Design of a Sand Filter to Remove Microfibers from Different Sources of Water

A Thesis Submitted in Partial Fulfilment of the Requirement for the Award of the Degree

Of

MASTER OF TECHNOLOGY

In

Food Technology and Biochemical Engineering

By

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CERTIFICATE

This is to certify that the thesis entitled " **Design of a Sand Filter to Remove Microfibers from Different Sources of Water"** submitted by **Ishita Mondal** of Registration No-**140863 of 2017-2018** is in partial fulfilment of the requirements for the award of degree of **Master Of Technology In Food Technology And Biochemical Engineering** of **Jadavpur University.**

This is an authentic work carried by her under our supervision and guidance. To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other university /institute for the award of any degree.

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Declaration of Originality and Compliance of Academic Ethics

I hereby declare that this thesis contains literature survey and original research work by me as part of my **Master of Technology in Food Technology And Biochemical Engineering** studies.

All information in this document have been obtained and presented in accordance with academic rule and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

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Abstract

In this thesis, widespread study was conducted by collecting water samples throughout the areas in Kolkata and its suburbs for estimating the microfiber content in water. Grab samples (**n=45**) were collected and were tested for microfiber count and mass of microfibers. The samples collected were stained with a biological stain to differentiate between synthetic and natural particles found under the microscope. The goal was to better understand the cause and consequences of the occurrence of microfiber in the water bodies which in turn is polluting the ecosystem. The primary cause of microfiber pollution is the process of laundering which generates and releases synthetic fibers into the environment. The effluent water released from the laundry was also collected for this study. The maximum estimated microfiber count including other non-biodegradable synthetic particles in tap water sample that belong to South Kolkata region was **2.5e+5** per ml of sample and the minimum count was **8.3e+3** per ml in the packaged drinking water sample. Water samples were also tested for its Bisphenol A content; Bisphenol A is a potent endorcrine disruptor and can cause serious health hazards. It is a by product of microfiber and microplastics, as these microfibers leaches chemicals like BPA on degradation. The BPA concentrations were estimated in the UV-Vis Spectrophotometer at the wavelength of 265nm. The results obtained on microfiber count and BPA content is quite alarming, the highest concentration of BPA in the wash effluent sample was found to be **6.5e-6 μg/ml** and the lowest BPA concentration among the tested samples were found to be **8.5 e-6 μg/ml**. To overcome this problem, a real time cross flow microsand filtration system design has been proposed in this thesis. A lab scale experimental filter setup was built in the laboratory for better understanding of the design parameters like height of the packed bed (H) and different mesh size sand i. e. bed packing material. The experimental filter setup was used to calculate the pressure drop (ΔP) and flow rate (Q). Different design parameters were altered to obtain the desired flow rate and optimum filtration efficiency. These parameters were finally used to design a real time cross flow filtration system in this thesis and is believed to achieve a optimum filtration efficiency greater than 80% with a laminar flow (Reynolds Number, **Re = 8**) and a flow rate of **60 l/ hr**.

Key Words: Microfiber, Effluent, Laundry, Bisphenol A, Sand filter, Filtration Efficiency, Flow rate, Reynolds Number

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Glossary of Terms

WWTP - WasteWater Treatment Plant

PCB – PolyChlorinated Biphenyl

PBD – Pyrrolobenzodiazepines

PAH – Poly Aromatic Hydrocarbon

BPA – Bisphenol A

SSF – Slow Sand Filtration

CFM – Cubic feet per minute

WHO – World Health Organization

EFSA – European Food Safety Authority

EPA – Environmental Protection Agency

NTU - Nephelometric Turbidity Unit

DBP – Disinfection Byproduct

PFC- Polyfluorinated Chemicals

HDPE – High Density Poly Ethylene

RBS – Rose Bengal Stain

PBF – Packed Bed Filter

CONTENTS

OBJECTIVE OF THE THESIS

This thesis work seeks to explore the potential impacts of microfiber on the environment especially in drinking water and to quantify microsynthetic fibers released from clothes made up of synthetic material and to identify scope and opportunities for further research. Also, this thesis work suggests a potential solution to this microfiber problem that can be widely applicable and beneficial for man and environment.

Specific objectives and deliverables include:

1) To conduct a widespread study on the identification and level of contamination of microfibers and other non-biodegradable particles in the water samples collected from different areas and sources in and outside Kolkata.

2) To differentiate between the natural and synthetic particles i.e. microorganisms and microfibers or microplastics using a biological stain. An innovative, replicable, and controlled experiment was designed to achieve the approximate total of microfibers and other non-biodegradable particles in samples that were collected during the course of this thesis work.

3) Detection and quantification of BPA in different water samples. The concentration of BPA was determined in µg/ml using UV-Vis Spectrophotometer.

4) Fabrication of a filter with appropriate cost effective filter media. Selection of low cost packed bed filter media was the main focus as this will reduce the overall cost of the filter thereby enabling access and affordability to a larger section of user.

5) Development of experimental filter setup using selected filter media for process optimisation. A laboratory filter setup was built to calculate the pressure drop and the type of flow.

6) Design of a Cross flow micro-sand filtration system for removal of microfiber with optimum filtration efficiency versus flow rate was carried out. The primary goal was to design a filter with maximum microfiber removal efficiency at a desired flow rate of 60 lit/hr.

STRUCTURE OF THE THESIS

This thesis is divided into six chapters. A brief idea about each chapter is provided as follows.

Chapter 1: INTRODUCTION

This chapter gives an introductory idea about the microfiber pollution, its threats, solution to this problem and theory of filtration.

Chapter 2: LITERATURE REVIEW

This chapter vividly provides the literature review relevant to this research work. It provides the history and background of microfiber pollution through, works of different researchers on the risks associated with the problem and existing alternative solutions to overcome the microfiber problem.

Chapter 3: RESEARCH AND EXPERIMENTAL WORK

It consists of three parts. The 1st part deals with the survey carried out on microfiber contamination in different water samples carried out for this thesis work. All procedures followed for sample collection and processing are discussed here. The 2nd part narrates the work done on various water samples for Spectrophotometric estimation of Bisphenol A. The 3rd part provides detailed information on the filter design prototype and fabrication details and parameters required for designing the filter.

Chapter 4: OBSERVATIONS AND FINDINGS

This chapter is also divided into three parts as mentioned above. This chapter gives information on the observed and recorded data and visual observations. The 1st part contains tables showing microfiber count and microfiber mass found in samples. The 2nd part shows the BPA absorbance peaks for different samples as shown by the UV-Vis Spectrophotometer. The 3rd part shows filtration efficiency i.e. the %age microfiber removal before and after filtration as carried out in the filtration setup.

Chapter 5: RESULTS AND DISCUSSIONS

Chapter 5 contains 3 parts like the previous two chapters and consists of graphical representations and inferences of the data obtained in all three different but related parts of this work. The proposed filter design is also discussed in this chapter.

Chapter 6: CONCLUSION AND FUTURE WORK

The last chapter includes discussions related to the topic and experimental works that has been done during the course of this work. It throws light on the significance of this work. Also, future scope to continue work on this research topic is discussed in this chapter.

CHAPTER 1

INTRODUCTION

Microfiber is a microscopic particle, an interesting research to the world. It has no good definition, as it is the outcome or residue of the laundry wash. It is not created or manufactured in the industries or any construction companies. Microfiber is actually polyester and nylon that is used to make fabric. **It is a synthetic artificial fiber and is not a naturally occurring material**. The marine creatures seem to be unhealthy and various fibers are found in their stomach, intestine that inspired the researcher to attempt to find the actual cause. **Microfiber pollution** is a very important topic in the modern world as it not only is polluting the oceans but also is affecting the underwater creatures and the predators as well. The pollution from plastic products and eventually from microfiber synthetic products from textile industries is an alarming and sensitive issue nowadays. The washing of plastic-based synthetic fabrics and clothing items (like polyester, fleece, nylon, spandex, and more) in washing machines results in shedding of tiny plastic fibers. These tiny pieces of plastic are too small to be caught by conventional filtration systems used within washing machines or by Municipal Water Treatment Plants, therefore, it flows freely out into our environment in great numbers via wastewater effluent. As a result of the widespread use of synthetic fabrics and a lack of adequate filtration, our environment, the waterways and food resources are becoming inundated with these invisible plastics.

Microfibers from laundering synthetic textiles are the **number one global source of primary microplastics** . 34.8% of primary microplastic released into the oceans are from the washing of plastic fabrics (**Boucher & Friot, 2017**). Globally, 60.1% of the clothes we buy are made out of plastic (68% in developing economies, 48.2% in developed economies) (**Boucher & Friot, 2017**). Emerging research from around the world examining the abundance of microfibers is being published very frequently.

1.1 MICROFIBER

Microfibers are synthetic <u>ultra-fine fibres</u>, <u>finer than 1.0 denier or decitex/thread,</u> having a diameter of less than 10 micrometers. Microfibers are extremely thin synthetic fibres made from polyester and polyamide. It is a type of micro-plastic, which is wash off from clothing made from synthetic fabrics like polyester. Microfibers come from the wear and tear of clothing, furnishings and carpeting. Microfibers are one hundred times finer than a human hair, up to thirty times finer than cotton fibre, and forty times finer than wool. A single strand of micro fibre is approximately $1/20^{th}$ the diameter of a strand of silk.

It is found that single synthetic fleece jacket releases 250,000 microfibers when washed. The old jackets release more microfibers than that of new jacket due to the weakening of the fibers. It is also found that if 100,000 fleece jackets are washed then an average 30kg of microfibers are released and later found in the water across the globe. The microfibers are released 5 times more when the fleece jacket is washed in the top load washing machine than in the front load machine. The aging of the fleece jackets acts accordingly in the washing machine. Again garments of higher quality and durability shed less in the wash than low quality synthetic products.

1.2 THE PROBLEM

1.2.1 <u>The base of the chain</u>

On washing plastic-based synthetic fabrics and clothing (like polyester, fleece, nylon, spandex, and others) in washing machines, these items shed tiny plastic fibers. Those minute pieces of plastic are too small to be caught by conventional filtration systems used within washing machines or by municipal water treatment plants, instead flowing freely out into our environment in great numbers via wastewater effluent. As a result of the widespread use of synthetic fabrics and a lack of adequate filtration, our environment, waterways and food resources are getting contaminated with these microscopic plastics that are invisible to the naked eye.

1.2.2 Marine creatures are ingesting microfibers.

In many environments, synthetic fibers are the predominant form of microplastic (upto 85% in intertidal zones), it is likely that many of the microplastics being consumed by freshwater and marine organisms are microfibers shed from clothing during washing **(Mathalon & Hill, 2014; Browne et al., 2011)**. From the lowest trophic levels to the apex of the food chain, microplastics have been recovered from the gastrointestinal tracts and tissues of zooplankton, shrimp, mussels, pelagic fish, and whales **(Cole et al., 2013; Devriese et al., 2015; Mathalon & & Hill, 2014; Browne et al., 2011).** From the lowest trophic levels to the apex of the food chain, microplastics have been recovered from the gastrointestinal tracts and tissues of zooplankton, shrimp, mussels, pelagic fish, and whales **(Cole et al., 2013; Devriese et al., 2015; Mathalon & Hill, 2014; Neves et al., 2015; Besseling et al., 2015; Lusher et al., 2015).** The consumption of these microplastics is not always directly from the

surrounding ocean waters, however, as natural trophic transfer between organisms in a marine food web have been observed **(Farrell & Nelson, 2013).**

Like microplastics, microfibers are a similar size to plankton **(Nel & Froneman, 2015).** This small size poses a huge problem because a wide variety and high number of marine species eat plankton via filter feeding**. While targeting plankton, these species appear to frequently consume microplastics as well.** In fact, the chemical properties of plastics may even cause some organisms like corals to target microplastics **(Allen et al., 2017).** Studies have shown that species such as zooplankton, coral, fish, crabs, mussels, whales, and many others ingest microplastics directly **(Besseling et al., 2015; Desforges et al., 2015; Hall et al., 2015; Rummel et al., 2015; Watts et al., 2015; Van Cauwenberghe & Janssen, 2015).**

1.2.3 <u>Humans are consuming them too</u>

Research has shown that because human populations rely on the ocean as a major food source, we are consuming microplastics as well. It is estimated that average shellfish consumption could lead an individual to ingest 11,000 microplastic pieces per year **(Van Cauwenberghe & Janssen, 2015).** In another study, 83% of fish caught by local fisherman - win the Pajeú river crossing in Serra Talhada, Brazil contained plastics, with microfibers being the most commonly observed type (**Silva-Cavalcanti et al., 2017).**

Dietary exposure to microplastics is not exclusive to meat, as another study found microplastic contamination present across 15 brands of table salt for sale in China **(Yang et al., 2016)**. <u>**Even more shocking is recent research that found 83% of drinking water samples tested around the world to contain microplastics**</u> **(Kosuth et al., 2017).** This truly is a challenge faced by the entire global community together.

1.3 SOURCES OF MICROFIBRE CONTAMINATION

- One significant source of microfiber contamination is synthetic clothing fibres, less than 1 mm in size, that are discharged from clothes washers, through wastewater.

- A recent study reveals that each <u>**cycle of a washing machine could release 700,000 fibres**</u> into the water and environment through drainage and other water channels.

- About 60% of all clothing on earth is made of polyester, a form of plastic derived from fossil fuels, which are largely responsible for water contamination.

- A single piece of synthetic clothing can shed more than 1900 fibers in one wash **(Browne et al., 2011).**

- Orb Media (an independent journalism media) also **found fibers in tap water drawn from underground sources!**

- The studies indicate that the fibers in our clothes could be poisoning our waterways and food chain on a massive scale.

1.4 Microfibre Contamination Cycle

Wastewater Treatment Plants (WWTPs) play a critical role in the fate and transport of microfibers into the environment. In countries with sewage infrastructure, the greywater generated by washing machines is discharged into the local sewer system. This influent is treated by the WWTP and then discharged as treated effluent, which is released into water bodies such as rivers, streams, and oceans. Whereas, in developing countries like India, Pakistan, Bangladesh and Sri Lanka there are no Wastewater Treatment Plants i.e. in these countries the sewage and effluents are directly discharged into the water bodies thereby polluting them.

Numerous studies have found evidence of microplastic and microfiber contamination in WWTP influent, with varying levels of incoming microfiber concentration. These variations are likely due to differences in sampling methods; for example, the study of the Lysekil, Sweden WWTP only analyzed fibers 300 μm and larger while other studies analyzed fibers 20 μm and larger **(Talvitie et al., 2015).** Variations can also be attributed to the time of day and season of the sampling**. (Talvitie et al., 2015).** Apart from the Viikinmaki, Finland WWTP, all of the WWTPs studied had higher concentrations of microfibers than microplastics. As such, it is likely that

microfiber pollution accounts for the majority of the microplastic contamination reaching WWTPs.
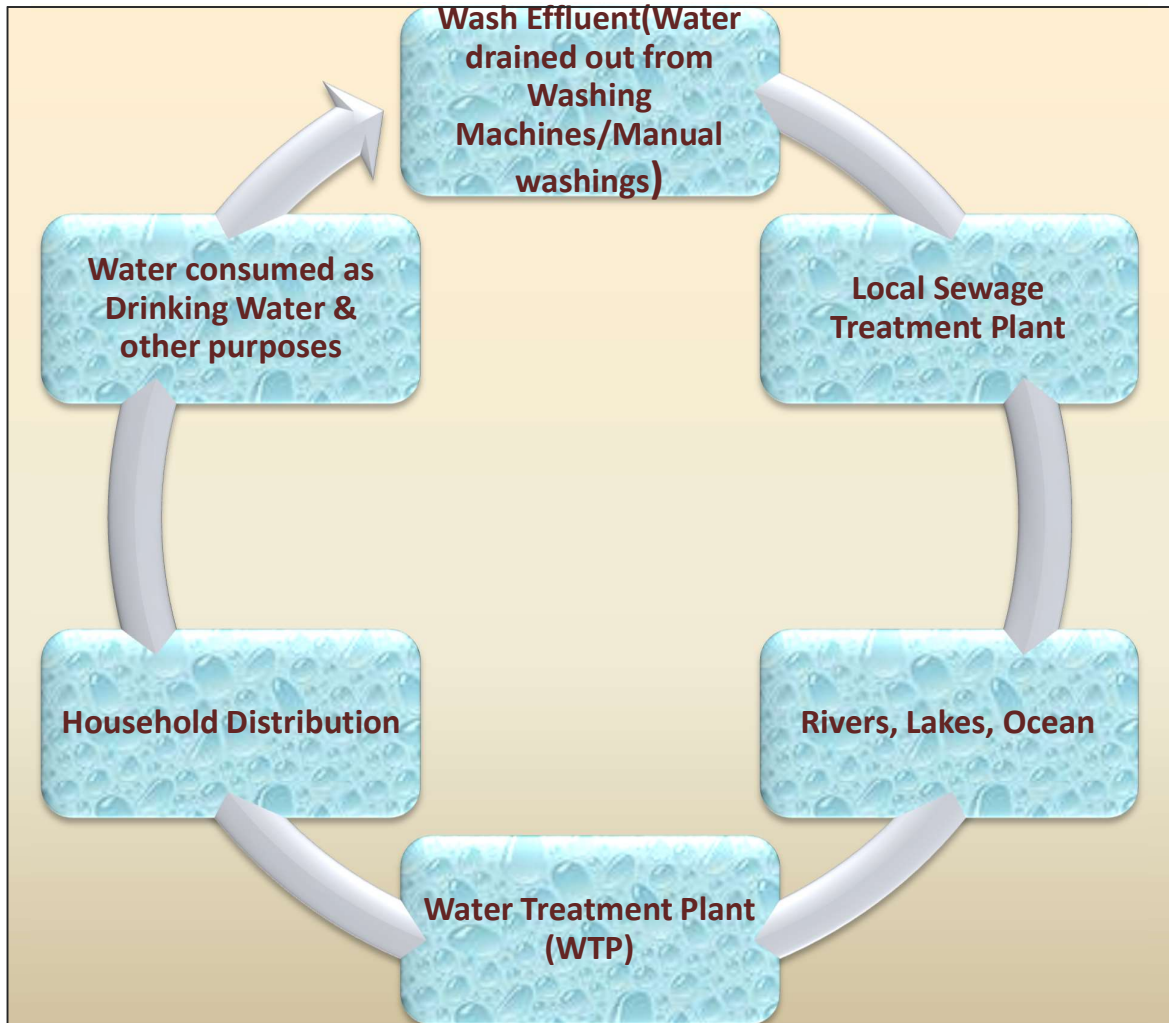
Comparing the influent and effluent concentrations from each WWTP studied indicates a removal rate of 65-99.9%. The majority of microfibers appeared to be removed during primary sedimentation and mechanical removal, and secondary sedimentation had little effect on microfiber concentrations **(Talvitie & Heinonen, 2014; Gasperi et al., 2015; Talvitie et al., 2015).** Lysekil, Sweden, had much lower concentrations of microfibers in its effluent.

There are a greater proportion of smaller microfibers in WWTP effluent, which indicates that smaller fibers are more likely to make it through the WWTP process **(Gasperi et al., 2015).** This difference in filtration size indicates that studies analyzing 300 μm and larger fibers might not capture the true amount of fibers released. Despite the efficient removal rates in WWTPs, a large number of microfibers do escape the treatment process and enter into the environment each day. For example, based on a discharge rate of 270,000 m3/day, the Viikinmaki, Finland WWTP, discharges 3.73 billion fibers per day.

Using the linear density of microfibers of 0.15mg/mm, this is equivalent to a discharge of 81 kg/day of microfibers into the environment. The discharge of this effluent could have a significant effect on the water bodies into which effluent is released; high microfiber concentrations have been found in sediment and ocean samples around WWTP effluent pipes **(Magnusson & Norén, 2014; Talvitie et al., 2015).** Additionally, microfibers discharged in effluent are more mobile in the environment than other microplastics. At the Lysekil WWTP, an equal portion of microfibers and other microplastics were discharged from the effluent pipe into the ocean; however, only microfibers were found in the seawater samples around the effluent pipe **(Magnusson & Norén, 2014).**

1.5 Some Facts & Figures

➢ Microfibers are washed off up to 2 gram per wash and flowed down through the drain to the local sewage treatment plant. **These fibers are so tiny that water treatment plants do not catch them all**, so they easily move through Waste Water Treatment Plant (WWTP) and more than 15% mix up in the ponds, lakes & oceans.

➢ The microfibers have static electric charge making it attract other pollutants such as chemicals and oil and act as poisonous substances.

➢ A recent Norwegian study suggested that up to 1000 tons (2,204,623 pounds) of microfibers go down the drain in Norway each year **(Sundt et al., 2014).**

➢ It's already estimated that there are 1.4 million trillion microfibers in the ocean, which is about 200 million microfibers for every person on the planet.

Table 1: Reported average microfiber concentrations (fibers/m3) in wastewater treatment plant (WWTP) effluent.

Wastewater Treatment Plant	Microfiber Concentration in Effluent (fibers/m$_3$)
Paris, France	32,000
Viikinmaki, Finland	13,800
Lysekil, Sweden	4
St. Petersburg, Russia	1,60,000

Sources: Talvitie & Heinonen, 2014; Gasperi et al., 2015; Talvitie et al., 2015

<u>Micro-plastics absorb, accumulate, and pass on environmental toxins.</u>

While the full effect of consuming microplastics on animal and human health are only beginning to be understood, microplastics have been shown to absorb, carry, and retain pollutants (**Hankett et al., 2016; Hirai et al., 2011**) and leach those compounds into the tissue of animals that consume them **(Tanaka et al., 2013; Yamashita, 2011).** Studies are beginning to emerge that highlight the negative impacts of microplastic ingestion on marine life. For example, microplastic consumption has been linked to liver toxicity in fish, decreased reproductive potential in oysters, and decreased survival and predator aversion ability in beachhoppers **(Rochman et al., 2013; Sussarellu et al., 2016, Tosetto et al., 2016).** Animals may be affected by the toxins carried by microplastics even without ingesting them, with one study finding that brown mussel larvae were sensitive to being in the mere presence of leachate from plastics **(Gandara e Silva et al., 2016).** These studies altogether suggest that plastics in the ocean accumulate toxins, pass those chemicals to the tissues of organisms that consume them, and can create a significant health risk to marine animals and potentially humans.

1.6 <u>MICROFIBERS AND ITS IMPACT</u>

Microfibers fall in the category of secondary microplastics. The presence of synthetic fibres, synthetic dyes and nanoparticles in high concentrations in finished garments poses a potential risk to human health and ecotoxicity via direct contact or chemical release from washing a garment. Possible release pathways are shown in the figure below.
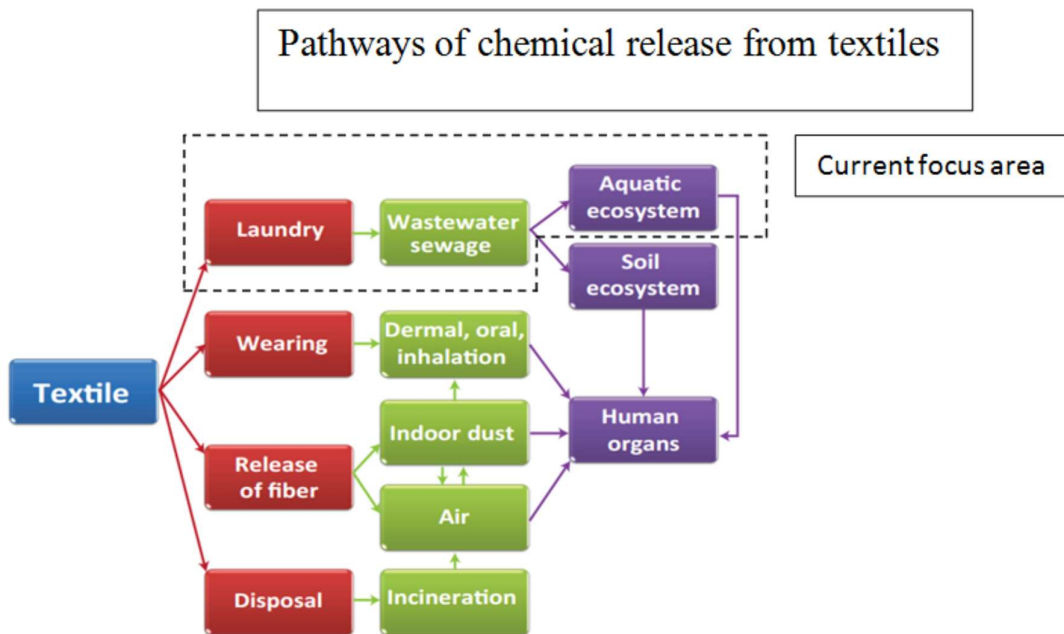
Chart showing Chemical release pattern from textiles. (Source: Luongo, 2015)

When plastics are exposed to natural forces like sunlight and wave action, plastics will degrade into microplastics that are defined as plastic particles under 5 mm in size. This definition commonly includes plastic pieces in the nano-scale, < 1 μm in size. The extent of plastic degradation depends on several factors including polymer type, age, and environmental conditions like weathering, temperature, irradiation, and pH. Over time, these plastic particles contaminate the marine ecosystem and the food chain, including foodstuffs intended for human consumption. In vivo studies have demonstrated that nanoplastics and micro plastics can translocate into all organs. Evidence is evolving regarding relationships between micro- and nanoplastic exposure, toxicology, and human health.

Plastics are hydrophobic and have been known to adsorb chemicals from the environment such as PCBs, PBDEs, and PAHs, some of which are known reproductive toxicants and carcinogens. Plastic can also adsorb metals and bacteria, sometimes at concentrations many times higher than their immediate surroundings. Furthermore, there is evidence that once ingested some of these organic chemicals can desorb in the guts of animals. Plastics can also leach synthetic additives, such as phthalates, alkylphenols, and **bisphenol A (BPA)**. A more recent study indicates that plastics can be cytotoxic to human cells. Finally, plastic debris can serve as a unique microhabitat for marine organisms and aid in the transport of invasive

species. These known issues highlight why micro plastics are considered a contaminant of emerging concern.

1.7 <u>Occurrence of Bisphenol A</u>

We get exposed to these chemicals mainly from handling plastics or other products which contain bisphenol A. Heating such items increase the exposure because more leaching can occur as a consequence. These chemicals can then enter our system through food or drink stored inside the items or even through items like dental sealants. We can also get exposed to bisphenol A by dermal absorption. Recent studies showed that bisphenol A can enter blood through the tiny pores on the skin. The biggest concern is that because most soaps facilitate their dilution, cleaning your hands with soap after handling items containing these chemicals can result in more dermal absorption. So it is better not to use soap after handling the different items that have bisphenol A.

1.7.1 <u>Bisphenol A (BPA)</u>

Bisphenols are chemical compounds characterized by two phenol rings. There are several bisphenols but bisphenol A is most widely used. Bisphenol A (BPA) is one of the most used plasticizers with more than 4.8 million tons produced in 2012. BPA is also an endocrine disruptor that has been linked to adverse health effects such as cancer, obesity, behavioural and mood changes, reduced fertility, developmental changes and more in humans and other animals. The evidence of the toxicity of BPA, even at very low levels, has caused many countries to limit its use, especially in baby bottles and other baby-related hard plastic items.
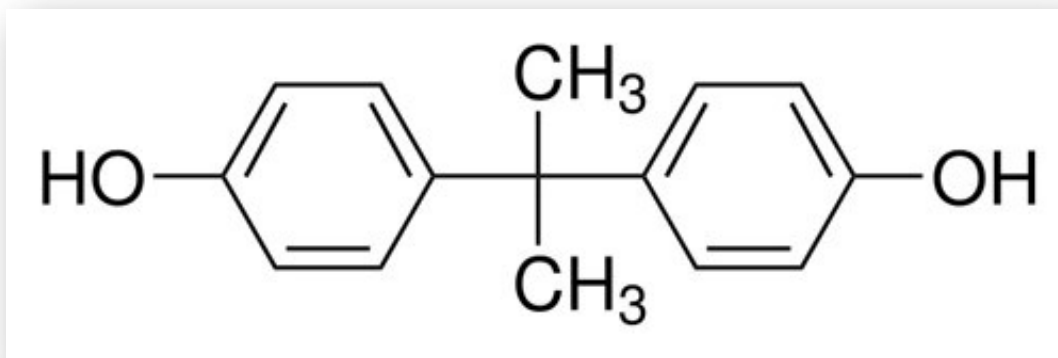
Fig 1: <u>Structure of Bisphenol A</u>

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1.7.2 History of BPA

BPA was invented by the Russian chemist Aleksandr Dianin in 1891 but its synthesis was first reported by Theodor Zincke in Germany in 1905 (Dianin, 1891; Zincke, 1905). BPA was created by the reaction of phenol with acetone following a 2 to 1 ratio in the presence of an acid catalyst leaving water as the sole by-product. The usefulness of BPA in the production of plastics became evident by the middle of the 20th century. Although polycarbonates had been produced in the laboratory since the late 19th century, it was not until 1953 that polycarbonates were efficiently synthesized by reacting bisphenol A with phosgene as discovered by Bayer chemist, Dr. Hermann Schnell. The new material was patented in October 1953 under the name of Makrolon and polycarbonate production rapidly expanded to reach industrial levels by the summer of 1960.

1.7.3 Effects of BPA

- BPA is present all around us in the environment and in manufactured products.

- Research has linked exposure to fertility problems, male impotence, heart disease and other conditions.

- Some reports say that current levels of BPA are low and not a danger to humans.

- It can imitate the body's hormones, and it can interfere with the production, secretion, transport, action, function, and elimination of natural hormones.

- BPA can behave in a similar way to oestrogen and other hormones in the human body.

- Infants and young children are said to be especially sensitive to the effects of BPA.

From the earlier mentioned information, it is evident that microfibers and compounds like Bisphenol induces several potential treats to the environmental ecology and human health.

So it is necessary to eliminate those harmful matters from the water, or in some cases we have to prevent those hazardous materials from mixing with open water bodies.

The most convenient solution to this is to filter microfiber and BPA containing water before drinking and mixing in water bodies.

1.8 Sand Filtration

Sand filtration has been an effective water treatment process for preventing the spread of gastrointestinal diseases for over 150 years, having been used first in Great Britain and later in other European countries (LOGSDON 2002). **Slow Sand Filtration (SFFs)** is still used in London and were relatively common in Western Europe until recently and are still common elsewhere in the world. The move away from slow sand filtration in industrialised countries has largely been a function of rising land prices and labour costs, which increased the cost of SSF produced water. Where this is not the case, SSFs still represent a cost-effective method for water treatment (WHO). Since these conditions prevail in many developing countries, it is a very promising technique for water purification and, therefore, the development of a sustainable water system.

The basic principle of the process is very simple. Contaminated freshwater flows through a layer of sand, where it not only gets physically filtered but biologically treated. Hereby, both sediments and pathogens are removed. This process is based on the ability of organisms to remove pathogens.

In this context, it is important to distinguish slow and rapid sand filtration. The difference between the two is not simply a matter of the filtration speed, but of the underlying concept of the treatment process. Slow sand filtration is essentially a biological process whereas rapid sand filtration is a physical treatment process (WHO). Although the physical removal of

sediments is an important part of the purification process, the relevant aspect is the biological filtration. The top layers of the sand become biologically active by the establishment of a microbial community on the top layer of the sand substrate, also referred to as '*schmutzdecke*'.

These microbes usually come from the source water and establish a community within a matter of a few days. The fine sand and slow filtration rate facilitate the establishment of this microbial community. The majority of the community are predatory bacteria that feed on water-borne microbes passing through the filter (WHO). Hence, the underlying principle of the SSF is equivalent to the bio-sand filtration. While the former is applied to semi-centralised water treatment, the latter mainly serves household purposes.

1.9 Physics of Filtration

There are five ways in which particles are trapped in fine filter media. Those are sieve effect, impaction, interception, Brownian diffusion, and static charge effect. The first is the **sieve effect** which stops large particles that are just too big to fit through the open areas of the filter. For the primary type of filter which include all particles above 5um in size and larger. As you go smaller in particle size, say between 1um to 5um, occasionally some of these particles get through, but the efficiency for removal is still well into the 99.9999+% range. This is still due primarily to sieve effect and the beginning of inertial impaction effect.

Inertial impaction occurs when large particles are unable to quickly adjust to changes in the flow stream around fibers. The particle, due to its inertia, impacts a fiber and is captured. This effect is dominant from around the 0.5um region up to around 5um. The next effect is interception. **Interception** occurs when a particle flowing through a water stream comes within one particle radius of a fiber. When this occurs the particle is trapped by the fiber. Particles that are farther than one particle diameter will not be removed by this process. This is one reason for the high fiber volume density of the 200 CFM media. More the density, higher the probabilities of particle capture. This effect is dominant from about 0.1um up to about 1um. **Brownian diffusion** is perhaps the most mysterious of the filtering effects. Ultra fine particles in the water stream will collide with molecules and create a random path through the media. The smaller the particle the longer the particle will zigzag around. This random motion increases the probability of the particle contacting a fiber. This effect is

dominant for all particles smaller than 0.1um. The last effect, which does not get as much notoriety, is electrostatic effect. The reason is that this effect is a function of the type of media used, the environment in which it is used, and the geometry of the fibers. The geometry of the fiber will also dictate how much localized electrostatic charge will build on the fiber surface. The particle capture effects mentioned are all subject to how the filter media is made. Fiber diameter, spacing, fibber cross section, and media thickness are big drivers in how effective a filter is. The smaller the fiber, greater the small particle capture efficiency. The smaller the fibber spacing, the greater the filter efficiency. Larger the cross-section, greater the capture capability.

CHAPTER 2

LITERATURE REVIEW

2.1 <u>Background</u>

The contribution and impacts of microplastic pollution are of growing public concern, as recorded by recent state and federal legislation banning microbeads from cosmetic products (California AB-888; H.R. 1321). These actions have forced changes in how the cosmetic industry makes its products and have led to increasing concerns surrounding other categories of microplastics, such as microsynthetic fibers, referred to as microfibers. <u>Microfibers are released by synthetic clothing through regular wear and washing.</u> Although no current legislation related to microfiber pollution exists, the growing evidence that they are a hazardous issue could lead to future regulatory efforts. Just as the cosmetic industry had to adapt to the ban of the microbeads, very soon the apparel industry will likely bear the responsibility for new microfiber regulations.

The cosmetic industry was able to replace microbeads with natural alternatives such as sand and nut shells that provided the same function as their plastic counterparts. However, the apparel industry faces a more difficult situation as alternatives to synthetic textiles are limited and it's a struggle to mimic the performance capabilities of materials like polyester and nylon. Since its invention in 1979, the use and demand for polyester-based clothing has grown exponentially.

According to Technon OrbiChem's 2014 technical report of the textile industry, the growth of polyester was two to three times that of all other fibers over the course of the last five years. Polyester also makes up over 95% of the future global synthetic fiber production growth. By 2025, production is expected to reach 84 million metric tons. As demand for this textile rises, environmentalists are becoming increasingly concerned about the life cycle effects of this fiber. Polyester fiber production is increasing exponentially.

Fig 2 :The exponential increase of Polyester fiber production
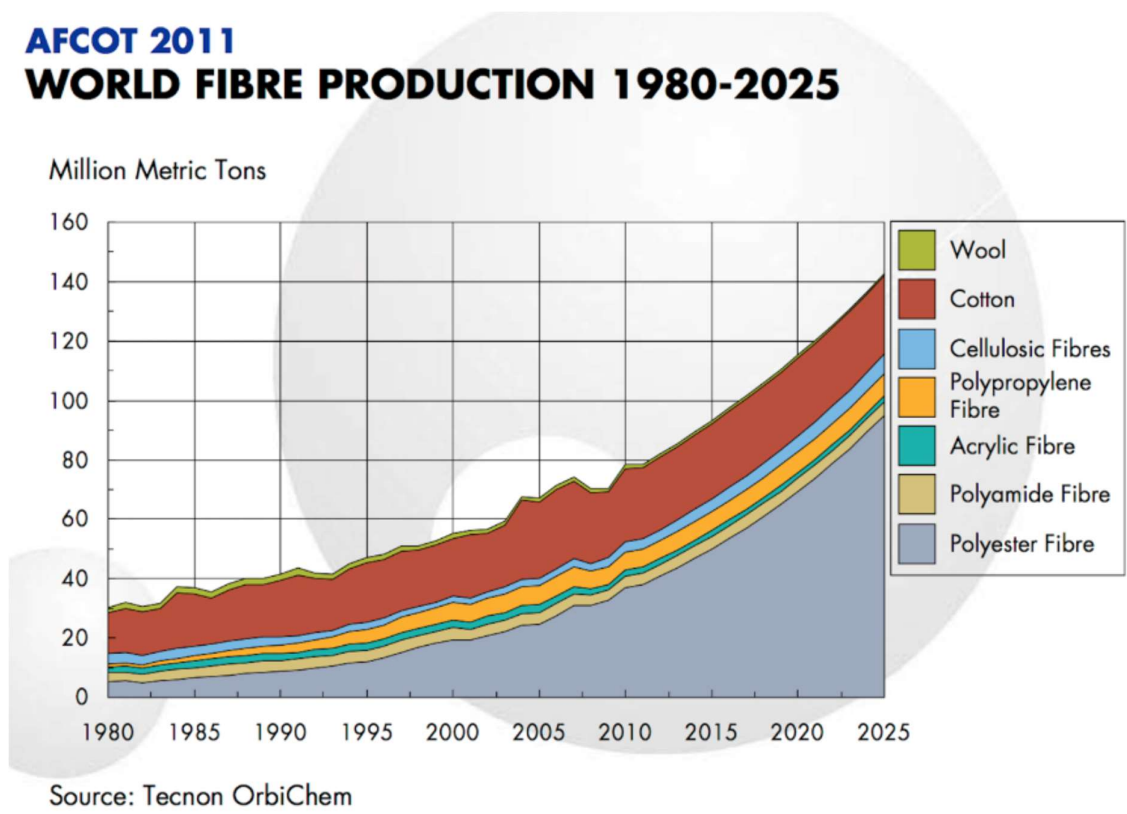
Chart Showing Historical and projected global fiber production (in million metric tons) from 1980 to 2025.

Source: Yang, 2014.

2.2 Microfibers

Microfibers are a type of microplastic (defined as plastic pieces less than 5 mm in size), that are threadlike in shape and between 100 µ - 5 mm long **(Miller et al., 2017; Moore, 2008).** The majority of these tiny threads of plastic are fibers from synthetic fabrics such as fleece and polyester **(Browne et al., 2011).** These particles enter our environment, especially our

waterways, via contaminated wastewater effluent from the laundering of these plastic-based fabrics **(Browne et al., 2011).**

Microfibers are found aloft in our air, lacing our land, floating in our oceans, and even tainting our food and drinking water **(Browne et al., 2011; Kosuth et al., 2017; Le, 2017; Rillig, 2012; Rochman et al., 2015).** Microfibers appear to be far more common and problematic than microbeads and recent studies from across the globe suggest that microfibers are in fact the most common type of plastic polluting our oceans today **(Anderson et al., 2017; Bagaev et al., 2017; Nel & Froneman, 2015; Peng et al., 2017).**

Global sampling data has shown a ubiquity of microfibers in aquatic environments and distribution throughout atmospheric and terrestrial environments as well. Literature on the distribution of microfibers was primarily focused on the presence or absence of polyester, polyethylene terephthalate, rayon, and polyamide fibers; all of which are commonly in connection with the textile industry.

2.3 Microfibre Distribution Web

Review of microfiber distributions indicated the pervasiveness of microfibers throughout fresh water and marine environments. Rivers are often the entry point for microfibers via WWTP effluent and, from there microfibers are then distributed to lakes, reservoirs, and the ocean. Because of their tendency to be negatively buoyant, most fibers are found in sediments, especially along coastal zones and shorelines near human populations. The omnipresence of microfibers in the environment indicates the severity of microfiber pollution and the potential for widespread impacts.

Distribution papers on micro- and macroplastics were also used as a proxy for the movement patterns of microfibers. High microfiber concentrations have been found in sediment and ocean samples around WWTP effluent pipes **(Magnusson & Norén, 2014; Talvitie et al., 2015).** Additionally, microfibers discharged in effluent are more mobile in the environment than other microplastics. Based on the large residence time of microfibers in soil, large volumes of fibers could flow from the terrestrial ecosystem to the aquatic, where the distribution patterns are best understood. Despite the efficient removal rates in WWTPs, a large number of microfibers do escape the treatment process and enter into the environment each day.

- **Africa** : Microplastics were collected in all 21 sample sites along the southeastern coast of South Africa and 90% of those analyzed were microfibers **(Nel & Froneman, 2015).**

- **Antarctica** : Microfibers were found abundantly in a sampling study in Admiralty Bay, Antarctica in 2010 - 2011 **(Theresinha et al., 2017).**

- **Asia (China):** In the Changjiang Estuary of Shanghai, China, 53 sediment samples were examined and 93% of the microplastics discovered were microfibers (**Peng et al., 2017**).

- **Asia (Middle East)** : 83% of microplastics found across 5 sites from the Strait of Hormuz (Persian Gulf) were microfibers **(Naji et al., 2017)**

- **Australia**: Wastewater treatment plants were found to emit approximately 1 microplastic piece per liter of water, with microfibers being the most common type (**Browne et al., 2011).**

- **Europe:** 63% of water samples collected from the Baltic Sea contained microfibers **(Bagaev et al., 2017).**
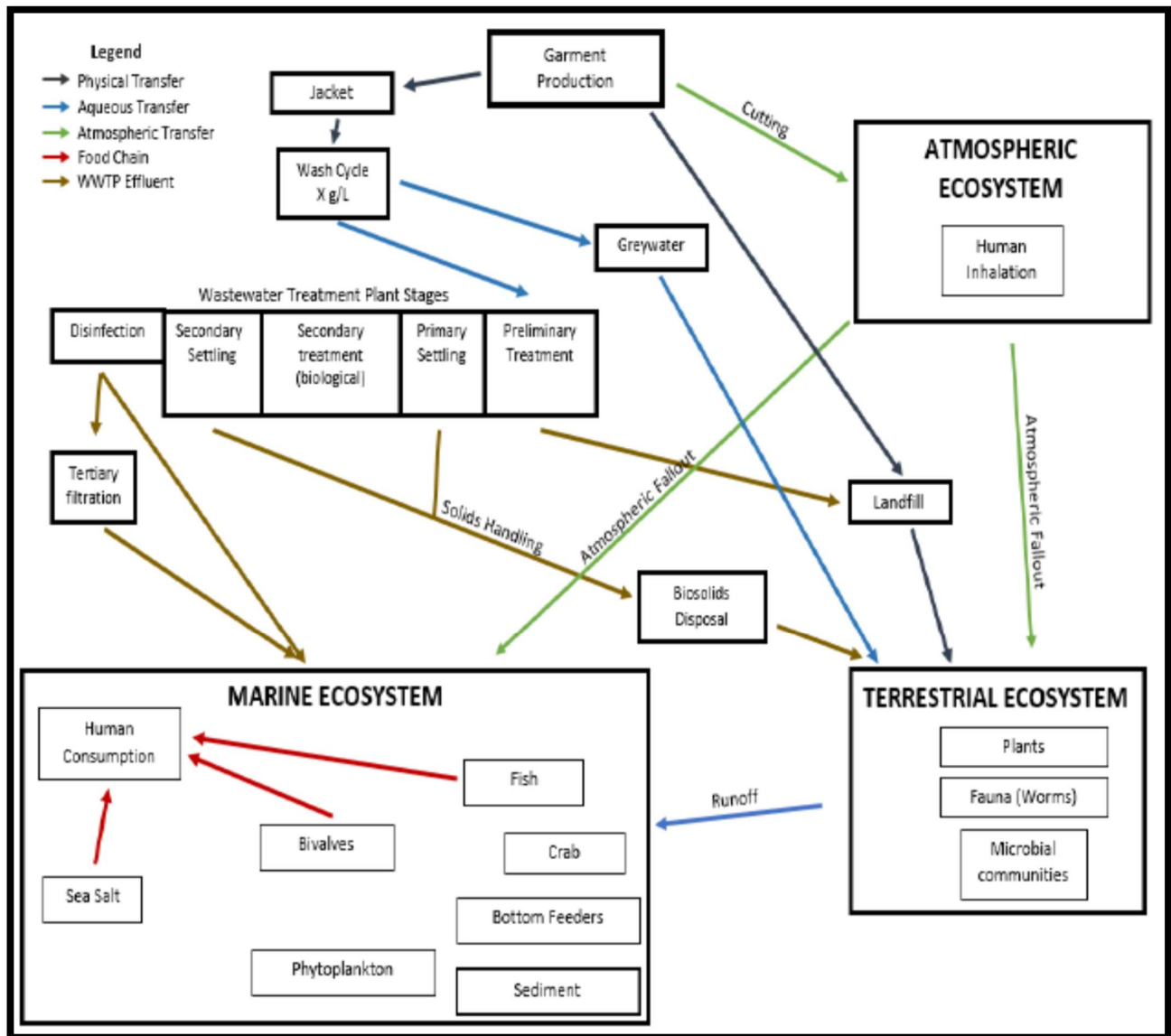
- **North America (Canada)** : Microplastics were found in all samples taken from Lake Winnepeg, Canada and the majority of those were microfibers **(Anderson et al., 2017). North America (US)** : An estimated 300 million microfibers flow from the Hudson River Watershed into the Atlantic Ocean each day **(Miller et al., 2017).**

- **South America**: 83% of fish caught by local fisherman in the Pajeú river crossing in Serra Talhada, Brazil contained plastics, with microfibers being the

most commonly observed type **(Silva-Cavalcanti et al., 2017).**

2.4 <u>Toxicity of Fibers and their Potential Risks</u>

A study conducted in Sweden tested for the presence of quinoline and its derivatives in finished garments manufactured in at least 17 countries. Quinoline was found in all garments made from 100% polyester, and the highest levels were found in the polyester samples. Quinolone is a class of compounds used in dyes and certain classes of quinoline compounds are skin irritants and/or probable human carcinogens **(Luongo et al., 2014).**

Researchers at Stockholm University conducted experiments to quantify the "wash out" effect of chemicals from garments in the laundry wash phase. Concentrations of quinoline, benzothiazole, benzotriazole and derivative compounds were quantified in the garment after 5 and 10 washes.

Results showed that different chemicals had different washout effects with the loss range being 20% to more than 50% after 10 washings. It was demonstrated that significant amounts of the chemicals remain in the clothes for a long time and thus have the potential of a chronic impact on human health while the released chemicals enter household wastewater **(Luongo, 2015).**

Another study tested the presence of per- and polyfluorinated chemicals (PFCs) in 36 of the 40 outdoor products sampled including jackets, trousers, footwear, backpacks, tents, sleeping bags and ropes. The highest concentrations of total volatile PFCs were 1,000 μg/m2 in footwear **(Santen, Brigden, & Cobbing, 2016).** PFCs are persistent in the environment, detected in the environment, plants, animal, fish, and birds as well as human blood and breast milk **(Santen, Brigden, & Cobbing, 2016; Whitacre, 2008).** There is evidence of liver toxicity in animals and reduced fertility and birth weight in humans **(Webster, 2010).**

These studies indicate that chemicals found in finished garments could pose a serious threat to human health and the environment if their concentrations are not monitored.

2.5 Bisphenol A (BPA): Risks associated with it

BPA is produced at over 2 billion pounds/year and is found in wide variety of dietary and non-dietary products. The dietary sources include both canned and non-canned foods categories ranging from "meat and meat products", "vegetables and vegetable products", and other packaged foods, and food handling consumer products like baby bottles, beverage containers etc. **(WHO, 2010; EFSA, 2015**). The non-dietary sources include medical devices, dental sealants, dust, thermal papers, toys and cosmetics (**Mendumet al., 2011; EFSA, 2015).**

Although ingestion of the BPA fromfood orwater is the predominant route of exposure **(Lorber et al., 2015)**, there are other non-dietary routes, which also equally contributes to the total BPA exposure, such as inhalation of free BPA (concentrations in indoor and outdoor air), indirect ingestion (dust, soil, and toys), and dermal route (contact with thermal papers and application of dental treatment) **(Myridakis et al., 2016).**

In addition, recent studies **(De Coensel et al., 2009; Sungur et al., 2014**) show that temperature has a major impact on the BPA migration level into water; an increase from 40 °C to 60 °C can lead to a 6–10 fold increase in the migration level.

BPA and its metabolites have been detected in maternal blood, amniotic fluid, follicular fluid, placental tissue, umbilical cord blood, urine and breast milk **(Schönfelder et al., 2002; Ikezuki et al., 2002; Kuroda et al., 2003; Kuruto-Niwa et al., 2007; Lee et al., 2008; Zhang et al., 2011, 2013; Cao et al., 2012; Muna et al., 2013; Gerona et al., 2014; Teeguarden et al., 2016).**

Recent research showed that BPA also has estrogenic potency and is therefore generally mentioned as one of the suspected endocrine disrupter **(Toppari et al., 1995).** U.S. Environmental Protection Agency (EPA) has declared the BPA as an endocrine-modifying chemical, which has been found to be reproductive, developmental, systemic toxicant, obesogenic and, weakly estrogenic **(Moriyama et al., 2002; Rey et al., 2003; Patisaul et al., 2009; Xi et al., 2011;Wang et al., 2012; Vafeiadi et al., 2016; Sharma et al., 2017).**

2.6 <u>Alternate Sustainable Solutions for the Removal of Microfibre</u>

Every aspect has positive and negative domains. Therefore, the negative effects can also be minimized if taken in consideration. **This thesis provides a economically and effectively**

potential solution to this microfiber problem; but there are other possible solutions that are already in use in the developed countries and which has effectively reduced the number of microfibers discharge into the environment are discussed below.

Cora Ball: Cora ball is a newly designed microfiber catching laundry ball. It was designed by a group of scientist who were working with Rozalia Project for a Clean Ocean. It is a round ball, which has tiny gaps similar to those in a hair comb and which is capable of catching the microfiber thread during the laundry. Cora ball is kept in the washing machine drum before starting the wash cycle. The Cora Ball can work in all types of washing machines. It is easy to use. There is no need to install anything before it is used. The Cora ball is kept in the washing machine along with the washable clothes. It has no negative effects and is environmentally friendly.

The lints that are captured by the Cora ball during the wash. The Cora ball can be used again after removing the lint that has been captured. It contributes in making the ocean a little cleaner. It is nearly impossible to capture 100% of the released microfiber thread as some of them escape through the effluent water.

Guppy Friend: There is another device, which helps to reduce the release of microfiber in the ocean. It is called GUPPY friend GUPPY Friend is a washing bag, which is made of a specially designed micro filter material. It captures the microfiber that can be seen after each wash.

GUPPY friend in which the clothes that are to be washed are kept and washed in the washing machine. The residues of microfiber are collected inside the bag. The residues that are collected inside the bag can easily be disposed of after the wash.

2.7 Filtration: SLOW SAND FILTER DESIGN

Slow sand filtration is a type of centralised or semi-centralised water purification system. A well-designed and properly maintained slow sand filter (SSF) effectively removes turbidity and pathogenic organisms through various biological, physical and chemical processes in a single treatment step. Only under the prevalence of a significantly high degree of turbidity or algae-contamination, pre-treatment measures (e.g. sedimentation) become necessary. Slow sand filtration systems are characterised by a high reliability and rather low lifecycle costs. Moreover, neither construction nor operation and maintenance require more than basic skills. Hence, slow sand filtration is a promising filtration method for small to medium-sized, rural communities with a fairly good quality of the initial surface water source. As stated by the WHO, slow sand filtration provides a simple but highly effective and considerably cheap tool that can contribute to a sustainable water management system.

The components of a slow sand filter include intake, pre-treatment, filter box and piping. Two or more independently operated equal sized cells should be included in the filter box.

Every layout is site specific. The bed area of the filter is calculated as the maximum expected flow divided by the maximum permissible hydraulic loading rate. The depth of the filter chamber is determined by the sum of all different kinds of bed packing e.g gravel, sand etc plus the maximum water depth. Provision must be provided for the filter to waste, drainage of headwater, backwashing of the sand bed, and adjustment of flow to each filter. An overflow needs to be installed at the maximum headwater level. A distributed incoming flow should be maintained around the filter bed at low velocity and into a headwater of $\geq 0.3m$ depth above the sand bed to minimise the erosion of sand bed. The under drain system needs to be designed using the 'manifold' hydraulic principle i.e. the head loss within the main pipe should be less compared to the head loss through the orifices into the main pipe. When the manifold principle is maintained, the hydraulic loading rate across the bed of the filter should be uniform. The design is empirical and established rules needs to be followed.

2.7.1 Advantages

- Very effective removal of bacteria, viruses, protozoa, turbidity and heavy metals in contaminated fresh water
- Simplicity of design and high self-help compatibility: construction, operation and maintenance only require basic skills and knowledge and minimal effort
- If constructed with gravity flow only, no (electrical) pumps required
- Local materials can be used for construction
- High reliability and ability to withstand fluctuations in water quality
- No necessity for the application of chemicals
- Easy to install in rural, semi-urban and remote areas, Simplicity of design and operation
- Long lifespan (estimated >10 years)

2.7.2 Disadvantages

- Minimal quality and constant flow of fresh water required: turbidity (<10-20 NTU) and low algae contamination. Otherwise, pre-treatment may be necessary.
- Cold temperatures lower the efficiency of the process due to a decrease in biological activity.
- Loss of productivity during the relatively long filter skimming and ripening periods. May require electricity.

- Very regular maintenance essential; some basic equipment or ready-made test kits required to monitor some physical and chemical parameters.
- Possible need for changes in attitude (belief that water that flows through a green and slimy filter is safe to drink without the application of chemicals), Chemical compounds (e.g. fluorine) are not removed.
- Natural organic matter and other DBPs precursors not removed (may be formed if chlorine is applied for final disinfection).
- Requirement of a large land area, large quantities of filter media and manual labour for cleaning, Low filtration rate.

CHAPTER 3

RESEARCH AND EXPERIMENTAL WORK

3.1 PART 1: SURVEY ON MICROFIBRE CONTAMINATION IN WATER

The first part of the thesis work was based on the survey that was carried out by collecting samples (including drinking water and washing machine effluent) from a wide range of area. Those collected samples were prepared for physiological testing to obtain the microfiber count contained in each sample. Different testing protocols were followed while testing the sample for its microfiber count.

3.1.1 MATERIALS AND METHODS

3.1.1.1 Experimental Design

This thesis work was done to study the widespread distribution of microfibers in water and to propose a viable solution in eliminating microfibers that are escaping into the environment via washing machine effluent. For this, different water samples were collected from different sources and were stained and observed under the compound microscope at 40 X and 100 X magnifications respectively to obtain the count of microfibers in each sample. The count observed at 40X magnification was noted down. Also, each collected sample of a specific volume was passed through filter paper and later the filter paper was dried in a hot air oven. The weight of dried filter paper was then deducted from the weight of empty filter paper before use to obtain the mass of microfiber in each sample.

3.1.1.2 Sample Collection

45 grab samples (n=45) were collected from different drinking water sources in Kolkata and Ranaghat, Nadia district, West Bengal. Strict protocols were maintained during the collection of the grab samples to avoid contamination. Sealed HDPE bottles were bought and used for collecting the samples from the respective sources. The bottles were capped immediately after filling them up until overflowing with the water samples. Most samples (about 97% of the samples) were collected by running the water source for 30 seconds prior to filling a 250mL HDPE bottle to the point of overflowing. While leaving the water running, the bottle

was filled once and dumped once before being filled a final time and capped. This was done to rinse the bottle prior to the final sample collection. Each water sample bottle was labelled properly, mentioning information about the source and the time of collection. The bottles were closed tightly and brought to the laboratory for testing.

Table 3(A) : General Information about the Water Samples used for Analysis

Area	Source: Public /Private/ Packaged	No. Of Samples	Filtered: Yes/No
South Kolkata	Private	9	Yes
South Kolkata	Public	8	Yes, No
Central Kolkata	Public	3	No
North Kolkata	Private	4	Yes
North Kolkata	Public	6	No
Ranaghat, Nadia Dist., W.B.	Private	8	Yes
Ranaghat, Nadia Dist., W.B.	Public	5	Yes, No
South Kolkata Shop	Packaged Drinking Water (Mineral Water)	2	Yes

Also one set of washing machine effluent sample was collected from first wash and second wash cycle of a wash programme from a running washing machine.

3.1.2 LABORATORY ANALYSIS

3.1.2.1 Sample Processing

3.1.2.1.2 STAINING AND MICROSCOPIC OBSERVATION

In order to aid the visualisation of microfibers present in the water samples, Rose Bengal stain was used. It is a biological stain and thus it binds to only natural materials and fibers. Therefore, use of this stain helped identifying the biological and non-biological matter (stained and unstained) under the microscope.

- **Preparation of Rose Bengal (RB) Stain**: 0.25g of Rose Bengal Indicator was added to 100mL distilled water, mixed well and then placed on the magnetic stirrer for 5 minutes. Stored in the refrigerator for further use.

25 mL volume of sample was taken in a double-rinsed conical flask and it was added to 5mL RB stain, mixed well and was put to boiling on the plate heater for 20 minutes. Then, the solution was cooled by placing the flask on chunks of ice crystals. The cooled solution was then passed through the filter paper (Whatman Cellulose filter paper of 110mm dia and pore size 11μm). This used filter paper was then washed with distilled water four to five times to completely get rid of the colour. Finally, the filter paper was again washed with 1000 μL of distilled water twice and from the last wash, with the help of a sterilised dropper, one drop of sample was taken on a clean glass slide (grooved slide), covered with a square cover slip and it was observed under the compound microscope at 40X and 100X magnification respectively. This process was repeated for every sample and the direct microscopic count (both for stained and unstained particles) for each sample at 40X magnification was noted down.

3.1.2.1.3 FILTRATION AND DETERMINATION OF MIRCROFIBRE MASS

All original samples were processed by vacuum filtration through a 110mm dia Whatman Cellulose Grade 1 filter paper with a pore size of 11μm.The weight of empty filter paper was measured and recorded. To ensure complete evacuation, sample bottles were rinsed with deionized water, with the rinse water being passed through the same filter as the original sample. Volume of water was measured and recorded at the time of filtration. Before the filtration started, lab surfaces were wiped down with ethanol to reduce potential contamination. All glasswares and other tools that were used in this analysis were rinsed thoroughly as well as forearms and hands. After the completion of filtration, the filter papers were stored in a double-rinsed petridish to dry for a minimum time of 2 hour. All petridishes that contained the filter papers were marked and labelled properly for correct identification. Petridishes containing the filter papers were then placed in a hot air oven at 60°C for 20 minutes to ensure complete drying of the filter paper. The weight of every dried filter paper was measured in the weighing balance and was noted down. Finally to obtain the mass of microfibers present in each sample, the weight of fresh and empty filter paper was deducted from the weight of dried filter paper for each sample.

3.1.2.1.4 MICROSCOPIC OBSERVATION OF MACHINE WASH EFFLUENT

Two samples were collected from two corresponding wash cycles of a running washing machine. Two cleaned glass slides were taken. A drop of the first wash effluent sample was poured onto the surface of the glass slide with the help of a double rinsed dropper. Same was repeated for the second wash effluent sample. Both glass slides were then viewed under the microscope at 40X magnification.

3.1.3 DATA AND STATISTICAL ANALYSIS

45 different samples had been collected from different locations around Kolkata and its suburbs, West Bengal. Samples were investigated for total microfiber content. The data obtained from different water samples will help us to understand the level of microfiber contamination in different areas of the state. The data collected from each sample was expressed statistically that will be shown in the fifth chapter.

PART 2: ESTIMATION OF BPA IN WATER USING UV-VIS SPECTROPHOTOMETER

3.2 Materials & Methods

3.2.1 Reagents

HPLC Grade BPA 98% for Synthesis was obtained from Loba Chemicals Pvt. Ltd. BPA has a relatively low solubility in water, ranging from 120 to 300ppm at 21.5°C. Commercially available BPA is provided as solid granules of pure BPA. 99.9% pure ethanol available in the laboratory was used.

3.2.2 Preparation of standard stock solution of BPA

A method of dissolving BPA with a certain amount of ethanol was found from a study made by Akira Motoyama **(Motoyama et al).** In order to make a 100ppm stock solution of BPA, 10mg of BPA granules are dissolved in 100ml of distilled water containing 5 v/v % of ethanol. The choice of using ethanol solution was to help increase solubility. It was specifically used because of their polarity, affordability, and simplicity. Ethanol being a polar solvent can dissolve BPA.

Initially, two test tubes were taken and marked, one for blank (without BPA) and other containing the BPA in dissolved form. In the first test tube, 10ml ethanol was poured and in the second test tube, 10ml ethanol and 2-3 granules of BPA was added to it and then it was subjected to a magnetic stirrer for dissolving the BPA in ethanol.

Table 3(B): Samples tested for BPA

No.	Samples	Sample Codes
1	1st Wash Effluent	W.E.1
2	2nd Wash Effluent	W.E.2
3	Filtered W.E. 1	F1
4	Filtered W.E 2	F2
5	Department Tap Water	T.W

The filtered W.E1 and W.E2 as mentioned above are the samples of the machine wash effluent which were filtered in the experimental filter setup built in the lab which will be discussed later in this chapter.

3.2.3 Experimental Method and Conditions

3.2.3.1 Sample Preparation

Five test tubes were taken and were marked with sample codes and in each test tube 1ml of the samples were poured. 10ml ethanol was added to each of the test tube and all the test tubes were shaken well. All the reagents and samples were stored at room temperature.

The Blank solution and the BPA Standard Stock solutions were scanned in the range of 200-1100nm in the UV-Vis Spectrophotometer available in the laboratory.

Later, the five samples were scanned in the UV-Vis Spectrophototmeter simultaneously and their respective peaks were obtained which will be shown in the following chapters.

3.2.3.2 UV-Vis Apparatus and Operating Conditions

Thermo Scientific Orion Aquamate 8000 UV-Vis Spectrophotometer was used in this research work. The UV /VIS Spectrophotometer used in this research project could go up to 2 absorbance units and had wavelengths values that were in the range of 200-1100nm. But for this particular work i.e. BPA determination in the samples, the required range of absorbance values were between 200-280nm as this was the area where BPA peak could be seen since it

is BPA's range of wavelength emission. Absorption spectra give information about the amount of light at a particular wavelength absorbed by a specific chemical. They are used in studies to determine and differentiate chemicals. For this method to be used, the chemicals have to emit light at different wavelengths.

3.2.3.3 UV-Vis Spectrophotometric Quantitation

All samples used were filled three quarters of the 1 cm cuvette cell used in the UV-VIS Spectrophotometer. This approximates to a 1.5mL sample.

Equation used for calculating concentration of BPA at 260nm

$$A = \varepsilon * b * [X]$$

Where, A is the absorbance,

 ε is the molar absorptivity,

 b is the cell size (b=1cm),

 X is the concentration in μg/ml

The calculations for absorbance and concentrations for each sample as determined by the UV-Vis Spectrophotometer are shown in the next chapter.

3.3 PART 3: DESIGN OF A NEW SAND FILTER

Packed bed filters (PBFs) incorporating naturally occurring treatment media such as sand and gravel are used successfully for treating small to medium volume wastewater flows for decades. Sand filters are frequently used, especially when water contains large amounts of organic contaminants. This type of filter has the advantage of its simplicity and that the main filtration mechanism is based on depth filtration. As the prediction of the head losses is of practical interest for the design of the sand filter system, the main objective of this paper is to present and validate an analytical model of a sand filter that effectively removes microfiber from water.

3.3.1 Design Parameters

For designing a packed bed filter, there are certain variable parameters that can be altered only while fabricating the design of a filter. In this thesis work, while designing the filter, it was taken into considerations that by varying some parameters like thickness of sand grain, bed height and diameter, an effective filter with desirable and optimum microfiber removal rate can be achieved. Therefore, before designing the final filter prototype, the above mentioned different design parameters were varied to achieve the desired result i.e. a filter with optimal flow rate and pressure drop that would effectively remove microfibers from water at a remarkable rate.

- **Mesh Size Sand Grains**: 60 mesh, 80 mesh, 100 mesh, 120 mesh ; Laboratory sieving was done in order to separate sand grains based on their particle size. The size extracted sand grains were stored separately for the purpose of filter bed packing during the course of this thesis work. Finer the size of the grain, larger the pressure drop (ΔP)
- **Filter bed height, h** : 2.5 cm, 5cm, 10 cm
- **Filter Tube Diameter, D** : 0.5cm, 3.5cm
- **H/D ratio** : The ratio was maintained at 2:1, the height of the bed selected here was more than two times that of the diameter.

3.3.2 DEVELOPMENT OF A NEW FILTER PROTOTYPE
Design and fabrication of a new sand filter prototype was developed in the laboratory.

➢ Initially, a **burette was used as a model for packed bed filter** for trial run. The burette was tightly attached to the burette stand in a vertical position. The burette was filled with sand upto **2.5cm height**, and was closed with cotton plugs to prevent sand from flowing out. The sand used was **80 mesh size sand** grain. The burette has **an inner diameter of about 0.5cm**. Earlier collected water samples were passed though the burette via the sand column. Filtration time and sample volume before and after filtration were noted down for calculating flow rate and pressure drop. Filtered sample was examined microscopically to determine the filter removal efficiency rate.

➢ **Another burette set up was prepared with a bed column height of 5cm** and **80 mesh size sand grain**. The same process as above was repeated for water sample.

➢ A **customised cylindrical glass tube filter with sand bed packing was developed**. This was developed to measure the pressure drop (P_1-P_2) of the packed bed filter. The filter design consisted of a cylindrical glass tube with both sides open and was placed in a horizontal position. The full length of the glass tube was 18cm with an **internal diameter of 3.5 cm**. The glass tube comprised of two vertical openings in the base having a diameter of 0.5cm. The two vertical openings were separated by a distance of about 10cm. **For packing of the filter bed, sand was used.** Different mesh size sand grains were used for examining the flow rate and filter efficiency with varying thickness of the sand grains. **Samples were passed through 60, 80, 100 and 120 mesh size sieves respectively**. Sand of 60, 80, 100 and 120 mesh sizes were used separately to prepare packed bed in the glass tube. It was ensured that no void remains in the bed packing. Cotton was placed on both sides of the packed bed to avoid leakage. Next, the two open sides of the horizontal glass tube were closed with the help of two metal caps with perforations. Finally, a **cylindrical tube pipe made of rubber of internal diameter 1cm was attached to the two vertical openings present in the glass tube** with the help of grease. **The pipe was attached in the shape of 'U' in a suspended manner**. Before attaching the pipe to the glass tube openings, **The pipe was filled with kerosene** and the level on both sides were marked.

Bed packing: The packing of the filter bed was done using different mesh sizes sand grains 60, 80, 100 and 120 respectively. The glass tube sand filter that was designed for this thesis work was ordered from a local glass manufacturing company. The manufacturers delivered the glass tube to the lab, but it was not made according to the design provided to them. Therefore, due to the manufacturing defect, the bed height had to be increased. **The bed packing with sand was done and it had a height of 11cm.** The spacing between the two openings in the glass tube provided was 11cm, to minimise pressure drop, this whole area had to be filled with sand. Due to this problem, the bed height instead of 5cm, it had to be kept at 11cm. Diameter of the cylindrical tube was 3.5 cm as mentioned earlier.

3.3.2.1 FILTER RUN

The water samples were passed through the glass tube sand filter with different mesh sizes sand and the effluents were collected for calculating the flow rate and for checking the filtration efficiency. The filtration time was also recorded. The change in height of the fluid (kerosene) i.e. the initial and final height changes (h_1-h_2) that occurred after filtration in the rubber tube kept connected to the glass tube filter in U form was noted for calculating the

pressure drop. Flow rate and pressure drop were calculated for different type of mesh size sand to standardize the optimum filtration condition and performance.

3.3.2.2 Equation for Pressure Drop

As a fluid passes through a packed bed it experiences pressure loss due to factors such as friction. The relationships required to predict the pressure drop for a fluid flowing through a packed bed have been known for some time, with Darcy observing in 1896 that the laminar flow of water through a bed of sand was governed by the following relationship:

$$\Delta P / H \propto U$$

Where,

ΔP : Pressure drop through the packed bed (Pa)

U: Superficial fluid velocity (m/s)

H : Height of the packed bed (m)

This relationship was initially analysed in terms of the **Hagen-Poiseuille equation** for laminar flow through a tube and was later formulated as the Carman-Kozeny equation for pressure drop for laminar flow through a packed bed in 1937. The following sections present the Carman-Kozeny equation and subsequently Ergun's general equation for the pressure drop through a randomly packed bed of spheres.

The pressure drop for laminar fluid flow through a randomly packed bed of monosized spheres with a specific diameter may be calculated using the Carman-Kozeny equation as follows:

$$-\Delta P / H = 180 * (\mu\, U\, (1-\varepsilon)^2) /\ \ x^2\, \varepsilon^3$$

Where,

-ΔP = Pressure drop through the packed bed (Pa)

H = Height of the packed bed (m)

U = Superficial fluid Velocity (m/s)

μ = Viscosity of the fluid flowing through the packed bed (Pa.s)

ε = Bed voidage

x = Spherical equivalent particle diameter (m)

Another Equation for Pressure drop

$(P_1 - P_2) = 128\mu LQ/\pi D^4$

Q = Flow Rate (m^3/sec)

D = Pipe Inside Diameter (m)

L = Pipe Length (m)

ρ = Density (Kg/m^3)

μ = Dynamic Viscosity (N-s/$m^{2)}$)

3.3.2.3 Pressure Drop Equation Derivation

From Hagen Poiseulli's Equation for pressure drop, we know

- $dP / dx = 8 \, \upsilon \, \mu / R^2$

υ is the velocity of the flow (m/s)
μ is the dynamic viscosity of the fluid used (N-s / m^2)
R is the radius of the cylindrical bed (m)

or, $- dP = (8 \, \upsilon \, \mu / R^2) * dx$

On integrating we get,

- $[P_2 - P_1] = (8\,\upsilon\,\mu\,/\,R^2) * (x_2 - x_1)$

Also, $[P_2 - P_1] = \Delta P = \rho\,g\,\Delta h$

Where, ρ is the density of the fluid placed in the U tube

$\rho = m\,/\,V$ [m = mass of the fluid (kg), V = Volume of the fluid (m^3)]

g is the gravitational constant (9.8 m/s)

Δh is the change in depth of the fluid in the U tube after filtration

Therefore, $\rho\,g\,\Delta h = 8\,\upsilon\,\mu\,L\,/\,R^2$

Where, L is the height of the packed bed

or, $\Delta P = 8\mu LQ\,/\,\pi R^4$;

where Q is the Volumetric flow rate (m^3/s)

For steady flow of an incompressible fluid in a constant diameter horizontal pipe using the Darcy-Weisbach friction loss equation, the energy equation is expressed in terms of pressure drop as:

$$P_1 - P_2 = \frac{f\rho L V^2}{2D}$$

Where,

$$A = \frac{\pi D^2}{4} \qquad V = \frac{Q}{A} = \frac{4Q}{\pi D^2} \qquad Re = \frac{\rho V D}{\mu}$$

When Re < 10, flow is laminar for packed bed and:

$$f = \frac{64}{Re} = \frac{64\,\mu}{\rho VD} = \frac{64\,\mu}{\rho D}\left(\frac{\pi D^2}{4Q}\right) = \frac{16\,\pi\mu\,D}{\rho Q}$$

Where, f=Moody friction factor, A=Pipe area

Then pressure drop is:

$$P_1 - P_2 = \frac{f\rho LV^2}{2D} = \left(\frac{16\,\pi\mu\,D}{\rho Q}\right)\frac{\rho LV^2}{2D}$$

$$= \frac{8\,\pi\mu LV^2}{Q} = \frac{8\,\pi\mu L}{Q}\left(\frac{4Q}{\pi D^2}\right)^2 = \frac{128\,\mu\,L\,Q}{\pi\,D^4}$$

The final pressure drop equation is often called Poiseuille's law after the original researcher (Munson et al., 1998, p. 468).

Unit abbreviations, symbols: kg=kilogram, m=meter, N=Newton, s=second.
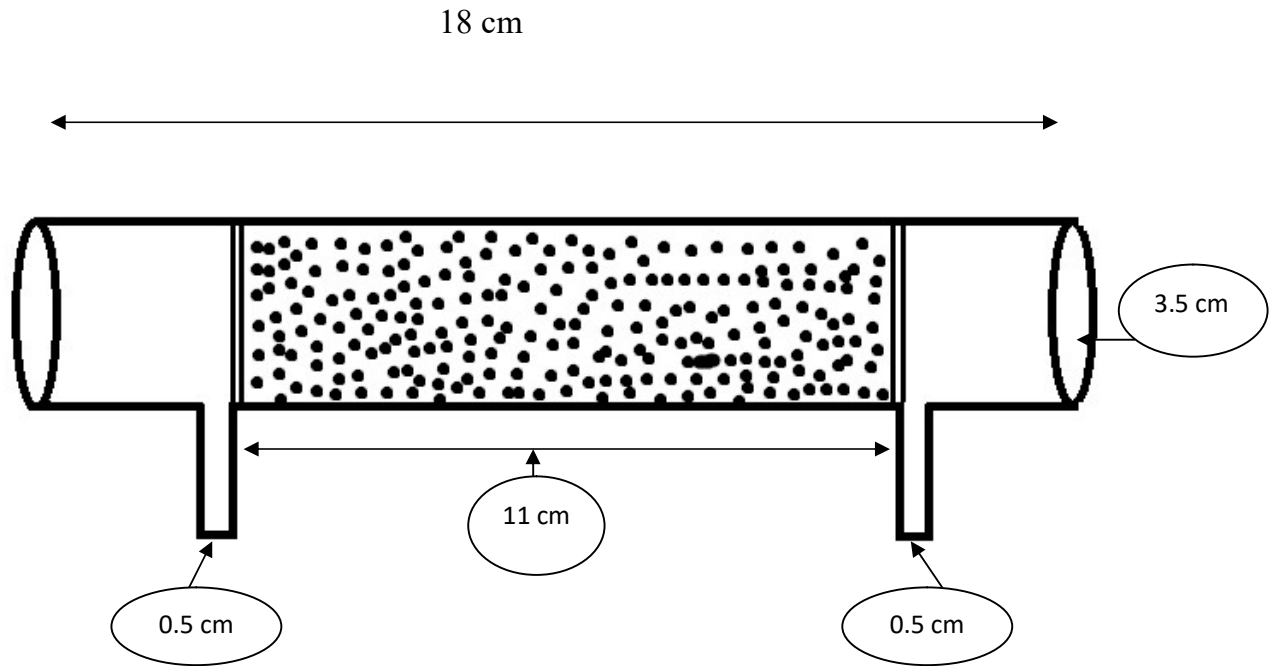
Fig 3: <u>Design illustration of the Glass Tube Filter with Sand bed packing</u> **(H=11cm, D=3.5cm)**

One sample from different regions was run through the filter and its effluent was collected from the filter outlet for further examination. Also, two washing machine effluent samples were run through the filter and effluent was collected for its microfiber count and BPA determination. After filtration water samples were examined for microfiber content. The samples those were run through the filter are listed below.

1. **Sample A (**South Kolkata Region from Private Source- Sample No.7)
2. **Sample B (**South Kolkata Region from Public Source- Sample No. 15)
3. **Sample C (**Central Kolkata Region from Public Source- Sample No.18)
4. **Sample D (**North Kolkata Region from Private Source- Sample No. 24)
5. **Sample E (**North Kolkata Region from Public Source- Sample No. 25)
6. **Sample F (**Ranaghat Region from Private Source- Sample No. 34)
7. **Sample G (**Ranaghat Region from Public Source- Sample No. 40)
8. **Sample H (**Wash Effluent 1st Cycle W.E1)
9. **Sample I (**Wash Effluent 2nd Cycle W.E.2**).**

The pressure drop (P_1-P_2) was calculated for four different mesh size sand grains (60, 80, 100 and 120) for comparison. The calculation of pressure drop will be shown in the next chapter.

3.4 Design of a Real time Cross Flow Micro-sand Filtration System.

The data obtained from the experimentally designed filter that was developed and run in the lab were used for the theoretical designing of a real-time household filter for commercial purpose. The pressure drop that was calculated from the designed glass tube sand filter was used for modification of the real-time filter.

The design was developed theoretically by studying and demonstrating different design parameters for a filter design in the experimental setup that was built in the laboratory. The details of this filter will be discussed in the following chapters.

CHAPTER 4

OBSERVATIONS AND FINDINGS

4.1 PART 1: SURVEY OF MICROFIBRE CONTAMINATION IN WATER

4.1.1 Staining & Microscopic Observation

For each stained sample, the microscopic observation at 40X magnification for ten different microscopic fields was noted down. The following table shows the average number of stained and unstained particles in each sample as seen in 10 microscopic fields.

Table 4(A) : Microfiber and Microorganisms count from the Microscope for Different Samples

Sample	Source	Microorganisms (avg. 10 microscopic field)	Microfiber (avg. 10 microscopic field) Σ_{10}
Area :- **South Kolkata Private**			
1	Department Filter Water, Jadavpur University	1	3
2	Home Filter Water (RO+UV)	0	2
3	Home Storage Filter Water	1	2
4	Home Ceramic Filter Water	2	3
5	Home Filter Water (RO)	1	1
6	Home Filter Water (UV)	1	4
7	Home Clay Filter Water	4	7
8	Home Water (RO+UV)	1	2
9	Apollo Clinic (Bansdroni) Filter Water	2	2

	Area:- **South Kolkata: Public**		
10	Tollygunge Metro Station Tap Water	2	6
11	Rabindra Sarobar Metro Station Tap Water	2	3
12	C.N.I Boys School, (Keorapukur) Tap Water	3	7
13	State Bank of India, (Kabardanga) Filter Water	1	4
14	Jadavpur University Canteen Tap Water	3	7
15	St. Pauls' Church,(Keorapukur) Tap Water	3	8
16	Bangasree Sweet Shop Filter Water	2	2
17	Tollygunge Railway Station Tap Water	5	9
	Area:- **Central Kolkata: Public**		
18	Esplanade Metro Station Tap Water	3	4
19	Park Street Metro Station Tap Water	1	2
20	Sealdah Railway Stn. Tap Water	3	7
	Area:- **North Kolkata: Private**		
21	Home Filter Water (Activated Carbon)	1	3
22	Home Filter Water (RO)	1	2
23	Home Storage Filter Water	0	1

24	Home Ceramic Filter Water	2	5
Area:- **North Kolkata: Public**			
25	Dum Dum Railway Jn. Tap Water	5	4
26	St. Stephen's School Tap Water	3	4
27	Shyambazar Metrro Station Tap Water	3	5
28	R.G.Kar Medical College & Hospital Tap Water	4	7
29	Dum Dum International Airport Tap Water	2	3
30	GNIT, (Sodepur) Tap Water	4	4
Area:- **Ranaghat, WB: Private**			
31	Home Filter Water (UV)	2	3
32	Home Filter Water (RO)	2	2
33	Home Storage Filter Water	3	4
34	Home Ceramic Filter Water	4	3
35	Home Filter Water (RO)	3	2
36	Home Clay Filter Water	4	5
37	Home Filter Water (RO+UV)	1	2
38	Home Storage Filter Water	5	4
Area:- **Ranaghat, WB: Public**			
39	Allahabad Bank Drinking Water (Filtered)	2	1
40	Monoroma Hospitex	4	2

	Drinking Water		
41	Convent of Jesus & Mary School Tap Water	4	2
42	Ranaghat Railway Junction Tap Water	3	3
43	St. Luke's Church Tubewell Water	3	2
Packaged Drinking Water: South Kolkata			
44	Aquafina	0	0.3
45	Pabitra Jal	1	1.1

Table 4(B): Microfiber and Microorganisms Count of Samples Collected from Washing Machine in Two Wash Cycles

Wash Effluent 1 (1st Cycle) W.E.1	11	9.4
Wash Effluent 2 (2nd Cycle) W.E.2	7	8.2

The data given in the previous table showed the average microfiber count present in average 10 microscopic fields. (Σ_{10})

1 grooved slide contains 2 separate squares

Total blocks in one square of grooved slide under the cover slip = 9 * 9 = 18

Volume capacity of one square of grooved slide = 0.004 µl * 18 = 0.072 µl = 0.000072ml

Microfiber count per ml = (Σ_{10} * 2) / 0.00072

Table 4(C): Total Average Microfiber & other non-biodegradable particle count per ml of Sample

Samples	Microfiber Count per ml
South Kolkata: Private	
1	$8.3 * 10^4$
2	$5.5 * 10^4$
3	$5.5 * 10^4$
4	$8.3 * 10^4$
5	$2.7 * 10^4$
6	$1.1 * 10^5$
7	$1.9 * 10^5$
8	$5.5 * 10^4$
9	$5.5 * 10^4$
South Kolkata: Public	
10	$1.6 * 10^4$
11	$8.3 * 10^4$
12	$1.9 * 10^5$
13	$1.1 * 10^5$
14	$1.9 * 10^5$
15	$2.2 * 10^5$
16	$5.5 * 10^4$
17	$2.5 * 10^5$
Cental Kolkata :Public	
18	$1.1 * 10^5$
19	$5.5 * 10^4$
20	$1.9 * 10^5$
North Kolkata : Private	
21	$8.3 * 10^4$

22	$5.5 * 10^4$
23	$2.7 * 10^4$
24	$1.3 * 10^5$
North Kolkata : Public	
25	$1.1 * 10^5$
26	$1.1 * 10^5$
27	$1.3 * 10^5$
28	$1.9 * 10^5$
29	$8.3 * 10^4$
30	$1.1 * 10^5$
Ranaghat: Private	
31	$8.3 * 10^4$
32	$5.5 * 10^4$
33	$1.1 * 10^5$
34	$8.3 * 10^4$
35	$5.5 * 10^4$
36	$1.3 * 10^5$
37	$5.5 * 10^4$
38	$1.1 * 10^5$
Ranaghat: Public	
39	$2.7 * 10^4$
40	$5.5 * 10^4$
41	$5.5 * 10^4$
42	$8.3 * 10^4$
43	$5.5 * 10^4$
Packaged Drinking Water	
44	$8.3 * 10^3$

45	$3.0 * 10^4$

Table 4(D): <u>Average Microfiber and other Synthetic Particle Count For Washing Machine Effluents</u>

W.E.1	$2.6 * 10^5$
W.E.2	$2.2 * 10^5$

4.1.2 Filtration and Determination of Microfiber Mass

The weight of empty filter paper (before use) was deducted from the weight of hot air oven dried filter paper to obtain the mass of microfibers.

Weight of empty filter paper = 0.832 g

Volume of each sample filtered = 20ml

Mass of Microfiber (in g) = Weight of dried filter paper – Weight of empty filter paper (in g)

Table 4(E) : <u>Mass of Microfibers found in Water Samples</u>

Sample & Source	Mass of Microfibres (in g)
South Kolkata: Private	
Sample 1	0.024
Sample 2	0.020
Sample 3	0.025
Sample 4	0.030
Sample 5	0.011
Sample 6	0.028
Sample 7	0.041
Sample 8	0.015
Sample 9	0.019

South Kolkata: Public	
Sample 10	0.033
Sample 11	0.019
Sample 12	0.045
Sample 13	0.029
Sample 14	0.048
Sample 15	0.048
Sample 16	0.017
Sample 17	0.050
Central Kolkata: Public	
Sample 18	0.025
Sample 19	0.016
Sample 20	0.044
North Kolkata: Private	
Sample 21	0.028
Sample 22	0.017
Sample 23	0.012
Sample 24	0.046
North Kolkata: Public	
Sample 25	0.027
Sample 26	0.029
Sample 27	0.032
Sample 28	0.048
Sample 29	0.031
Sample 30	0.038

Ranaghat, WB: Private	
Sample 31	0.011
Sample 32	0.011
Sample 33	0.015
Sample 34	0.010
Sample 35	0.011
Sample 36	0.021
Sample 37	0.013
Sample 38	0.018
Ranaghat, WB: Public	
Sample 39	0.009
Sample 40	0.011
Sample 41	0.010
Sample 42	0.010
Sample 43	0.008
Packaged Drinking Water: South Kolkata	
Sample 44	0.004
Sample 45	0.009

Table 4(F): <u>Mass of Microfiber found in washing machine Effluent Samples</u>

Wash Effluent 1 (1st Cycle) **W.E.1**	1.2 g
Wash Effluent 2 (2nd Cycle) **W.E.2**	0.8 g

4.2 PART 2: ESTIMATION OF BPA IN WATER USING UV-VIS SPECTROPHOTOMETER

4.2.1 BPA Absorbance in Different Samples

STANDARD PEAK FOR STOCK SOLUTION OF BPA
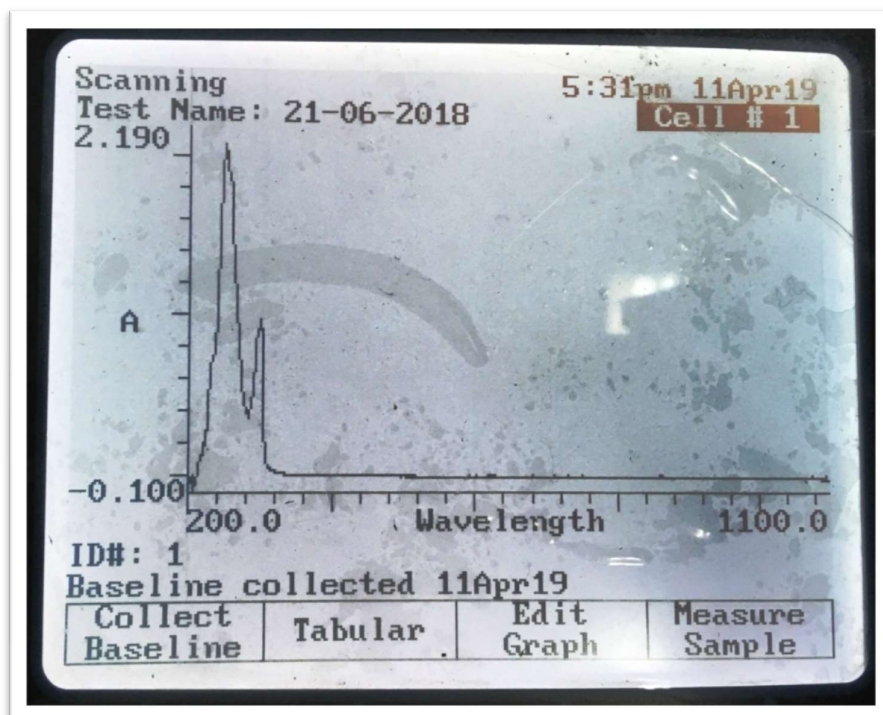
The highest peak for BPA was observed at 265 nm and absorbance 2.190.

Table 4(G) : Samples with absorbance at highest wavelength (265 nm) for BPA

Samples	Absorbance
W.E.1	0.230
W.E.2	0.030
F1	0.130
F2	0.055
T.W	0.040

PART 3: DESIGN OF A NEW SAND FILTER

The sand grains of different mesh sizes were used in the filter. The sand grain size for each different mesh are given as follows-

60 mesh = 0.250mm; 80 mesh = 0.177mm; 100 mesh = 0.149mm; 120 mesh = 0.125mm

The different design parameters as discussed and mentioned in the previous chapter were experimented with both the trial and the designed filter.

The images showing the experimental filter setups that were built in the laboratory for calculating the pressure drop, flow rate, velocity and Reynold's Number are shown in the next pages.

For the burette column setup, two different heights (H= 2.5cm, 5cm) were used with 80 mesh size sand bed packing. Whereas, for the Glass tube sand filter, the height of the sand bed was kept fixed at 11cm with different sand bad packing (60, 80, 100 and 120 respectively) for better understanding of the design parameters.
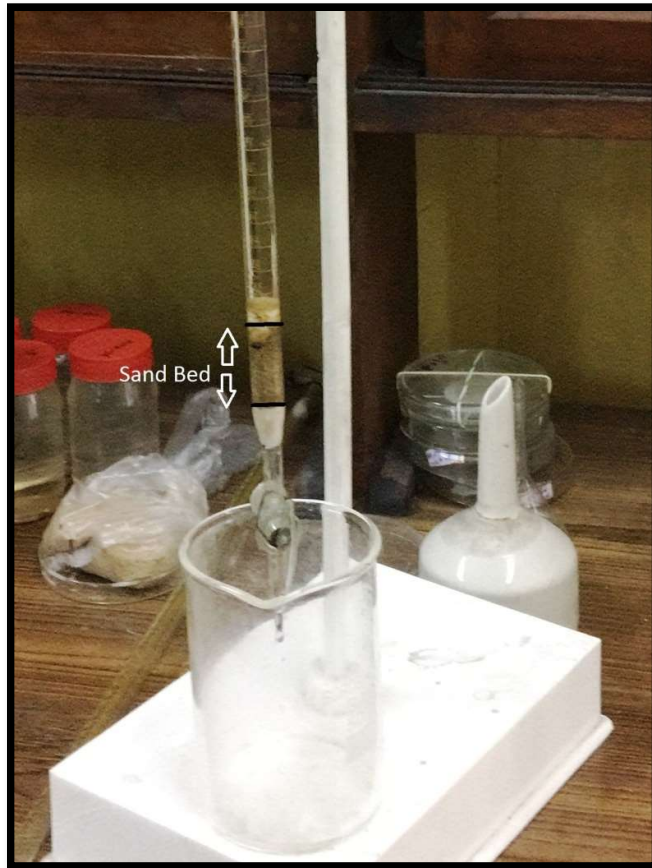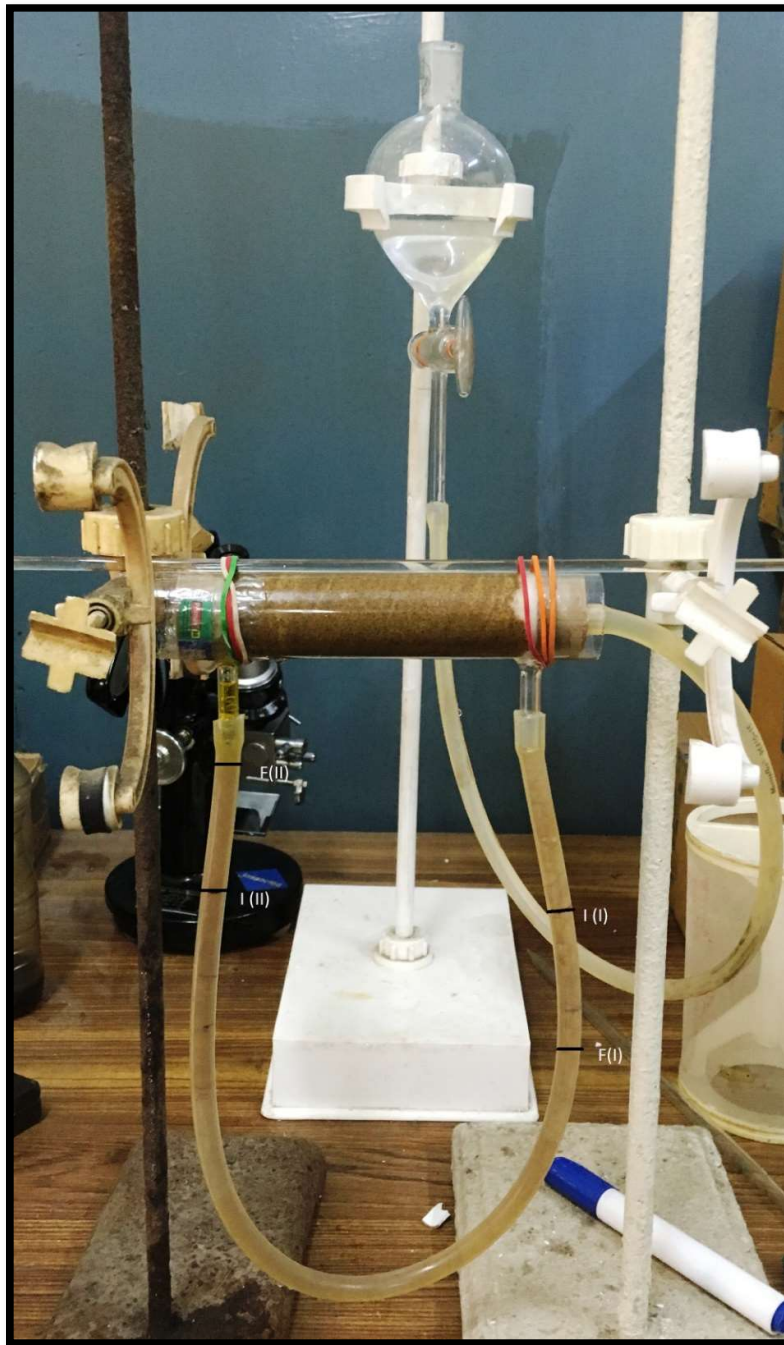
Image showing the burette column set up done for filtration in the lab. Sand bed of height 2.5cm was packed in the burette column.

The designed sand filter set up is shown as follows. Glass tube Sand Filter with a suspending U tube attached to the two openings. Bed Height, H = 11cm, Diameter, D = 3.5cm

The U tube was filled with kerosene and its initial heights were marked on both sides. After filtration, the change in the level of kerosene in the U tube was also marked to obtain the Δh value. The sample was kept at an elevated position to facilitate better flow.

Table 4(H): <u>Microfiber count of Samples before and after filtration in burette</u> (H = 2.5 cm;   D = 0.5 cm, Mesh size = 80)

Samples	Bed height, H (in cm)	Microfiber Count per ml	
		Initial	Final
Sample A	2.5	7	1±0.6
Sample B	2.5	8	2±0.08
Sample C	2.5	4	1±0
Sample D	2.5	5	1±0.2

Table 4(I) : <u>Microfiber count of Samples before and after filtration in burette</u> (H = 5 cm; D = 0.5 cm, Mesh size = 80)

Samples	Bed height, H (in cm)	Microfiber Count per ml	
		Initial	Final
Sample A	5	7	1±0.4
Sample B	5	8	1±0.76
Sample C	5	4	0±0.78
Sample D	5	5	1±0.19

Table 4(J) : <u>Microfiber count of samples before and after Filtration in Glass tube</u> (H = 11cm, D = 3.5cm)

Sample Code;	Sand (60 mesh)		Sand (80 mesh)		Sand (100 mesh)		Sand (120 mesh)	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
A	7	2±0.66	7	1±0.54	7	0±0.45	7	0±0.41
B	8	2±0.56	8	1±0.68	8	0±0.57	8	0±0.45
C	4	1±0.24	4	0±0.88	4	0±0.32	4	0±0.27
D	5	1±0.8	5	1±0	5	0±0.46	5	0±0.38

E	4	1±0.48	4	1±0.92	4	0±0.39	4	0±0.32
F	3	1±0.87	3	1±0.54	3	0±0.24	3	0±0.24
G	2	1±0.76	2	0±0.38	2	0±0.34	2	0±0.28
H	9.4	3±0	9.4	1±0.5	9.4	1±0.26	9.4	1±0.10
I	8.2	2±0.87	8.2	1±0.23	8.2	1±0.56	8.2	1±0.52

3.1 Pressure Drop Calculation

For calculating the pressure drop (ΔP) in the fabricated filter setup, the change in heights of the fluid (Kerosene) kept in the U tube was noted down. It was observed that in the filtration efficiency in the 100 mesh size sand grain was optimum. Therefore, 100 mesh sand filter setup was considered as the standard.

The change in height, Δh for 100 mesh sand bed filter was 5.9 cm

$\Delta h_{100} = 0.0059$ m

Height of sand bed, H = 11cm = 0.11m

Diameter of the bed, D = 3.5cm = 0.035m

$\Delta P = (m\ g\ \Delta h)\ /\ V'$

$m = \rho V$; ρ and V are the density and volume of kerosene in kg/m^3 and m^3 respectively

$m = (790 * 7 * 10^{-6})$ kg of Kerosene $= 5.53 * 10^{-3}$ Kg of Kerosene

V' = Volume of Packed bed (m^3)

$V' = \pi R^2 H = 1.06 * 10^{-4}$ m^3 (H = 0.11m ; R = 0.0175m)

$\Delta P = (790 * 7 * 10^{-6} * 9.8 * 0.0059)\ /\ (1.06 * 10^{-4)}$

$\Delta P = 30.16$ N/m^2 $= 30.16$ Pa

Therefore, the **pressure drop from the 100 mesh size sand bed with a height of 11cm and diameter 3.5cm was found to be 30.16 pa or 0.00437 psi.**
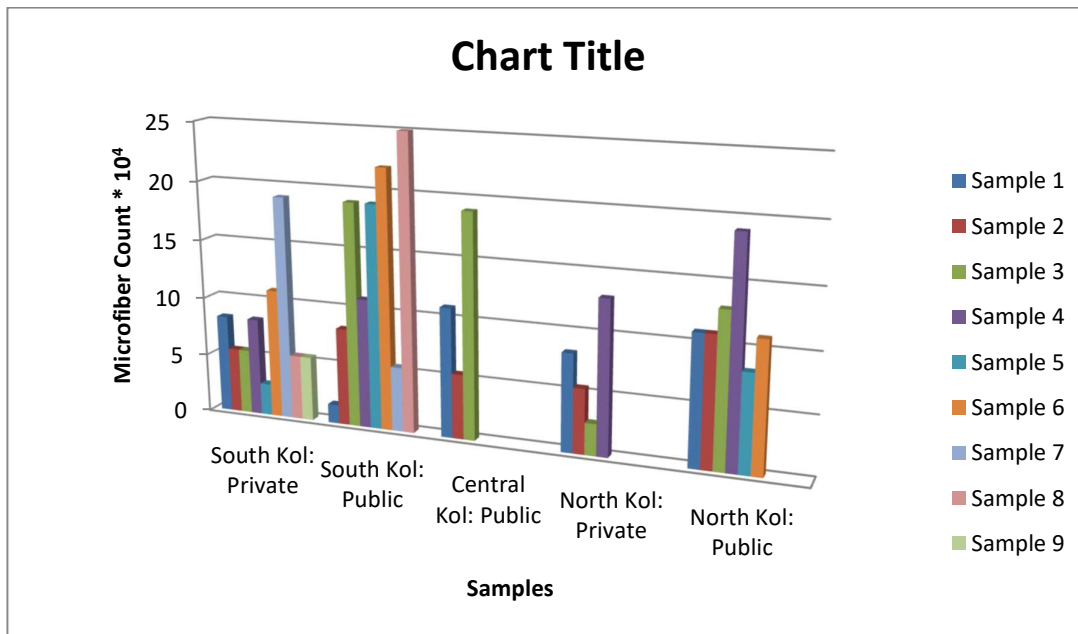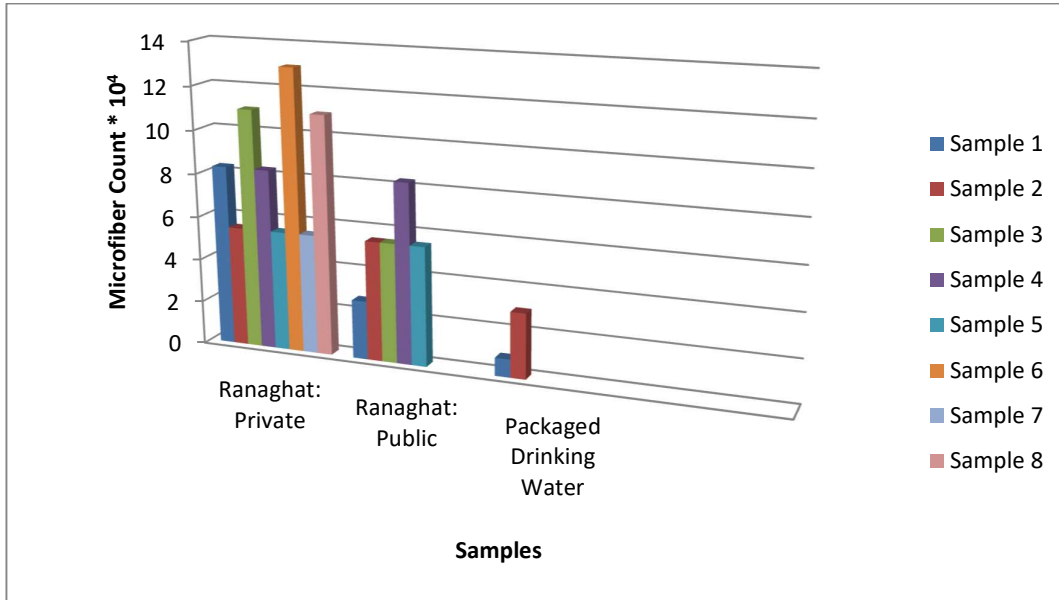
CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 PART 1: SURVEY OF MICROFIBRE CONTAMINATION IN WATER

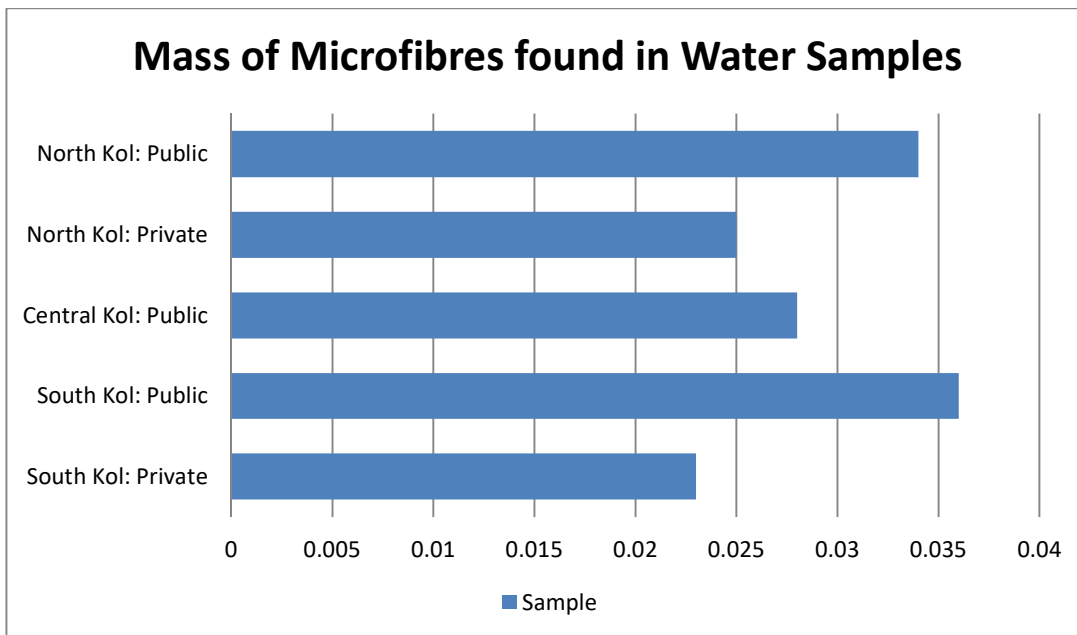**5.1.1 MICROSCOPIC OBSERVATION**

Fig 5(i) and (ii): Average Total Microfiber Count(along with other non-biodegradable matter) in Collected Water Samples
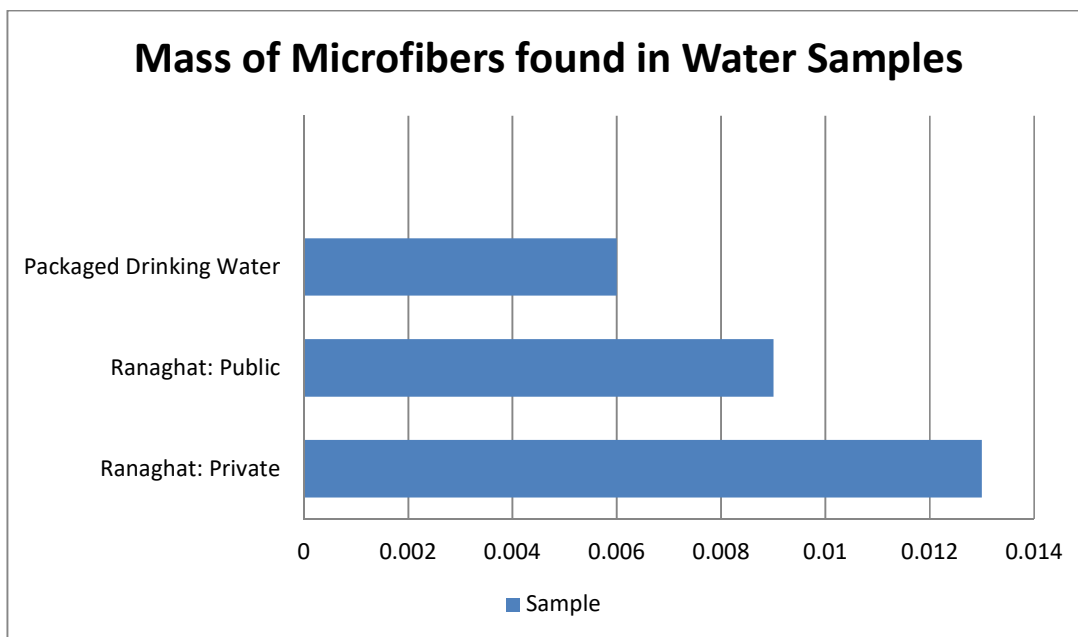
5.1.2 DETERMINATION OF MICROFIBER MASS

Fig 5(iii) & (iv): <u>Mass of Microfibers found in Collected Water Samples</u>

Mass of Microfibers found in Water Samples

From the above results, it is evident that the water samples collected from public facilities in South Kolkata has the maximum microfiber contamination. The level of microfiber contamination in this area is alarming. This level of microfiber contamination can cause significant health hazards as discussed in the initial chapters. From the results, it is clear that the filtration processes employed in Municipal Areas are not sufficient for the removal of microfiber.

5.2 PART 2: ESTIMATION OF BPA IN WATER USING UV-VIS SPECTROPHOTOMETER

5.2.1 UV-VIS SPECTROPHOTOMETRY

The UV /VIS Spectrophotometric method was the method used in the research project for determination of BPA in the water samples. This method is easy and affordable. It is very fast too because the detection time is under 1min. Due to the non availability of HPLC in working condition in our Research Lab and also other major labs in Kolkata, the UV Vis Spectrophotometric method was chosen as a substitute to BPA detection and was proven to be nearly efficient as HPLC.

5.2.1.1 BPA Absorption Spectra

 BPA's highest peak was seen at 265 nm.

Table 5: Absorbance and Concentration of Samples containing BPA at 265 nm

Sample Code	Absorbance	Concentration (X) in µg/ml
W.E.1	0.230	$6.5 * 10^{-6}$
W.E 2	0.030	$8.5 * 10^{-7}$
F1	0.130	$3.7 * 10^{-6}$
F2	0.055	$1.4 * 10^{-6}$
T.W	0.040	$1.14 * 10^{-6}$

Equation used for calculating concentration of BPA at 265nm,

$$A = \varepsilon * b * [X]$$

Where, A is the absorbance,

ε is the molar absorptivity in $M^{-1}cm^{-1}$

b is the cell size (b=1cm),

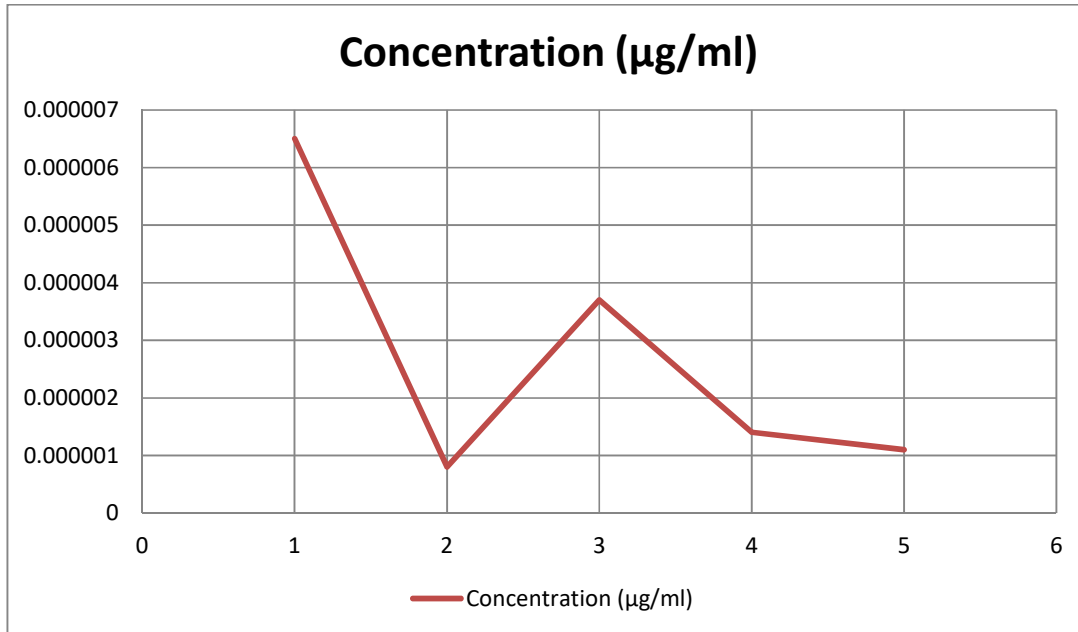X is the concentration in µg/ml

Calculation of concentration of standard stock solution of BPA

A = 2.190 (from Absorbance vs Wavelength peak)

$\varepsilon = 3.5 * 10^{4}$ $M^{-1}cm^{-1}$ (at 265 nm)

X = 2.190 / (3.5 * 10^{4}) = 6.25 * 10^{-5} µg/ml is the concentration of standard solution of BPA

Fig 5 (v) : <u>Concentrations of BPA found in Water Samples (in µg/ml)</u>

The microfibers eventually leach chemicals such as Bisphenol A as they degrade. When consumed this BPA accumulates in the organs like liver and kidney. Over time this BPA creates different health hazards like heart disease, hormonal disbalance, blindness, fertility problems, liver and kidney failure and neural disorders. Earlier amount of microfiber estimation was done. From those data any one can presume that those microfibers are the only source of contamination in water. But in the bigger picture, Bisphenol A posses greater threats to the environment than microfiber which is the result of microfiber decomposition in water. So, in this study the concentrations of BPA in different samples were evaluated. It was observed that the Machine Wash Effluent Sample (W.E. 1) which was collected directly fom the washing machine outlet has the maximum BPA concentration compared to the other samples that were tested.

5.3 <u>PART 3: DESIGN OF A NEW SAND FILTER</u>

It was observed and mentioned in the previous chapter that percentage of filtration efficiency is best for 100 mesh sand grain compared to others mesh size sand grain in glass tube filter. Also, removal efficiency was moderately good in the burette set up for 2.5 cm and 5cm column with 80 mesh size sand grain. Therefore, graphical representation of samples with their %age of microfiber removal efficiency after filtration is shown below.

5.3.1 FILTRATION EFFICIENCY

Fig 5(vi) & (vii): <u>Filtration Efficiency in Filter Columns with height 2.5 cm and 5cm respectively with 80 mesh sand</u>
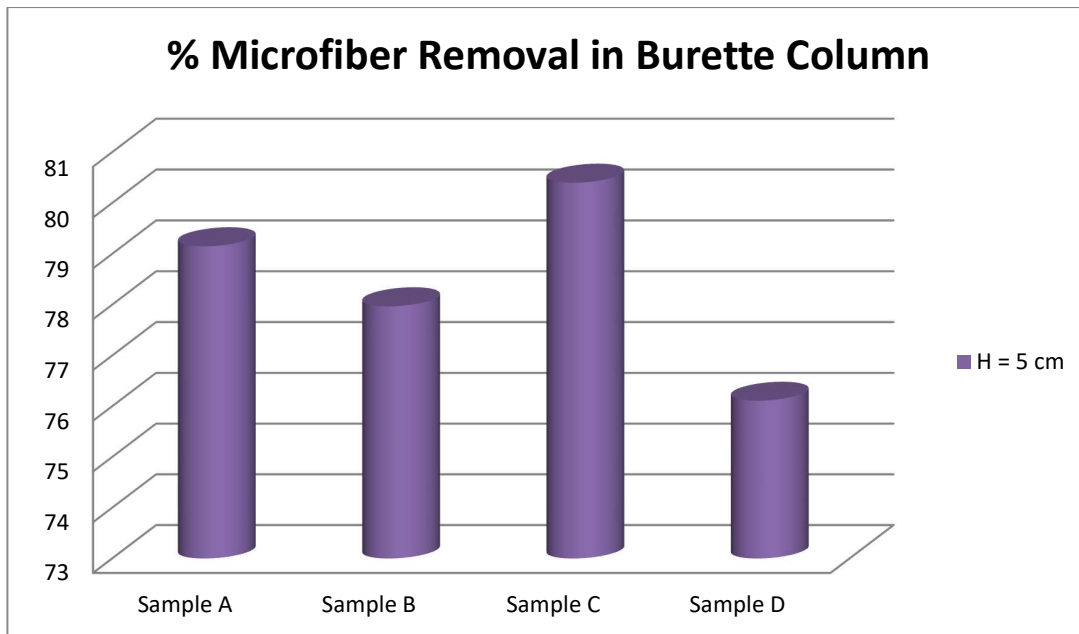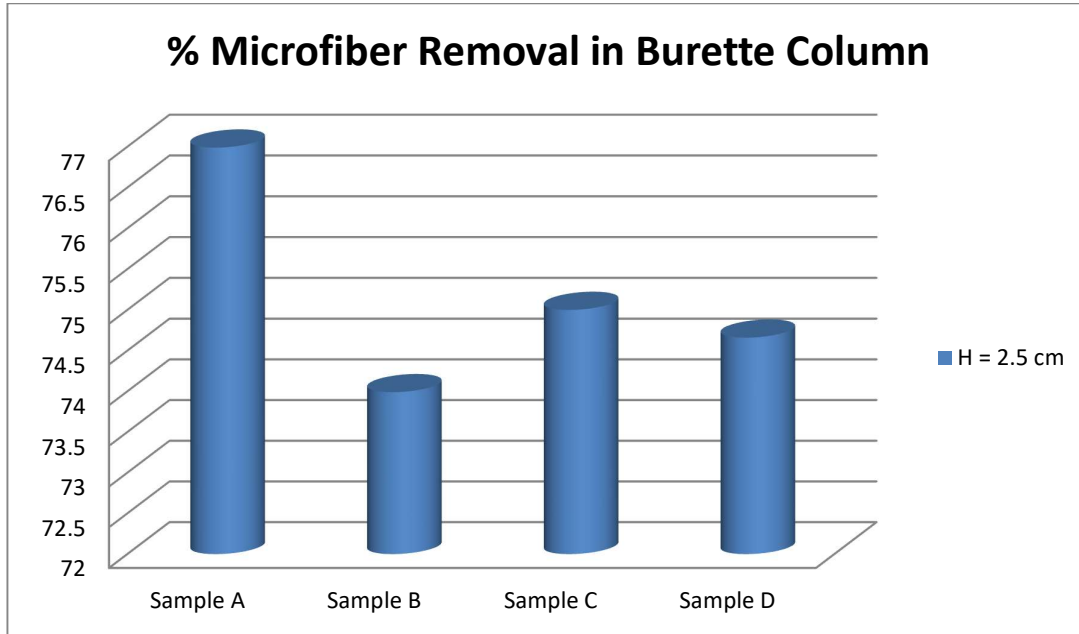
Fig 5(viii) & (ix): <u>Filtration Efficiency in Glass Tube Filter with height 11cm with 100 mesh sand</u>

% Microfiber Removal in Glass Tube Filter

	Sanple A	Sample B	Sample C	Sample D	Sample E	Sample F
■ % Microfiber Removal	93.51	92.86	91.9	90.9	90.3	92.19
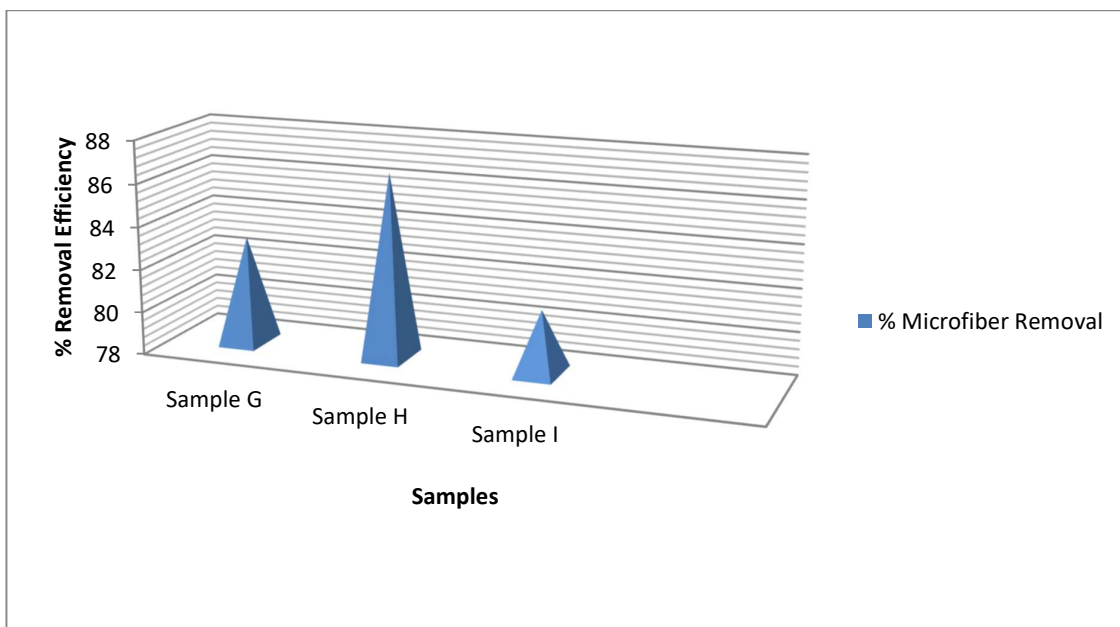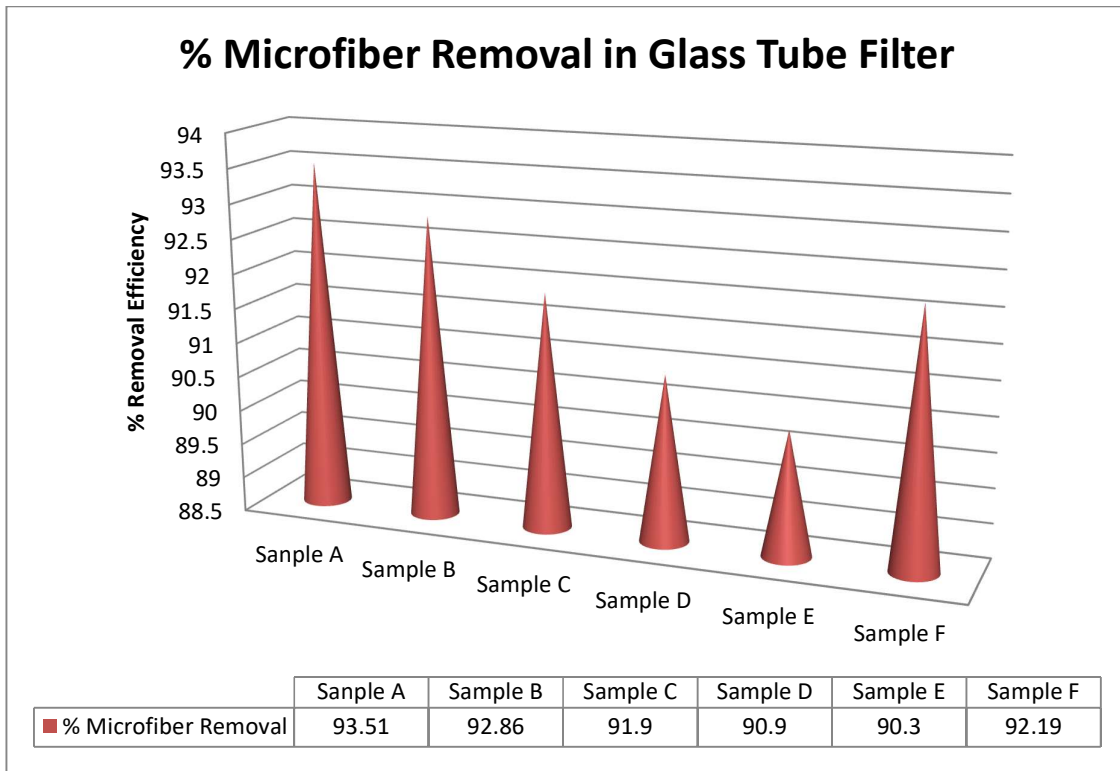
Fig 5(x): Filtration Efficiency in case of Machine Wash Effluent in Glass Tube Filter with height 11cm and 100 mesh size sand
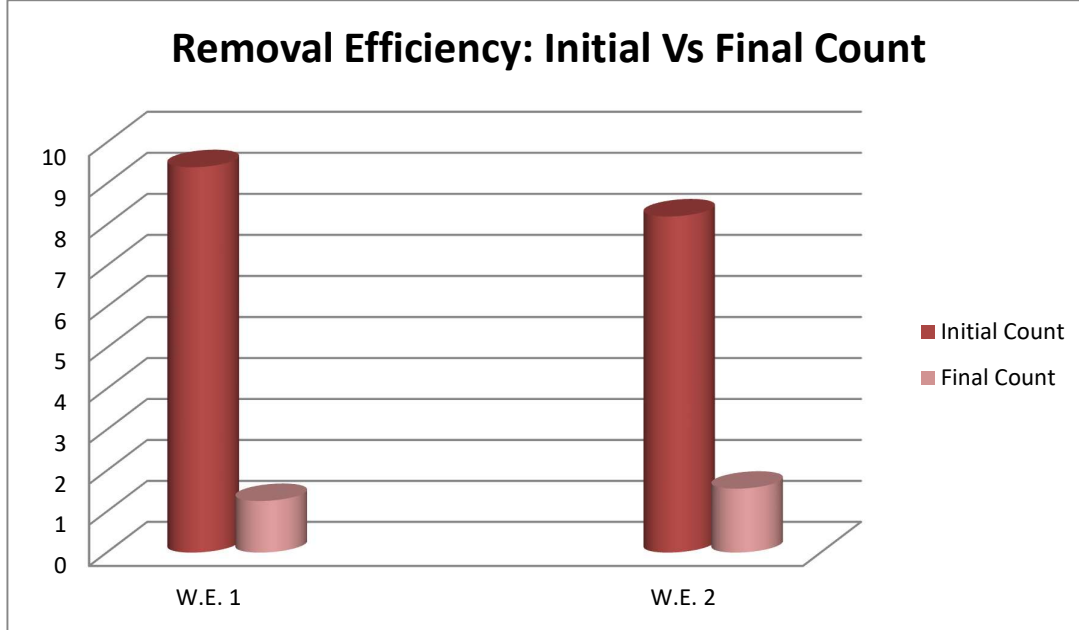
The filtration efficiency was way above 80% and less than 95% for the water samples filtered in the Glass Tube Filter containing 100 mesh size sand and having diameter 3.5cm and height 11cm compared to the filtration efficiency of the burette column with diameter 0.5cm and height 2.5cm and 5cm respectively, where the % microfiber removal varied between the range of 70-80%. Keeping this in mind, the proposed filter design was developed to achieve a filter with optimum flow rate and greater microfiber removal efficiency.

For the machine wash effluent samples, the filtration efficiency was 86.61% and 80.93% respectively.

5.3.2 <u>Design of a Real time CrossFlow Microsand Filtration System</u>

The theoretically designed real time filter was developed to achieve a flow rate of 60 l/hr. The proposed design of this filter was fabricated keeping in mind that this filter will be attached to the washing machine outlet **to eliminate microfiber release into the environment**.
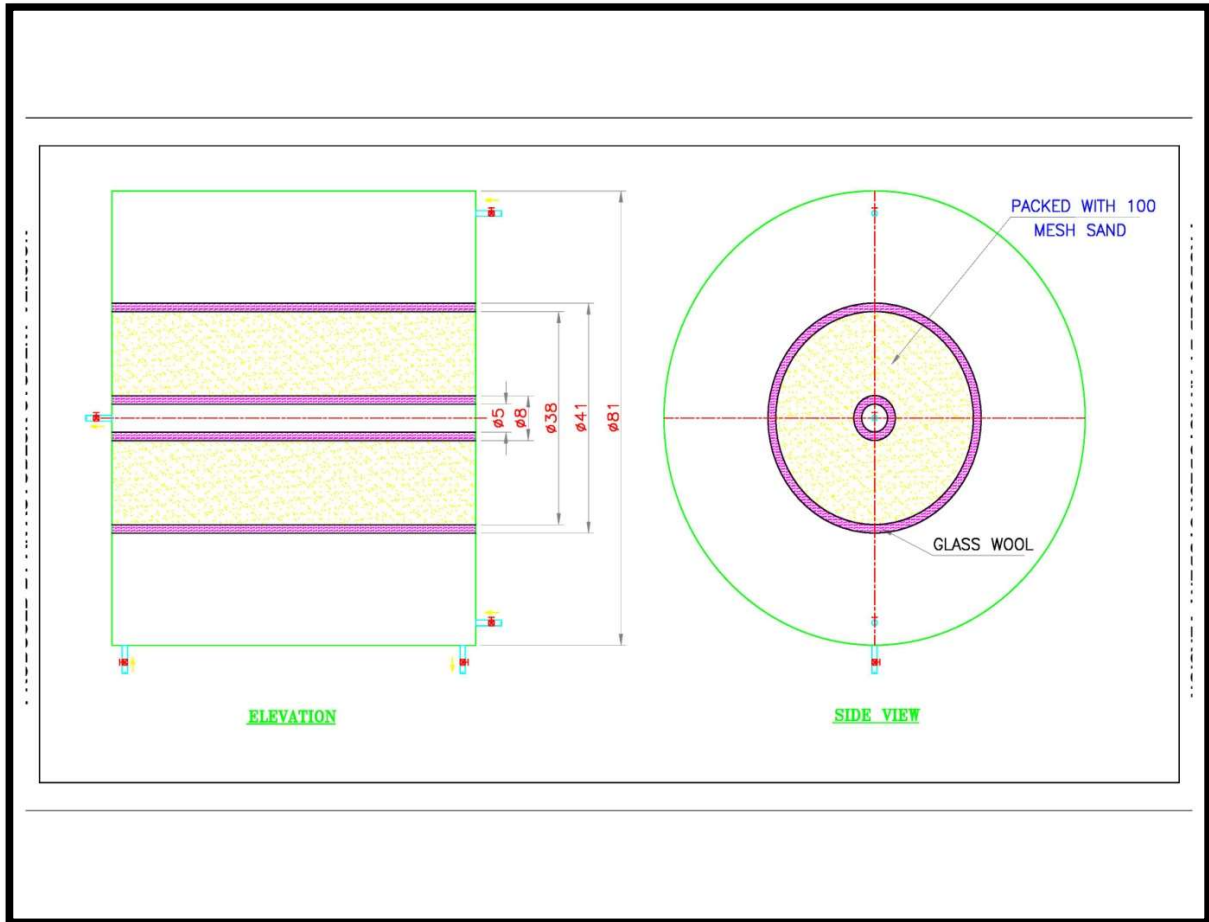
Fig 5(xi): <u>Design Illustration of a real time crossflow microsand filtration system microfiber removal</u>

Diameter of the sand bed, d = (15 + 15) = 30cm = 0.30m

Total Diameter of the Cylinder, D = 5 + 3+ 30 + 3 = 41 cm = 0.41m

Contact Area, A = π D L

Where L is the length of the packed bed; L = 70cm = 0.70m

A = 0.9011 m^2

Volumetric Flow Rate, Q = 60 lit/hr = $1.66 * 10^{-5}$ m^3/s

Velocity, V = Q / A = $1.84 * 10^{-4}$ m/s

Now, Reynold's Number, $Re = D V \rho / \mu$;

Where ρ is the density of water $= 997$ kg/m^3, μ is the viscosity of water $= 8.90 * 10^{-4}$ Pa-s

$Re = 8.46$

Therefore, **for a volumetric flow rate of 60 lit/hr through the filter bed with diameter 30cm and length 70cm, the Reynolds Number is 8.46 (i.e < 10) which denotes that the flow through the sand bed filter will be laminar, ensuring optimal removal of microfibers.**

This proposed sand filter can filter up to 120000 litres of water and after that the filter column need to be replaced.

5.3.2.1 Backwashing:-

For better results the filter column need to be cleaned periodically otherwise microfiber particles will reduce the porosity of the filter which will reduce the flow rate eventually.

For better filtration results and flow rate, the filter needs to be washed periodically every after 300-500 litres of filtration.

In case of back washing the inlet valve will be used as outlet and outlet valve will act as inlet. The flow rate will be 60 lt / hour.

CHAPTER 6

CONCLUSION AND FUTURE WORK

Microfiber pollution is a major environmental and human health challenge. In the face of such a broad threat to all environments, wildlife, and human communities, it is easy to feel overwhelmed and despaired. In these moments, it is critical to focus on hope and unity. We are in this together as a global community and through that interconnected network; we can make a real difference. While it is true that humans are the source of this issue, that fact inherently means that we are also the solution. People are natural innovators - we are constantly using new, creative ideas to make the world a better place from new technologies to new waves of activism. We simply need to harness that energy and intellect toward this problem to protect the future of this planet and the human and animal communities that rely on it.

This thesis work has focussed on the ever growing microfiber pollution issues and its consequences. The results show greater threats and potential risks to man and the ecosystem. The trend is increasing every year. Therefore, it is high time to take proper serious action or find alternative in resolving this problem. Filtration is one of the alternative solutions to this microfiber problem. **This work was mainly focussed in developing a real time microsand filtration system to provide maximum microfiber removal at a low cost and low power to ensure accessibility to every household.**

Microfibers are likely responsible for transporting chemical substances from apparel products into the environment. Therefore, integrating a filter system for microfiber removal in every household having access to washing machine should become a standard. This in turn will result in less microfiber release in to the environment. **The designed real time sand filter was established on the basis of mathematical calculations and logical presumptions**. It is obvious that this type of fabricated model of sand filter will face certain obstacles practically. But these problems can be overcome by the modification of design and operational parameters.

The real time crossflow microsand filter system that was proposed in this thesis have the potential to remove microfiber at a very high rate with a filtration efficiency > 80%. Also, the filter is economically affordable and easy to operate. The proposed idea is to attach the filter

to the washing machine outlet thereby filtering the wash effluent every time it is released through the machine outlet during the wash cycle.

Since, the theoretical design of the commercial filter is done on the basis of the experimental laboratory filter setup, therefore the need backwashing of the filter after 300-500 litres filtration capacity is yet to be checked. However, the proposed design has qualified the desired requirements that are expected from a low cost high efficiency filter.

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