduled to run for 22 days. However, within these 22 days, a 5-day break was incorporated, resulting in 17 days of actual operation for Phase 1a. Subsequently, Phase 1b followed, lasting for 14 days. The capacity of the DHS-G3 reactor was established at 20 L of diluted synthetic wastewater per day. Meanwhile, other parameters, including synthetic wastewater preparation methods, recycle stream flow rate, and ventilation, were adjusted based on the DHS-G3 nutrient removal performance and the availability of resources within the laboratory.

5.2 Optimum Condition for Phase 1

As stated previously, the performance of the DHS-G3 reactor was continuously monitored on an hourly basis for 17 days during Phase 1a and for 14 days during Phase 1b. These phases were conducted to determine the optimal conditions for COD and nutrient removal in the DHS system. Various modifications and adjustments were made during operations to achieve optimal removal efficiency.

Firstly, on Day 0, the start-up of the DHS-G3 reactor commenced. The start-up process was initiated by preparing diluted synthetic wastewater. The concentrated synthetic wastewater was diluted at a dilution factor of 1:20 (1 part concentrated synthetic wastewater to 19 parts distilled water). Equation 5.1 was utilized to determine the initial volume of concentrated synthetic wastewater. Then, using a final volume of 20 L as an example, a sample calculation of the volume of concentrated synthetic wastewater required can be performed.

$$C_1V_1 = C_2V_2 \tag{5.1}$$

where

C_1 = initial concentration of concentrated synthetic wastewater, mg/L

V_1 = initial volume of concentrated synthetic wastewater, L

C_2 = final concentration of diluted synthetic wastewater, mg/L

V_2 = final volume of diluted synthetic wastewater, L

Since, the dilution factor is 1:20, the initial concentration was 20 times more concentrated than the final concentration; thus, $C_1 = 20\ C_2$.

$$C_1V_1 = C_2V_2$$

$$\frac{C_1}{C_2} = \frac{V_2}{V_1}$$

$$\frac{20\ C_2}{C_2} = \frac{20\ \mathrm{L}}{V_1}$$

$$V_1 = 1\ \mathrm{L}$$

Based on the sample calculation, the final volume of concentrated synthetic wastewater would be 1 L. Therefore, the diluted synthetic wastewater would be prepared by diluting 1 L of concentrated synthetic wastewater ("P-water") with 19 L of distilled water. Throughout Phase 1a, the synthetic wastewater was freshly prepared on a daily basis from Monday to Friday using 1 L of "P-water" and 19 L of distilled water. Similarly, for Phase 1b, the 1 L of "P-water" was diluted with 19 L of tap water. Freshly preparing the synthetic wastewater every day helped mitigate fluctuations in nutrient and organic matter concentrations within the wastewater. These fluctuations could arise from self-degradation or bacterial consumption when exposed to open air. Additionally, a lid was employed to seal the influent tank, reducing the risk of contaminants entering the synthetic wastewater. Additionally, the pH of the synthetic wastewater was controlled between 6.5 and 7.5.

5.3 Concentration Profiles

During the experiment, there was a weekly sample collection day. For this experiment, Day 0 samples were collected on 31st January 2024, Day 7 samples on 7th February 2024, Day 21 samples on 21st February 2024, Day 28 samples on 28th February 2024, and Day 36 samples on 6th March 2024. Samples collected on Days 1, 7, and 21 were designated for Phase 1a, while those on Days 28 and 36 were for Phase 1b. On each sample collection day, 5 samples were collected at 2-hour intervals, meaning samples were collected at 8 a.m., 10 a.m., 12 p.m., 2 p.m., and 4 p.m. Figures 5.1 and 5.2 illustrated the concentration profiles of nitrate nitrogen and COD during Phase 1. The COD concentration profile depicted in Figure 5.2 exhibited a consistent trend across different collection days. In contrast, the nitrate nitrogen concentration profile depicted in Figure 5.1 showed a dip on the eighth hour of Day 21. Overall, the DHS-G3 reactor performed well in both COD and nitrogen removal, with better performance observed in COD removal. Further discussion on these findings would be provided in the subsequent subsections.

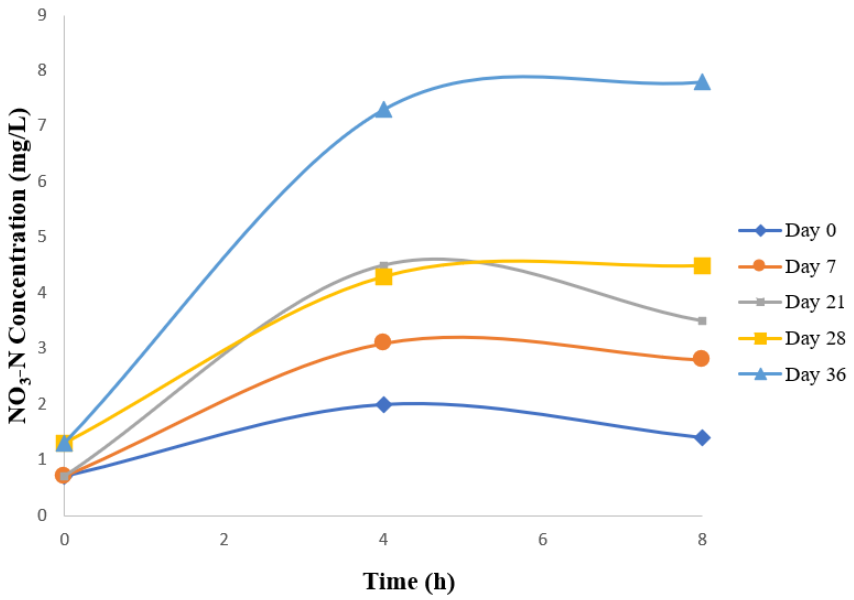


Figure 5.1: Nitrate Nitrogen ($NO_3^- - N$) Concentration Profile on Different Days during Phase 1.

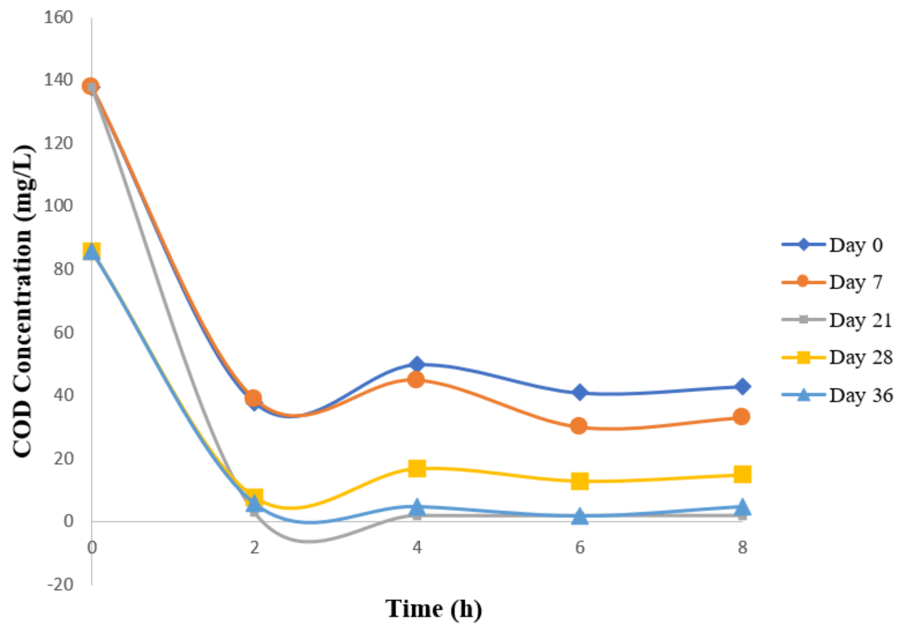


Figure 5.2: Chemical Oxygen Demand (COD) Concentration Profile on Different Days during Phase 1.

5.4 Nitrogen Removal

The source of nitrogen in this study was ammonium chloride, NH_4Cl, which was added during the preparation of concentrated synthetic wastewater. During this process, solid ammonium chloride dissolved in water, dissociating into ammonium ions (NH_4^+) and chloride ions (NO_2^-). Subsequently, the ammonium ions underwent nitrification and denitrification leading to their conversion into nitrogen gas. The succession of converting ammonium ions to nitrogen gas showed that the removal of nitrogen nutrients in water was achieved. Additionally, Equation 5.2 illustrated the chemical equation for the nitrification process, while Equation 5.3 presented the chemical equation for the denitrification process.

$$\text{Nitrification}: NH_4^+ \rightarrow NO_2^- \leftrightarrow NO_3^- \quad (5.2)$$

$$\text{Denitrification}: NO_3^- \leftrightarrow NO_2^- \leftrightarrow NO \rightarrow N_2O \rightarrow N_2 \quad (5.3)$$

Nitrification was a crucial process in the nitrogen cycle, which was essential for the cycling of nitrogen in the ecosystems. In aerobic conditions, nitrification process occurred, with ammonium ion (NH_4^+) dissociating into nitrite ions (NO_2^-). However, nitrite ions were non-stable intermediate product prone to oxidation. Therefore, the presence of oxygen in water led to the oxidation of nitrite ion (NO_2^-) to nitrate ion (NO_3^-). Moving on to the denitrification process, it typically occurred under anaerobic conditions. Nitrate ions serve as alternative electron acceptors when oxygen was limited in the system. During denitrification, denitrifying bacteria converted nitrate ions (NO_3^-) back to nitrite ions (NO_2^-) and then further into nitric oxide (NO) and nitrous oxide (N_2O). Eventually, nitrous oxide (N_2O) was converted into nitrogen gas (N_2). Nitrogen gas was the preferred outcome as it is environmentally benign. Removing excess nitrate ions from soils and water systems was desirable as it reduced the potential for nitrogen pollution, which can lead to eutrophication.

In the study, the removal of nitrogen by the DHS-G3 reactor was not directly measured by ammonium ion concentrations within the influent and treated effluent. Instead, the mode of nitrogen removal were nitrification efficiency and denitrification efficiency. To calculate the nitrification efficiency, the concentration of nitrogen atoms in ammonium ions ($NH_4^+ - N$) was computed. Then, this calculated concentration was compared with the concentration of nitrogen atoms in nitrate ions ($NO_3^- - N$) measured. For the concentration of nitrogen atoms in nitrate ions, the highest value was selected for each sample collection day. The highest value represented the peak of nitrification in that cycle. The difference between the concentration of $NH_4^+ - N$ and $NO_3^- - N$ served as an indicator of nitrification efficiency. Additionally, Equation 5.4 was utilized to compute the concentration of nitrogen atoms in ammonium ions ($NH_4^+ - N$), while Equation 5.5 was used to compute the nitrification efficiency.

$$Concentration\ of\ \mathrm{NH_4}^{+} - \mathrm{N} = \frac{MW_{\mathrm{N}}}{MW_{\mathrm{NH_4}Cl}} \times C_{\mathrm{NH_4}Cl} \qquad (5.4)$$

where

MW_{N} = molecular weight of nitrogen atom, g/mol

$MW_{\mathrm{NH_4}Cl}$ = molecular weight of ammonium chloride, g/mol

$C_{\mathrm{NH_4}Cl}$ = concentration of ammonium chloride, mg/L

$$Nitrification\ Efficiency\ (\%) = \frac{\mathrm{NO_3}^{\ -}\!-\mathrm{N}}{\mathrm{NH_4}^{\ +}\!-\mathrm{N}} \times 100\ \% \qquad (5.5)$$

Given that the molecular weights for a nitrogen atom and ammonium chloride were 14.0067 g/mol and 53.491 g/mol, respectively, a sample calculation for computing the concentration of nitrogen atoms in the ammonium ion and the nitrification efficiency on week 1 were presented.

$$\begin{aligned} \mathrm{NH_4}^{\ +}\!-\mathrm{N} &= \frac{MW_{\mathrm{N}}}{MW_{\mathrm{NH_4}Cl}} \times C_{\mathrm{NH_4}Cl} \\ &= \frac{14.0067\ \mathrm{g/mol}}{53.491\ \mathrm{g/mol}} \times 47.5\ \mathrm{mg/L} \\ &= 12.438\ \mathrm{mg/L} \end{aligned}$$

$$\begin{aligned} Nitrification\ Efficiency\ (\%) &= \frac{\mathrm{NO_3}^{\ -}\!-\mathrm{N}}{\mathrm{NH_4}^{\ +}\!-\mathrm{N}} \times 100\ \% \\ &= \frac{2\ \mathrm{mg/L}}{12.438\ \mathrm{mg/L}} \times 100\ \% \\ &= 16.08\ \% \end{aligned}$$

Furthermore, the denitrification efficiency was determined by the extent of nitrate removal. The difference between the highest and lowest concentrations of $\mathrm{NO_3}^{\ -}\!-\mathrm{N}$ in each cycle served as an indication of denitrification activities. Denitrification efficiency was calculated using Equation 5.6. Similarly, a sample calculation of denitrification efficiency on week 1 was presented.

$$Denitrification\ Efficiency(\%) = \frac{\mathrm{NO_3}^{-}{}_{high} - \mathrm{NO_3}^{-}{}_{low}}{\mathrm{NO_3}^{-}{}_{high}} \times 100\ \% \qquad (5.6)$$

$$Denitrification\ Efficiency\ (\%) = \frac{\mathrm{NO_3}^{-}{}_{high} - \mathrm{NO_3}^{-}{}_{low}}{\mathrm{NO_3}^{-}{}_{high}} \times 100\ \%$$

$$= \frac{2 \text{ mg/L} - 1.4 \text{ mg/L}}{2 \text{ mg/L}} \times 100 \%$$

$$= 30 \%$$

Additionally, a bar chart illustrating both nitrification efficiency and denitrification efficiency was included in Figure 5.3 alongside the COD removal efficiency. The purpose of Figure 5.3 was to examine the relationship between organic matter and nitrogen removal.

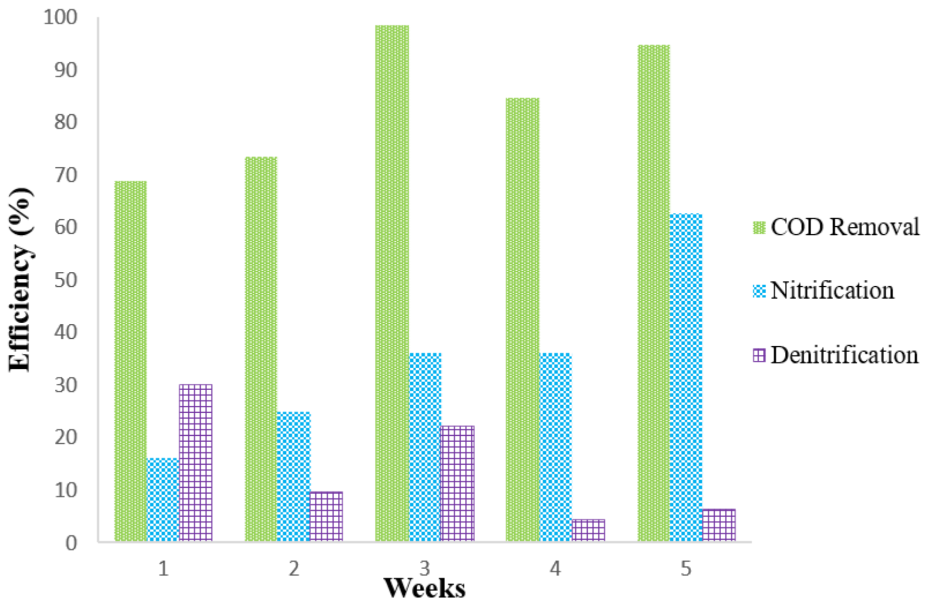


Figure 5.3: COD Removal, Nitrification and Denitrification Efficiency of DHS-G3 Reactor.

As depicted in Figure 5.4, the nitrification efficiency of the DHS-G3 reactor was 16.08 %, 24.92 %, 36.18 %, 36.18 %, and 62.71 % for weeks 1, 2, 3, 4, and 5, respectively. It was evident that nitrification activities within the DHS-G3 reactor steadily increased over time. However, in contrast, the denitrification activities of the DHS-G3 reactor showed inconsistent progress, with efficiencies of 30 %, 9.68 %, 22.22 %, 4.44 %, and 6.41 % for weeks 1, 2, 3, 4, and 5, respectively. These fluctuations were concerning as incomplete nitrate removal poses environmental risks. There were many existing literature reported the capability of DHS reactor in nitrogen removal. For instance, Mahmoud, Tawfik and El-Gohary (2011) achieved a TN removal of 73 %; Araki et al. (1999) reported a nitrogen removal of 78 %; Bundy et al. (2017) achieved a TN removal of 74.3 %.

In general, nitrifiers inhabiting the retained sludge of sponge media governed nitrification activities within the system, primarily in the aerobic zone (Araki et al., 1999; Tandukar, Ohashi and Harada, 2007). Subsequently, nitrite and nitrate could then be converted into gaseous nitrogen by denitrifiers inhabiting the anoxic zone of the sponge media (Araki et al., 1999; Tandukar, Ohashi and Harada, 2007). The aerobic zone was situated at the outer section of the sponge media, while the anoxic zone was located in the inner section. In an ideal scenario, the absence of oxygen in the inner section of the sponge media would generate an anoxic zone (or anaerobic zone) conducive to denitrification processes. However, the experiment indicated that the actual denitrification process may be hindered by the inconsistent distribution of sludge accumulation. A literature noted that the average percentage of accumulated sludge in the sponge inner section was 56 % while the accumulated sludge on the outer section were 44 % (Machdar et al., 2018). The imbalance may disrupt the formation of the necessary anoxic conditions for effective denitrification.

Many reports suggested that DHS reactors connected in series have distinct regions. For example, the upper portion (1st Segment) of the DHS system was primarily responsible for COD removal, while the lower portion (2nd Segment) was mainly responsible for nitrification and denitrification activities (Tandukar, Ohashi and Harada, 2007; Mahmoud, Tawfik and El-Gohary, 2011; Tawfik et al., 2011; Ikeda et al., 2013; Onodera et al., 2014). This situation arose primarily because the organic loading, or the food source for microbes, at the upper portion of the DHS system was more favorable for the heterotrophs, while the growth and activity of the nitrifiers were severely suppressed. According to Ikeda et al. (2013), competition between nitrifiers and heterotrophs for available carbon sources and oxygen might be high in the upper portion of the DHS reactor. Additionally, since a significant portion of the COD was removed in the upper portion, lower organic loading and reduced competition for oxygen were beneficial for nitrifiers in the lower portion. Bearing all this in mind, the experiment conducted was designed to focus on sampling from the lower section of the DHS-G3 reactor, revealing commendable nitrification efficiency consistent with existing literatures. The lower organic loading and reduced competition for oxygen in the 2nd Segment of DHS-G3 reactor offer favorable conditions for autotrophic nitrifiers, thereby enhancing nitrification activities.

Conversely, denitrification activities within the DHS-G3 reactor were limited, with the highest denitrification efficiency recorded at 30 % in week 1. This issue may stemmed from a decrease in available organic compounds as the synthetic wastewater progressed downstream of the DHS-G3 reactor. This limitation hampered the growth of denitrifiers within the reactor, as their growth is constrained by the lack of a carbon source. Additionally, the elevated nitrification activities in the system may have resulted in excessively high nitrate concentrations within the DHS-G3 reactor, which could have impeded the growth of denitrifiers. As highlighted by Albina et al. (2019), elevated nitrate concentrations could lead to nitrite accumulation, which is known to inhibit or even be toxic to denitrifying bacteria. However, a study conducted by Bundy et al. (2017), proposed that bypassing 30 % of raw synthetic wastewater could enhance overall denitrification and reduce total nitrogen levels within the system. Nevertheless, further enhancements to the DHS-G3 reactor were discussed in detail in Chapter 6.

5.5 COD Removal

Investigating COD removal alongside nitrogen removal in wastewater treatment was indeed critical, particularly given its significance as a measure of pollutants in wastewater. Developing a DHS-G3 reactor capable of meeting the standards outlined in the Environmental Quality (Sewage) Regulations 2009 guidelines, as indicated in Tables 2.2 and 2.3 (Chapter 2), was vital for ensuring environmental protection and public health. COD serves as a fundamental parameter in wastewater analysis, quantifying the amount of oxygen required to oxidize organic matter in a wastewater sample (ClearFox, 2023). High COD levels indicated a higher concentration of pollutants, highlighting the potential environmental impact of the wastewater. For instance, elevated COD levels may contain a large amount of oxidizable organic matter, leading to low dissolved oxygen concentrations within the wastewater samples. Low dissolved oxygen concentrations in wastewater were undesirable as it could create anaerobic conditions that were harmful to aquatic life.

The calculation of COD removal efficiency was relatively simple. As shown in Equation 5.7, COD removal efficiency could be calculated by comparing the initial concentration of COD in influent (untreated wastewater) to the concentration of COD in effluent (treated wastewater).

$$COD\ Removal(\%) = \frac{\mathrm{COD_{influent}} - \mathrm{COD_{effluent}}}{\mathrm{COD_{influent}}} \times 100\ \% \qquad (5.7)$$

Similarly, a sample calculation of COD removal efficiency on day 0 was presented. Then, the performance of DHS-G3 COD removal efficiency was shown in Figure 5.4.

$$COD\ Removal(\%) = \frac{\mathrm{COD_{influent}} - \mathrm{COD_{effluent}}}{\mathrm{COD_{influent}}} \times 100\ \%$$

$$= \frac{138 - 43}{138} \times 100\ \%$$

$$= 68.84\ \%$$

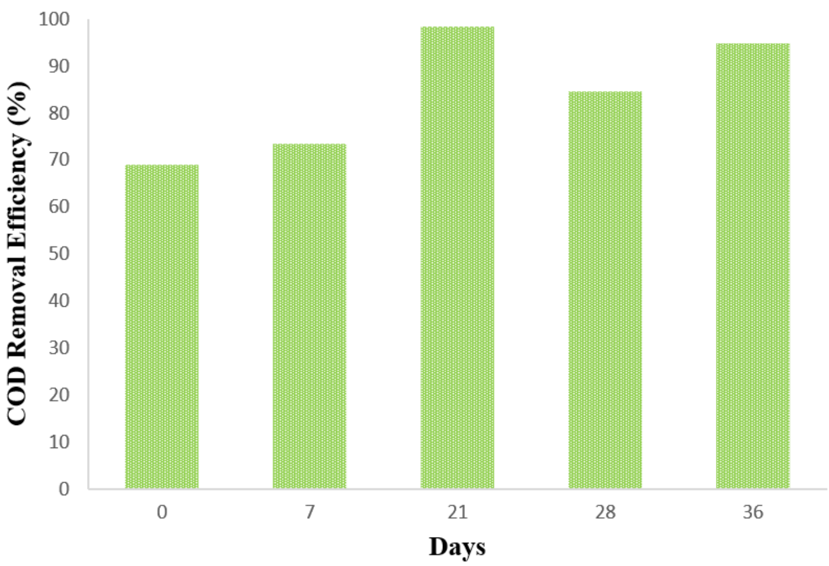


Figure 5.4: COD Removal Efficiency of DHS-G3 Reactor.

As shown in Figure 5.4, the COD removal efficiency of the DHS-G3 reactor gradually increased from 68.84 % on day 1 to 98.55 % on day 21. A slight decrease in COD removal efficiency can be seen on day 28 (from 98.55 % to 82.56 %), followed by an increase to 94.29 % on day 36. The lower COD removal efficiency on day 0 is attributed to influent loading (or OLR). Before starting up the DHS-G3 reactor, the sponge media underwent a 10-day cultivation period in a sludge solution. Transitioning these media to the DHS-G3 reactor (a new environment) necessitated adaptation of the microbial community within the sponge media, which had already acclimated to stable conditions during cultivation. The sudden down flow of influent to the sponge media created an organic shock load phenomenon. This abrupt change in flow conditions caused disruption to the microbial community and led to challenges such as detachment of attached activated sludge from the sponge medium. The detachment of activated sludge (biosolid escape) was attributed to the hydraulic shear force generated by the inflow of influent from the distributor. As a consequence of biosolid escape, a higher concentration of COD was observed on day 0.

A study conducted by Tawfik et al. (2011) observed that the COD removal efficiency decreased when the OLR increased, shifting from 96 % at 1.9 $\mathrm{kgCOD/m^3}$ day to 90 % at 6.8 $\mathrm{kgCOD/m^3}$ day. Similarly, Yoochatchaval et al. (2014) suggested that at a lower OLR, the removal efficiency of organic matter is higher. Specifically, the studies noted a drop in COD removal efficiency from 34 % to 29 % as the OLR increased. The increased in OLR led to a lower SRT, indicating detactment of activated sludge. Hence, examples from past researchers' work pointed out that a DHS system showed poor COD removal efficiency due to organic shock load and biosolid escape.

As the system operated continuously, the sludge trapped inside the sponge media gradually formed a filter cake. This occurrence facilitated a significant improvement in COD removal efficiency from day 7 (73.37 %) to day 21 (98.55 %). As noted by Tan (2020), the combination of pores within the sponge media and the formed filter cake serves as an effective bio-filter for COD removal from wastewater. Besides that, studies by Machdar et al. (2018) were comparable, showing an increased concentration of accumulated sludge as the experiment progressed. Consitently, Tan (2020) reported analogous results, illustrating a remarkable surge in COD removal efficiency from 28.69 % on day 0 to 84.85 % on day 1.

Furthermore, a noticeable decline in COD removal efficiency was observed on day 28 (from 98.55 % to 82.56 %). This decline occurred due to the introduction of a new formulation of synthetic wastewater into the system. Similarly, the microbial community inside had become accustomed to the previous synthetic wastewater prepared with distilled water, requiring time for adaptation. The disparity between tap water and distilled water was evident; one is conventional water while the other is pure. Typically, distilled water underwent distillation and condensation process where bacteria, ions, and gases were removed (Butler, 2020). In contrast, tap water may contain various impurities, including bacteria, which were challenging to replicate accurately in synthetic wastewater preparations using chemicals. Besides that, utilizing tap water to prepare synthetic wastewater was cheaper and faster compared to distilled water. It was easily obtained and requires no preparation time.

The COD removal efficiency observed on day 36 (94.29%) indicates that the removal efficiency has rebounded to a desirable level. This suggests that the microbial community inside the sponge successfully adapted to the new environment. Moreover, this recovery served as evidence of the robustness of the microbial communities within the sponge media. The ability of the microbes to recover and restore removal efficiency underscored their resilience and adaptability to environmental changes, maintaining positive functionality over time.

The resilience demonstrated by the microbial community implied an inherent capacity to adapt to fluctuations in their surroundings, ensuring the continuation of essential processes. Furthermore, the positive trend in nitrification efficiency, as depicted in Figure 5.3, from week 4 to week 5, reinforces the adaptability and functionality of the microbial community. However, the persistence of low denitrification activities raised the possibility of a longer adaptation period required for denitrifiers to establish themselves effectively. Thus, an extended observation period is necessary to conclusively ascertain the absence of denitrifiers in the system and understand the dynamics of their presence or absence over time.

Overall, the performance of DHS-G3 reactor designed showed an excellent removal of COD. The COD removal efficiency of 68.84 % on day 0 to 94.29 % on day 36 were similar when compared to other studies. Research studies by Tawfik et al. (2011), Ikeda et al. (2013) and Tan (2020) showed similar COD removal efficiency of above 90 %. In addition, studies by Tandukar, Ohashi and Harada (2007) showed a lower COD removal efficiency of 89.7 %. This consistency in COD removal across various studies underscored the effectiveness and reliability of the DHS-G3 reactor design in wastewater treatment. The DHS-G3 performed well in stable and fluctuating conditions of changing synthetic wastewater preparation and changing flow conditions. Its robustness in handling varying conditions further highlighted its potential for practical application in wastewater treatment plants.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In this experiment, a laboratory-scale DHS system was developed for wastewater treatment. Specifically, a two-segment DHS-G3 reactor was constructed with a working volume of 20 L per day, and the HRT was set at 2 hours. The design of the DHS-G3 reactor utilized easily accessible materials such as polyurethane sponge, bioballs, silicone tubes, straws, and plastic containers. The performance of the DHS-G3 reactor was evaluated, revealing simultaneous nitrogen and COD removal. The efficiency of COD removal, nitrification, and denitrification ranged from 68.84 % to 98.37 %, 16.08 % to 62.71 %, and 4.44 % to 30 %, respectively. These results demonstrate that the DHS-G3 reactor exhibited outstanding performance in organic matter removal, coupled with decent nitrogen removal.

Furthermore, it was observed that the top segment of the DHS-G3 reactor is primarily responsible for organic and COD removal, while the bottom segment facilitates nitrification and denitrification activities. The presence of an aerobic zone within the sponge media was identified, evidenced by satisfactory nitrification activities within the system. Additionally, the increase in nitrate concentration within the system indicated the presence of nitrifiers. However, the limited denitrification efficiency of the DHS-G3 reactor suggests that the anoxic zone within the sponge media is less pronounced. It was an interesting finding that the DHS-G3 reactor designed are more favourable for nitrification activities than denitrification activities. The high nitrate concentration at the end of phase 1 are said to be toxic for the denitrifiers in the system. Without suitable conditions, the denitrifiers are unlikely to convert nitrate ions into nitrogen gas.

Moreover, it was found that tap water is suitable for the preparation of synthetic wastewater, as the results data are not severely affected by the change in preparation method. The robustness of the microbial community was proven as it adapted to a new environment and showed increasing organic matter removal and nitrification efficiency by Week 5. The resilience exhibited by the microbial community implies that it possesses an inherent ability to adjust to environmental changes, thereby ensuring the uninterrupted functioning of the DHS system.

In summary, the DHS-G3 reactor emerges as a cost-effective solution for wastewater treatment, efficiently conducting aerobic nutrient removal and organic removal without requiring an external aeration system. The proposed DHS-G3 reactor shows promise as a potential solution to address the prevalent issue of clean water scarcity in rural areas of Malaysia. It could be integrated with existing wastewater treatment facilities in Malaysia to treat effluent effectively, providing significant aerobic nutrient removal and exceptional COD removal.

6.2 Recommendations for future work

One of the significant challenges encountered during the DHS-G3 reactor design is the limited denitrification activities within the system. To address this issue, several suggestions have been proposed. Firstly, it is recommended to implement an additional bypass, particularly targeting the bottom segment of the reactor. This strategy aims to increase the available carbon source for denitrifying bacteria, especially those situated in the bottom segment of the DHS-G3 reactor. However, determining the optimal bypass percentage for a specific application would depend on specific circumstances and various other factors.

Moving forward, it is advisable to use tap water for synthetic wastewater preparation due to its cost-effectiveness, accessibility, and ease of preparation. Additionally, it is recommended to introduce carbon sources such as sodium acetate to the bottom segment, where nitrification and denitrification activities frequently occur. This addition could potentially enhance denitrification activities within the system, consequently improving nitrogen removal efficiency.

Furthermore, collecting samples from different segments of the DHS-G3 reactor is recommended to gain a comprehensive understanding of the system's activities. Analysis of samples from various segments allows for the identification of spatial variations in nutrient concentrations, oxygen levels, and microbial populations. This information facilitates targeted interventions and adjustments to optimize reactor performance.

Moreover, for the upscale implementation of the DHS-G3 reactor in Malaysia, it is essential to conduct pilot plant testing and modeling simulations locally. These activities are crucial for providing optimal conditions and trainings for DHS system operation, ensuring its effectiveness in addressing wastewater treatment challenges in the region.

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APPENDICES

Appendix A: Results Table

Table A-1: Physio-Chemical Parameters of DHS-G3 Reactor in Phase 1

Day	Hour (h)	Nitrate Nitrogen Concentration (mg/L)	COD Concentration (mg/L)
0	0	0.7	138
	2	-	38
	4	2	50
	6	-	41
	8	1.4	43
7	0	0.7	138
	2	-	39
	4	3.1	45
	6	-	30
	8	2.8	33
21	0	0.7	138
	2	-	3
	4	4.5	2
	6	-	2
	8	3.5	2
28	0	1.3	86
	2	-	8
	4	4.3	17
	6	-	13
	8	4.5	15

Table A-1 (Continued)

36	0	1.3	86
	2	-	6
	4	7.3	5
	6	-	2
	8	7.8	5

Table A-2: Performance of DHS-G3 Reactor in Phase 1

Week	Efficiency (%)		
	COD Removal	Nitrification	Denitrification
1	68.84	16.08	30.00
2	73.37	24.92	9.68
3	98.37	36.18	22.22
4	84.59	36.18	4.44
5	94.77	62.71	6.41