Performance and Reliability Analysis of a Horizontal Roughing Filtration (HRF) System in the Treatment of Urban Pond Water: A Case Study of Kolkata City

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

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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 the undersigned candidate, as part of my **Master of Engineering** in **Water Resources & Hydraulic Engineering** in the Faculty of Interdisciplinary Studies, Jadavpur University during academic session 2022-2024.

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

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

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ABSTRACT

Almost all real life datasets consist of missing values. These missing values require special attention on analysing the data. One approach to solve incomplete data problems is adoption of imputation techniques. This paper discusses the usage of linear interpolation technique to estimate the missing values. The study involved conducting experiments with a horizontal roughing filter which was present at Fluvial Hydraulics Laboratory, School of Water Resources Engineering, Jadavpur University to assess its capacity to lower turbidity levels. The raw water is collected from Jheel of university and measured turbidity values at inlet and outlet of HRF system during filtration to gauge the filter's efficiency. Then calculate the turbidity values by linear interpolation taking each fourth value of actual turbidity as reference. To assess the effectiveness of linear interpolation, the estimated turbidity values were compared with actual measurements. The thesis investigates the accuracy of the interpolation by calculating the percentage error between interpolated and actual turbidity values. This analysis provides insights into how well linear interpolation performs in filling gaps within the dataset and its impact on the overall evaluation of the filter's performance. The results indicate that the horizontal roughing filter significantly reduces turbidity 82.92%, demonstrating its effectiveness as a water treatment solution. Linear interpolation was found to be a useful technique for estimating missing turbidity values, with error 9.825%. Generally within an acceptable range, suggesting that it is a reliable method for handling incomplete data in turbidity studies. This study contributes to the understanding of horizontal roughing filter systems and their application in turbidity removal. It also highlights the importance of accurate data interpolation in water quality assessment and provides insights into the reliability of different methodologies for handling incomplete data.

Keywords: Horizontal roughing filter (HRF), Error analysis, Surface water treatment, Turbidity measurement, interpolation

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ABBREVIATIONS

HRF: Horizontal Roughing Filter

MSF: Multi-Stage Filtration

SSF: Slow Sand Filtration

UV: Ultra Violet

TDS: Total Dissolved Solids

GAC: Granular Activated Carbon

NTU: Nephelometric Turbidity Unit

SS: Suspended Solids

BAC- Biological Activated Carbon

BF: Biofiltration

MF: Microfiltration

UF: Ultra Filtration

NF: Nano-Filtration

BDOC: Biodegradable Dissolved Organic Carbon

EBCT: Empty-Bed Contact Time

THMs: Trihalomethanes

MCL- Maximum Contaminant Level

THMFP: Trihalomethanes Formation Potential

ASSF: Aerated Slow Sand Filter

CHAPTER: 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1. Background of the Study

Urban ponds in Kolkata City often face significant pollution due to urban runoff, waste discharge, and other contaminants. Effective water treatment solutions are necessary to address these issues and improve the quality of water in these ponds. Horizontal Roughing Filters (HRFs) offer a promising preliminary filtration technology for removing larger particulates and sediments.

The availability and quality of fresh water resources is the most pressing of many environmental challenges in India [Central Pollution Control Board, 2013]. Although 89 per cent of the urban population in India has access to water supply, the average availability is less than four hours a day and in some areas water is supplied only for one hour on alternate day [Asian Development Bank, 1997]. The human body requires minimum approximately 3 litres per capita per day (lpcd) intake of drinking water to sustain life before dehydration occur in tropical climate [White et al., 1972]. When other uses like hygiene (washing and cleaning) get added to it, the requirement increases to 45–55 lpcd [Bhandari and Gupta, 2010]. Safe drinking water is essential for good health as is sanitation [Bhandari and Gupta, 2010], and lack of these two essential elements result in significant increase in morbidity and mortality conditions [Jalan and Ravallion, 2001; Shreshtha, 2006; World Bank, 2006]. In developing world, majority of children and adults suffer from repeated episodes of infectious diarrheal diseases annually, where water is considered as the major source of exposure to diarrheal pathogen [Sobsey et al., 2003].

Urban India largely depends upon water supply system that either draws from proximate surface or subsurface water bodies [Bhandari and Gupta, 2010]. There has been a constant problem regarding the availability of safe drinking water to the inhabitants in an urban area. In Kolkata, the problem is severe. Despite its location along the east bank of the River Hugli which means availability of abundant water in its vicinity, instead the city faces a grave problem of good quality water supply [Tata Energy and Research Institute, 2013]. The problems are acute to those living in the slum [Kundu, 2003]. On the other hand, in the absence of efficient surface water availability, people depend on underground water sources where its overuse leads to an increase in the arsenic concentration in many wards of the city [Shaban and Sharma, 2007]. Groundwater is generally less susceptible to contamination and pollution as compared to surface water bodies. But its intensive use for irrigation and industrial purposes causes aquifer contamination which resulted into mineralization of water resource [West Bengal Pollution Control Board, 2011].

In India, about 70% of the existing water is contaminated, out of which 8-16 % water is contaminated by industrialized pollution and 84-92% by sewage pollution and others. As a growing metropolitan city in a developing country Kolkata faces socioeconomic problems, overpopulation and substantial urban pollution. Urban Kolkata consists of about 3000 ponds and act as a model case to find out the role of the ponds in any city. In the ecosystem water is considered to be the most important component for the life but day by day the quality of water

become degraded. The water of the ponds, lakes and river are polluted mainly due to discharged waste water from residential areas, sewage outlets, solid wastes, detergents, oil wastes, and agricultural pesticides from farmlands. There are several diseases have been identified among the human beings, which are caused by using contaminated water. Water born disease infections occur during washing, bathing and consumption of contaminated water during food preparations. Therefore it is necessary that the quality of water should be checked at regular time of interval because the financial losses due to water borne diseases have negative impact on the nation. Without proper knowledge of water chemistry, it is very difficult to understand the biological phenomenon fully, because the chemistry of water reveals much about metabolism of the ecosystem and explains the general hydro-biological interrelationship. Physico-Chemical characteristics are highly important with regard to the occurrence and abundance of species. Discharge of urban, industrial and agricultural wastes have increased the quantum of various chemicals that enter the receiving water, which considerably alter their physico-chemical characteristics. Nutrients like phosphorous and nitrogen from the domestic wastes and fertilizers accelerate the process of eutrophication. Temperature, dissolved oxygen, Water pH, Free carbon-dioxide, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Phosphate Phosphorus, Nitrate-Nitrogen, and total alkalinity are significant parameters used to study the water quality.

Pollution of surface and ground water is major problem due to rapid urbanization and industrialization. The physico-chemical contaminants that adversely affect the quality of groundwater are likely to arise from a various sources, such as land application of agricultural chemicals, disposal of organic wastes, infiltration of irrigation water, septic tanks, infiltration of effluent from landfills, pits, lagoons and ponds used for wastewater discharge, that are significantly altering the water quality (Yokota et al., 2001). Pond is referred to as a man-made or natural water body which holds water for four months of the year or more and normally used as the ground water recharge source (Mushtaq et al., 2006; Passy et al., 2012; Rajaram & Das, 2008).

A pre-treatment of raw water before its introduction into SSF has become a necessity. There are a number of pre-treatment methods available, but Horizontal—flow Roughing Filters 1 (HRF) were found to be the most attractive (Wegelin, 1980). They are simple, do not have any moving mechanical parts, and can operate for a long time due to their high solids storage capacity. Several laboratory and field studies confirmed the ability of HRF to reduce turbidity to acceptable levels for SSF. These investigations were carried out under different climatic conditions, with various design methods, tested under varying velocities. They all claimed surprisingly good results without enough scientific explanation. As a result of this, it was felt that there was need to conduct intensive experimentation considering all possible variables that are likely to influence the horizontal filtration process.

1.2. Study Area

The model is situated at Fluvial Hydraulics Laboratory, School of Water Resources Engineering, Jadavpur University (22.49818^0 N, 88.37321^0 E). The water body, commonly referred to as "Jadavpur University Jheel," serves as a reservoir for rainwater harvesting and is the primary source of surface water supply. The pond is rectangular in shape, spanning

approximately 147.8 meters in length and 43.2 meters in breadth. It is prohibited to engage in activities such as bathing or disposing of waste in this water body. Given that the pond is unlined, it fosters a thriving ecosystem with numerous ecological activities taking place within it.

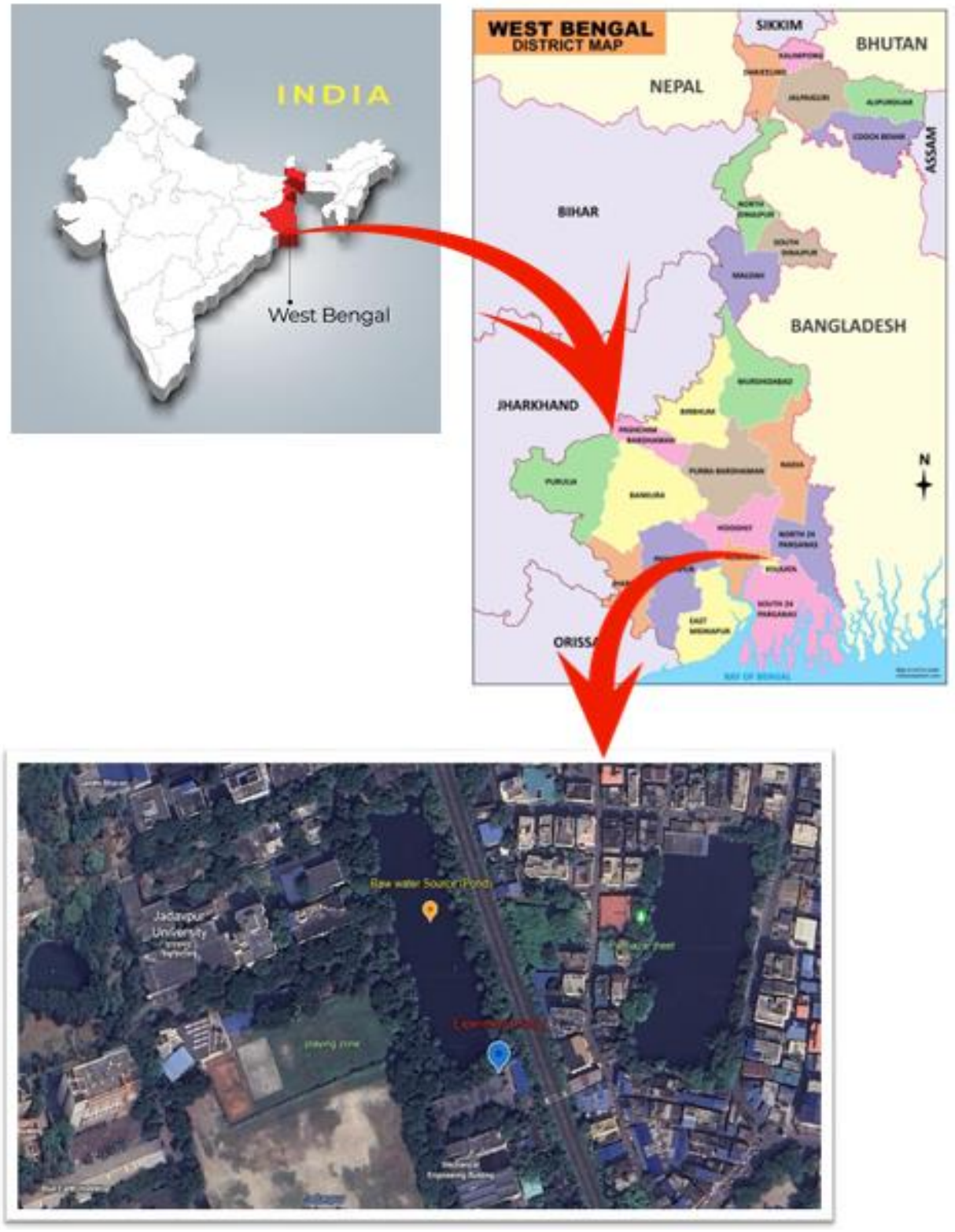


Figure 1.1 Experimental Setup Location (source: Google Map)

1.3. Research Gap

Despite their established use and benefits, there are several research gaps and areas where further study could enhance the effectiveness and applicability of HRFs. There is a need for research into the optimal types and configurations of filter media for HRFs. This includes studying the impact of different materials (e.g., sand, gravel, crushed stone) and their properties on the performance and reliability of the filter. The existing literature primarily focused on granite chips, sand gravel and composite gravel as a filter media placed in four chamber of decreasing size as 10mm, 5mm, 3mm and 2mm. By virtue of their capability to measure a wide spectrum of particles, light scattering techniques are strongly recommended for research aimed at investigating particulates removal. Mathematical models and real time monitoring technology of hydraulic performance and reliability of HRFs may need to be developed for better access. The effectiveness of HRFs across different types of raw water sources are needs further investigation. In the existing literature the water source is pond of Jadavpur University which serves as a reservoir for rainwater harvesting. It is prohibited to engage in activities such as bathing or disposing of waste in this water body. There is limited research on the long-term cost-effectiveness of HRFs compared to other pre-treatment technologies and environmental impact and sustainability of HRFs. HRFs can be effectively integrated with other water treatment processes (e.g., slow sand filters, activated carbon) is limited. Addressing these research gaps could lead to significant improvements in the design, operation, and application of horizontal roughing filters. This research could help optimize their performance, broaden their applicability, and ensure they are a viable option for a wider range of water treatment scenarios.

1.4. Research Objectives

When studying the performance and reliability of Horizontal Roughing Filters (HRFs) in pond water treatment in kolkata, it's essential to establish clear and focused research objectives. These objectives guide the investigation and help in evaluating how effectively HRFs can be used in different contexts, particularly for pre-treating raw water such as pond water. Here are some key research objectives for exploring the performance and reliability of HRFs:

- **Evaluate Filtration Efficiency:** Assess the effectiveness of HRFs in removing suspended solids, turbidity from pond water. Measure the reduction in turbidity before and after HRF treatment and analyze the removal efficiency of different types and sizes of filter media.

- **Assess Reliability and Operational Stability:** Evaluate the reliability and operational stability of HRFs under varying water quality conditions and flow rates.

These research objectives aim to comprehensively evaluate the performance and reliability of Horizontal Roughing Filters in urban pond water treatment. By addressing these areas, researchers and practitioners can improve the design, operation, and application of HRFs, ensuring they provide effective and reliable pre-treatment solutions for various water sources.

1.5. Overall Methodology

The overall research methodology is mainly divided into five components: Literature Review for Identification of goal and objective, Collection of the information of the present situation by primary survey and secondary survey, Data Presentation and Organisation of data analysis, Development of a method and design of horizontal roughing filtration system with different types of gravel media. The process encompassed sample collection and characterization, followed by the construction of the HRF model. Continuous monitoring of parameters such as turbidity, suspended solids, and head loss development took place. Subsequently, collected data underwent rigorous statistical analysis, enabling a comprehensive evaluation of the system's capacity to evaluate the performance and reliability of system in urban pond water treatment.

1.6. Propose Outcome

A comprehensive analysis of the performance and reliability of Horizontal Roughing Filters (HRFs) should yield several important outcomes. These outcomes will provide insights into the efficiency, effectiveness, and operational stability of HRFs in water treatment applications. Below are the proposed outcomes of such an analysis:

- **Quantitative Assessment of Performance:** Detailed data on the efficiency of HRFs in removing suspended solids, turbidity, and particulate matter from various water sources.
- **Identification of Best Practices for Design:** Guidelines for the optimal design of HRFs based on filter media characteristics and flow configurations.
- **Assessment of Long-Term Reliability:** Evaluation of the operational stability and reliability of HRFs under various conditions.

These proposed outcomes aim to provide a thorough understanding of HRF performance and reliability. By addressing these areas, the research can offer valuable insights into optimizing HRF design and operation, improving efficiency, and ensuring reliable performance in various water treatment scenarios.

1.7. Thesis Outline

The research and findings are presented in the following 6 chapters of the dissertation. Chapter 2 contains literature review of different similar nature of national and international scenarios of HRF units. Chapter 3 discuss about theoretical concept on water treatment technology. Chapter 4 consist of methodology and experimental design of different filtration techniques. Chapter 5 contains result and discussion part. Chapter 6 presents conclusions and recommendations of the thesis through addressing the study objectives, the implications of findings and significance of this research work. References are given at the end of the dissertation.

The structure of thesis for the modelling of HRF performance with its main components is presented below having research background, previous and current research studies, research approach techniques, research findings including conclusion and recommendations that are formally organized as shown:

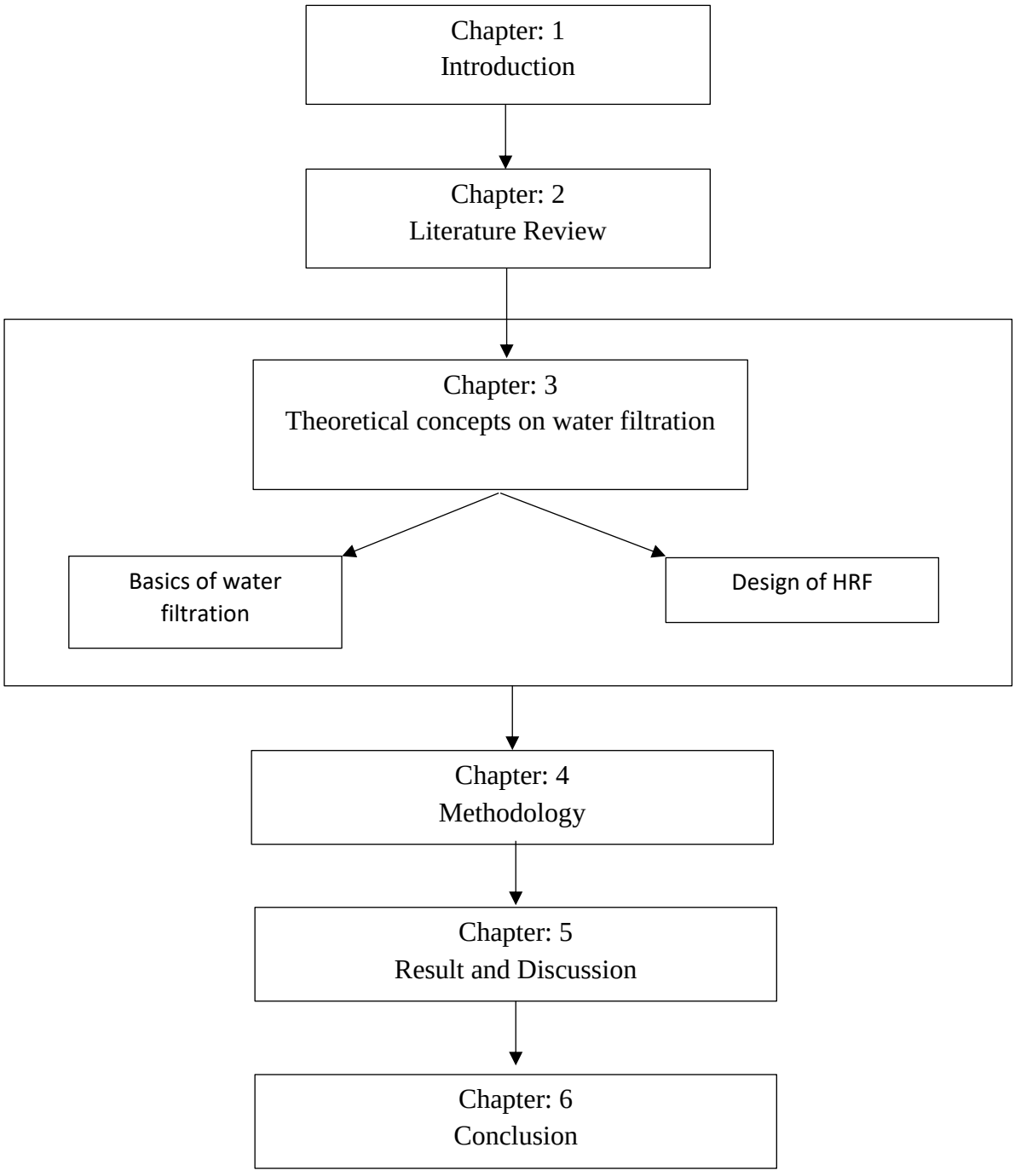


Figure 1.4 Schematic diagram of the dissertation outline

CHAPTER: 2

LITERATURE REVIEW

CHAPTER: 2

LITERATURE REVIEW

A literature review is a survey of academic books, journals, and other materials pertinent to a certain problem, field of study, or theory, and by doing so, it offers a description, synopsis, and critical evaluation of these works. The purpose of literature reviews is to show readers how your research fits into the greater body of knowledge and to give an overview of the sources you have used to do research on a certain issue. A literature review is a summary of the literature that is pertinent to a certain subject or field. It provides a summary of what has been stated, names of significant authors, descriptions of prevalent ideas and hypotheses, questions being posed, and approaches and procedures that are relevant and helpful. As a result, various technical papers on the Assessment of pesticide concentration and general parameters in wastewater have been presented at the research level from which I referred many papers for study. These papers are presented below.

Kusuma et. al. (2020) discussed the Water Treatment Plant (WTP) of Siwalanpanji Sidoarjo does not able to processed the raw water of Buduran River which has the Turbidity of 2500 NTU. This treatment plant can treat the water if it is below 100 NTU using ultrafiltration technology. Therefore, the turbidity has reduce to 100 NTU for better performance of the system. The process used here to reduce turbidity is pass the water through the filter media with variable diameter of filter media with small size to big size. Here the author used gravel media in varied diameter for 6 compartment in series which is called Upflow Roughing Filter (UFRS). This filter can reduce turbidity 95.95% with infiltration rate of 1 m/h.

Nabizadeh et. al. (2015) discussed Suspended solids and microorganism from aerated lagoon are removed by the use of horizontal roughing filter (HRF). The author take four month operational duration period with filtration rate of 0.5, 1.0 and 1.5 m^3/s. The authors get the value of turbidity 79±12 NTU, TSS 100±11 mg/dm^3, COD 190±12 mg/dm^3,pH 7±0.1, temperature 17±8 °C and flow rate of 0.82 dm^3/min. The pH and temperature of outlet water is not change significantly. The removal efficiency of HRF measures turbidity, TSS, and COD in HRF will be 81.1%, 63% and 66.3%. If filtration rate is increase then removal efficiency will decrease.

Dastanaie et al. (2007) evaluate the bank of Zayandehroud river near the village of Chamkhalifeh. In summer season the river water quality was worst and this time Horizontal flow roughing filter was run for three months (July, August and September). The filter has three compartment and separated with perforated baffles. These compartments are filled with locally available materials such as sand and gravel with decreasing order. The main function of this HRF is to remove turbidity and suspended solids. Also iron, manganese, colour and coliform are removed in some extent. In local area if no such other harmful chemicals are present then this HRF is considered as packed, low-cost and efficient pre-treatment process incase surface water is used as water supply for treatment. Author has getting the removal efficiency of coliform pollution 94%, Total suspended solids (TSS) 89.7%, manganese 64%, turbidity 63.4%, colour 20% and iron 15.6%.

Sittivate (2000) observed large gravel of size 10-20 mm filter media is used in a single package, uncovered and outlet at the top. The author has estimate the filter runtime in lab and wants to provide a field model. This model has designed for full scale and is easy to apply.

Affam et. al. (2013) investigate the removal of COD, BOD, turbidity and colour from leachate by vertical flow roughing filter. Here, Limestone (Density=2254 Kg/m^3) media with gradation of 4-8mm, 8-12 mm, 12- 18 mm are used. The leachate has inflow pH of 7.94 to 8.12 and outflow pH of 8.42. The maximum head loss is 20mL/min was 0.5cm. The optimum treatment was achieved in combination of 4-8mm, 8-12 mm, 12- 18 mm filter media size. The removal efficiency was for BOD 22-81%, COD 22-75%, turbidity 32-86% and colour 36-62%.

Mukhopadhay et. al. (2009) discussed Weglin's design criteria based on 1/2 – 2/3 filter theory to estimate the performance of the horizontal Roughing Filter (HRF). The raw water is treated by slow sand filter and HRF is used as a pretreatment unit. This study is done in laboratory with small scale by the help of weglin's design criteria for HRF. Here three models result were compared with the another two models which will verify the validity of former. The HRF is operated with filtration rate of 0.3 - 1.5 m/h and can remove the turbidity 50 – 1000 NTU.

Adel et. al. (2014) investigate the performance of various roughing filter configurations as pre-treatment for filtration process. UFRS has recorded the highest efficiency among the four RF configurations followed by the HFRS, DFRS, HFRS-IP (Hz roughing filter with inclined plates). Results revealed that the UFRS recorded average turbidity removal efficiency of 76.64, 83.02 and 87.88% at ROF 0.7m/h, 0.5m/h and 0.3m/h respectively. DFRS recorded average turbidity removal efficiency of 74.90, 76.19 and 78.59% at ROF 0.7m/h, 0.5m/h and 0.3m/h respectively. HFRS recorded average turbidity removal efficiency of 73.33, 76.80 and 80.73% at ROF 0.7m/h, 0.5m/h and 0.3m/h respectively. HFRS-IP recorded average turbidity removal efficiency of 69.88, 72.87 and 74.10 % at ROF 0.7m/h, 0.5m/h and 0.3m/h respectively. All configuration handled 30NTU influent turbidity without problems.

Nkwonta et. al. (2009) mainly focused on Roughing filtration can be considered as a major pre-treatment process for wastewater, since they efficiently separate fine solids particles over prolonged periods without addition of chemicals. This review article summarizes and evaluates modifications to roughing filtration technology, which may address these limitations without compromising the simplicity of the treatment process. Successful modifications includes broken burnt bricks, charcoal and coconut fibre as filter media. The paper also reviews the design concept and process capabilities for roughing filter and it also discusses recent innovations in roughing filter design that now enable this technology to be applied more widely than would have been appropriate 2 decades ago. Achieved results in this study shows that roughing filtration may be considered as efficient pretreatment process in case surface water is used as water supply.

Mahvi et. al. (2004) observed that the Vertical or horizontal flow gravel beds can be used in water treatment as roughing filters. In order to improve the performance of horizontal flow roughing filtration (HRF) this process has been modified earlier by applying a constant coagulant dose prior to filtration named direct horizontal roughing filtration (DHRF). In this research a lab scale DHRF pilot plant was used for investigate DHRF performance. The study results indicated that DHRF (6.5 m long consisting of 2.5 m first compartment with 12-18 mm diameter grain, 2 m/s compartment with 8-12 mm diameter and 1.5m third compartment with

4-8 mm diameter) was systematically yielded good effluent quality (<2NTU, C.I=0.95) with raw water quality of 200-400 NTU. DHRF is a versatile pretreatment process capable of handling wide fluctuation in raw water turbidity (200-400 NTU) while operating condition such as coagulant dose [2mg Fe (III)/L], mixing intensity, time and filtration rate remained unchangeable.

Dastanaie et. al. (2007) evaluate the feasibility of implementation of horizontal-flow roughing filtration for drinking water treatment a pilot was designed and run at the bank of Zayandehroud river near the village of Chamkhalifeh. Pilot running was performed in summer 2003 (July, August and September), when the quality of river water was in relatively worst condition. The filter is comprised from three different parts which are separated with perforated baffles. Each compartment is filled with some local sand and gravel considering a special decreasing size regime. The overall function of the filter in removing turbidity and total suspended solids is acceptable. Additionally, iron, manganese and color and coliform removal are also been covered to some extent. Achieved results in this study shows that horizontal-flow roughing filtration may be considered as a packed, low-cost and efficient pretreatment process incase surface water is used as water supply for treatment. Furthermore, when small scale societies are considered and when no major pollutants exist in the water supply as the case in this study_ this system may be posed as a total treatment system, in which treated water exited from the filter may be sent to distribution network after a simple post chlorination.

Guidice et. al. (2020) discussed Gravel roughing filters (GRFs) are used as a way to buffer small systems that are sensitive to contaminant spikes within influent waters, however they tend to fall short in the removal of contaminants such as arsenic or organic precursors. A possible solution to this shortcoming is the addition of granular Zero Valent Iron (ZVI) or Ion Exchange Resin to the GRFs. ZVI is non-proprietary and non-deleterious to biofiltration systems. Ion exchange resins are proprietary however they are non-deleterious to biofiltration systems. ZVI or resin can be added as a portion of the media in a vertical upflow filter and as a final filtration step in a horizontal filter. Our research shows the buffering capabilities that GRFs offer as well as some possible enhancements that can be added for additional treatment if desired. Two pilot sized surface-loaded horizontal gravel roughing filters (HGRFs) and two vertical gravel roughing filters (VGRFs) were constructed and installed in the pipe gallery of the UNH/Durham Water Treatment Plant. The two HGRFs are were used to evaluate Purolite A502p resin additions to the gravel media and their increased removals of dissolved organic carbon (DOC). Anion exchange resin was added to one of the HGRFs initially by means of a resin box which was easily constructed at the University of New Hampshire. GRF 1 acted as a control with no resin box or resin additions. This resin box was added to the final 7 inch portion of GRF 2 as a final treatment stage. Resin was added to the VGRFs in a similar manner. The resin was added to the final 3-4 inches of media.

Mistoro et. al. (2019) observed UGM Retention Pond as flood controller has its water supply from Belik River. Based on water quality monitoring results by the Environment Agency (BLH) of DIY in 2012–2016, the water status at the upstream area of Belik river has already contaminated before it flows to the retention pond. This study aims to make UGM Retention Pond not only as flood control, but also as a water treatment. The function can be fulfilled with the innovation of rough filter water type applied to horizontal flow, i.e. Horizontal-flow Roughing Filter. Mass balance analysis on the retention pond was calculated based on the assumption of the pond as a complete-mix reactor with BOD5 of 20.9 mg/L and TSS of 102 mg/L with discharge (Q) of 2.54 m3/s. The maximum target output produced for BOD5 was 3

mg/L and TSS was 50 mg/L so the target of filtering efficiency was 94 %. The analysis results showed the most optimal Horizontal-flow Roughing Filter was elongated beam-shaped design with length dimensions of 44.6 m, width of 2.5 m, and height of 1.7m. Filter media used in the form of pebble (gravel) with the size of 24–16 mm and assumed to have permeability coefficient k = 0.1 m/s.

Hopman et. al. (1994) discussed the drinking water sources are contaminated by the use of pesticides in agricultural land. The concentration frequently exceed EC standard pesticides in drinking water as 0.1µg/l. AS a consequence water supply companies have to treat the raw water in order to remove these pesticides. Several water treatment options are available such as Granular Activated Carbon (GAC), filtration, oxidation and membrane filtration. Granular activated carbon has very high adsorption capacity for pesticides, but under practical conditions adsorption kinetics and the presence of Natural Organic Matter (NOM) decrease GAC bed life drastically. In order to be able to perform research into possibilities to increase GAC performance are evaluated. Concerning the influence of NOM presence NOM removal during and prior the GAC-filtration process is described. The removal of NOM by rising with sodiumhydroxide during the adsorption process restores the original adsorption capacity for 50%. Membrane filtration prior to GAC filtration increases the GAC bed life for atrazine removal with a factor 4. Concerning the decrease of negative influence of adsorption kinetics the increase of contact time and the use of multi-stage column adsorption are discussed. Increasing mini-stage column adsorption are discussed. Increasing mini-column length to increase empty bed contact time increased the GAC bed life for simazine removal with a factor 10. By intensifying the research into these and other possibilities to reduce the negative influence of both adsorption kinetics and NOM presence not only the GAC bed life for removal of apolar pesticides can be extended, but also polar pesticides can be removed for longer periods against low costs.

Mushila et. al. (2016) focused on horizontal flow Roughing filter units (HRF) have been found to be the most effective and appropriate pre-treatment method used before slow sand filters (SSF) for application in developing countries. The main advantage of HRF being its simplicity in design, have low capital cost, ability to separate fine solids particles over prolonged periods (high solids retention capacity) without addition of chemicals. Most research on HRF has concentrated on turbidity (solids removal) whereas its role in removal of other parameters of concern such as microbiological (Faecal and Total coliform), colour, dissolved iron and manganese has received little attention. The general objective of this research was to evaluate the performance of HRF units by way of their removal efficiencies for the various water quality parameters under varied raw water conditions. In order to meet this objective a pilot plant unit was designed and run. The pilot plant was monitored between the months of January to June 2013. The response of the respective HRF units in removal of selected parameters guiding drinking water quality such as microbiological (Faecal and Total coliform), Turbidity, Suspended Solids (SS), dissolved iron and Manganese was investigated. With respect to microbiological raw water quality improvement, HRF units reduced Feacal coliforms load by 36 percent and Total coliforms load by 38 percent respectively.

Losleben et. al. (2008) mainly focussed on Northern Region Ghana (NRG), highly turbid rainwater runoff and intermittent streams are collected in earthen dams called dugouts. The water is collected from these dams and serve the communities for drinking and domestic water despite their physical and microbial contamination. SSF a low cost technology for treating water with <50 NTU. Two research objective objectives are address: to characterize dugout particle sizes and distribution and to test pilot horizontal roughing filter's (HRF) effectiveness

at removing turbidity from highly turbid dugout water. The author has tested four dugout in NRG, then they get typically have high concentration of non- settleable colloidal (< 1µm) and small particles supracolloidal particles (<10 µm). In addition, a pilot HRF at Ghanasco Dam in Tamale, NRG was conducted using three 7m tubes filled with three sizes of granite gravel, local gravel, and broken pieces of ceramic filters arranged by decreasing size. The pilot study was run for 52 days to test if HRF could reduce the high turbidity (305 NTU) to < 50 NTU to make SSF a viable option. There were a number of promising outcomes: the best performing media, the granite gravel, by removing an average 46% of the influent turbidity (filter coefficient **X** = 0.002 min-'), produced an average effluent turbidity of 51 NTU which almost achieved the goal of < 50 NTU. The granite gravel HRF removed twice as much turbidity (46%) as plain settling (25%). Overall, the granite gravel removed **76%** and 84% of the influent turbidity according to the settling test and pilot HRF data respectively.

Karki et. al. (2020) carried out to compare turbidity removal efficiency of anthracite up flow roughing filter (RF) model to gravel RF model at different flow rates. Two identical filter columns with (230*230*1570) mm^3 in internal dimensions were operated at same time. The low filtration rate implies longer detention time of water within the media layer eventually leading to the better removal efficiency. However, in later cases higher removal efficiency was achieved due to maturation of filter bed thereby leading to higher turbidity removal. Same grain size (2 - 4.75) and (4.75 - 9.5) mm were used in gravel model and anthracite model. All the sizes were achieved by properly sieving through standard sieve sizes (2, 4.75, 9.5, 12.5 and 25 mm). The study involved measuring turbidity every 2 hours and head loss once a day. Filter models were operated around 200 NTU influent turbidity until maximum allowable head loss was reached. Three sets of experiments were carried at filtration rate of .0.5 to 1.5 m/h. Anthracite model was 2.07% more efficient in terms of turbidity removal.

Nabizadeh et. al. (2008) discussed Horizontal roughing filters (HRF) can properly remove suspended solids and microorganisms from surface waters if they operate at filtration rates below 1.5 m/h. These filters are common raw water pre-treatment before slow sand filters. This study was conducted by installing an HRF pilot system on effluent pumping station city of Qom wastewater treatment plant based on the aerated lagoon process. The pilot was a horizontal cylindrical column consisting of three compartments filled with river gravel of various sizes. Grab samples were simultaneously taken from inlet and outlet of the HRF at three filtration rates: 0.5, 1, and 1.5 m/h. Total and fecal coliforms were tested according to standard methods for water and wastewater tests. Results indicated that filtration rate had a significant effect on the amounts of total and fecal coliforms in HRF effluent. For the HRF steady-state operation, average total coliform removal efficiency for all filtration rates was higher than 87 percent.

Boller et. al. (1993) discussed on filtration through roughing gravity filters at low filtration rates between 0.5 and 2 m/h has shown to be able to produce water with low particulate concentrations, which allow for further treatment in slow sand filters without the danger of solids overload. Theoretical considerations on particulate transport mechanisms in granular media filters revealed that sedimentation is the main transport mechanism for particle separation in gravel-type filters. Model calculations of particle transport trajectories in horizontal and vertical-flow filters suggest that horizontal pores are more efficient particle collectors. Roughing filters are particularly appropriate for applications in Third- World countries because of their high removal rates for particulates of colloidal size without addition of flocculant chemicals, their large solids storage capacity at low headloss, and their simple and reliable technology.

Hashimoto et. al. (2019) observe the Roughing Filter (RF) is effective as a pre-treatment system for Slow Sand Filter (SSF) with coagulant dosing and mixing with raw water. This RF system can pre-treat high turbidity raw water (1,000 NTU) to generate low turbidity (10 NTU) pre-treated water for SSF treatment. In the experiment, the types of filter media, height of the filter media, filtration rate and coagulant dosing were varied and the characteristics of each item were evaluated and the design guidelines were formulated. Water Treatment Plants (WTPs) consisting of pre-treatment with RF followed by SSF to treat river water were designed and constructed in Myanmar based on the design guidelines, and the operational performance was confirmed as effective to generate treated water with a turbidity under 5 NTU, which is in compliance with the WHO guideline despite the rather short working period of about one year. Sand scraping of SSF at a frequency of about once in every one to two months was implemented to maintain the design filtration rate.

Amin et. al. (2023) focussed on the pond water was used for many non-productive purposes, such as cooking, bathing, ablution, and washing clothes and kitchen utensils. About 11% of people in rural areas use pond water for drinking purposes, and 77.14% of households use sweet pond water as a secondary source for drinking and cooking purposes in southern Bangladesh. Filtration is one of the easy options for pond water treatment. However, most filtration systems are either expensive or performance not so good. Ceramic filters are reported to be one of the best treatment options for reducing turbidity and bacteria. A low-cost, simple ceramic filter (SCF) was successfully applied for arsenic removal from groundwater, which was expected to be useful for pond water treatment to obtain drinkable water quality. The purpose of this study is to evaluate the effectiveness of color, turbidity, iron, and bacteria (total coliforms (TC) and Escherichia coli (E. coli)) removal by filtration units using SCF combined with roughing filter from pond water. The results showed that the filtration system was highly effective in reducing the turbidity, iron, total coliforms, and total suspended solids in the pond water, making it safe for drinking purposes.

Bayati et. al. (2023) observed by using pilot plant. This pilot plant was designed and applied in Al – Wehda Water Treatment Plant which treats the raw water of Tigris River in Al – Karradah in Baghdad city. Design characteristics of the pilot HRF are 5.5m length × 1m width × 1m depth , the HRF length consists of inlet (0.5 m) , outlet (0.5 m) and three compartments (2m , 1.5m and 1m) filled with three different size of gravel (15mm , 10mm and 5mm) respectively . The HRF was continuously operated (24 h in a day) during the period from 15/ May / 2007 to 15/ July / 2007. Operated done in two stages. In the first stage, raw water (free from any addition) was used, with three different flow rate 1.3, 1.1 and 0.9 m3/h. While in the second stage, coagulated water (raw water + alum) was used, with flow rate 1.3 m3/h. To assess the performance of HRF, the required tests were carried out. These tests are Turbidity, S.S, Temperature, pH and Bacteriological tests. The results of tests were analysed statistically. These results indicate the high performance of HRF in turbidity removal.

Khazaeia et. al. (2015) observed that aerated lagoons are not reliable wastewater treatment systems to eliminate nutrient contents of municipal wastewater. This study aimed to enhance the aerated lagoon effluent quality by applying a simple filtration system. Removal of nitrogen and phosphorous from aerated lagoon effluent using horizontal roughing filter (HRF) was investigated. Also, the "1/3–2/3 theory" was applied to predict the TSS concentration of HRF effluent. An experimental setup of HRF was used to receive the continuous effluent from wastewater treatment plant. HRF was operated at three consecutive filtration rates, including 0.5, 1 and 1.5m^3 m^{-2} h^{-1}. Decreasing the removal efficiency was occurred during raising the

filtration rate ($p < 0.05$). Applying the "1/3–2/3 theory" revealed the significant correlation between predicted and measured TSS values. HRF can be applied as an appropriate alternative for tertiary treatment of the aerated lagoon effluent.

Elliott et. al (2011) discussed about the majority of people in developing countries lack access to piped drinking water; instead, they must carry, transport, and store water inside of their homes, which may result in a deterioration in the quality of the water. As a result, slow sand filtration has gained recognition as an effective filtering technique for getting rid of waterborne pathogens and reducing turbidity, as well as a perfect technology for drinking water purification in rural areas. In a single treatment procedure without the use of chemicals, it may produce effluent that is low in turbidity and devoid of bacteria, parasites, and viruses while also improving the physical, chemical, and microbiological quality of water.

Baidhani et. al. (2017) discussed the main objective of this study is to develop simple, inexpensive, efficient and chemical-free alternative pre-treatment process for water by using of up-flow roughing filter system. The raw water that used in present study was synthetic raw water. The turbid water obtained by adding kaolinite dose at specific concentration to achieve a turbidity from 20 to 418 NTU. The pilot plant unit was made from low-cost , locally and available materials. It consist of two steel filter columns with 1.5 m height and 30 cm in diameter. The marble media was installed in URFL.1 while the ceramic media was installed in URFL.2. The two filters was investigated with three filtration rates of 1, 0.75 and 0.5 m/h. The main aim of experimental work was to reduce the turbidity bellow 20 NTU that's acceptable to slow sand filter operation. The best performance filter was URFL.2 of ceramic media at filtration rate of 0.5 m/h. Where the URFL.2 could reduce the turbidity bellow of 109 NTU to value less than 20 NTU that's acceptable to slow sand filter operation.

Syazwan et. al. (2020) discussed the quality of groundwater at Rumah Nur Kasih consist high concentration of iron (6.12 mg/L) and manganese (0.56 mg/L). The groundwater only used for external usage such as cleaning purposes. In order to reduce iron and manganese, it is proposed cascade aerator system for oxidation process and horizontal roughing filter using limestone as the media for further removal. The oxidation process can reduce iron and manganese in water by increasing the dissolved oxygen. Meanwhile, the filtration by various size of the limestone can help to reduce the concentration of heavy metals as these limestones able to absorb heavy metals into theirs surface. In this study, two lab scale cascade aerators with different in height of cascade were used to find the highest removal of iron and manganese. It was found out that the optimum flowrate for both cascade aerator was 22mL/s. Three different sizes of limestone were filled into horizontal bed filtration for further removal. The adsorption of these limestone was observed and the smallest range of the limestone has the highest removal for both iron and manganese.

Hsu et. al (2001) discussed the filtration behaviours of Giardia cysts and Cryptosporidium oocysts, filters with 2 mm Dia glass beads and 2 mm Dia polystyrene beads were used in a laboratory setting. Target particles, such as protozoan parasites, were the pH and electrolyte concentration of the chemical system were changed. The findings strongly suggest that ionic strength has a beneficial effect. On the effectiveness of Giardia cyst removal and Cryptosporidium oocyst removal. While the removal effectiveness of two filters for Cryptosporidium slightly rippled beyond pH 8.7 and with the drop in pH up to pH 8.7, the removal efficiency of two filters for Giardia cysts slightly reduced from pH 2.4 to 8.7 and

decreased severely in pH as pH as pH up to 8.7. The semi-empirical single sphere model and clean-bed filtration theory were used to determine the experimental collision efficiencies from the interactions between colloids and the filter media. The outcomes also showed that oocysts display higher collision efficiency than cysts, with experimental collision efficiencies for (oo)cysts correlating to (oo)cysts removal efficiencies in all trials.

Khan et. al. (2011) focussed on effective water treatment is the prime goal of every water treatment facility. Chakwal Water Treatment Plant in Pakistan has been treating high-turbidity surface water through crude coagulation, sedimentation and slow sand filtration since the early 1980s. The process has always been tedious in terms of high coagulant dosage, large volumes of sludge and short filter runs especially after wet spells. A laboratory-scale study was conducted to see if roughing filtration, as the pre-treatment process, would help in reducing coagulant dose and sludge volume and improving effluent quality. Results indicated that up-flow rouging filtration with media grades decreasing in the direction of flow could reduce wet weather raw water turbidity (by more than 90%) and coagulant dose.

Gundry et. al (2004) examined the microbial pollution of home drinking water is linked to the frequency of certain illnesses in poor nations. Two health outcomes—general diarrhoea and cholera—and their connection to point-of-use water quality are the focus of this systematic study. Research of household water treatment and storage solutions are examined together with observational research looking into this link. There was shown to be a direct link between polluted water and cholera. Cholera was also reported to be decreased by home water treatment and storage treatments. No direct correlation between point-of-use water quality and general diarrhoea was discovered, despite the fact that interventions considerably decreased the frequency of diarrhoea. The reasons behind these seemingly incongruent results for general diarrhoea are examined, and recommendations for more study are made. Also explored are the findings' implications for policy.

Haque et. al. (2015) discussed an urban area, the water is supplied through centralised municipal tap water system. For the present enquiry, the municipal supply of water for drinking and sanitation purposes has been assessed in terms of its availability and accessibility to the people, possible sources of water contamination and related health issues in Kolkata. The relevant data have been accessed from various secondary sources where the published data from West Bengal Pollution Control Board (WBPCB) and Kolkata Municipal Corporation (KMC) are noteworthy. The data thus obtained have been assessed qualitatively to depict the ground reality on sanitation and health related issues. The analyses of the data reveal that in Kolkata, the availability of good quality drinking water is not sufficient as the supply is low and inadequate. On the other hand, the underground water which is considered as the alternative source to the people is found to be contaminated with heavy metals like arsenic and lead. The non-availability of sufficient water for drinking and sanitation purposes and consumption of contaminated water may result into poor health condition with various water borne diseases. The data on diseases from dispensaries (aided by KMC) in Kolkata has revealed that people with water borne diseases are significant in number where they are found to be affected with diseases like Acute Diarrheal Infection and Dysenteries. Some suitable measures have been proposed whereby applying those, the availability and accessibility of water for

drinking and proper sanitation could be enhanced and the occurrences of diseases might be avoided.

Mishra et. al. (2019) explained the Physico-chemical assessment of pollution of surface water of ghats along the bank of river Ganga in Varanasi. In this study they explained the important water quality parameters were temperature, pH, conductivity, total dissolved solid (TDS), acidity, chloride, total alkalinity, hardness, nitrate, phosphate, dissolved oxygen (DO), and biochemical oxygen demand (BOD). All four ponds site have objectionable water quality, especially with respect to human health, biotic life, and the entire ecosystem. The catchment area study to find out the major contributor to the deterioration in water quality of these ghats reveal various ritual activities, municipal wastewater, washing discharge of temple effluents, and animal waste.

Pettersson et. al. (2020) explained open storm water ponds have been frequently addressed as a method for treatment of stormwater since measurements show a considerable pollutant removal effect. Pollutant removal efficiency in two storm water ponds in Sweden is studied where field measurements of inflow and outflow pollutant loads for several successive storm events are described. Cumulative effects of inflow and outflow pollutant discharges are studied and for the outflow a strong correlation to constant outflow pollutant discharges appears that indicate an independence of inflow pollutant load for the two ponds. Hereby, it becomes possible to extrapolate the annual loads from the ponds to the receiving waters of studied pollutants. The specific pond area (m^2 /ha) is 20 times larger in one of the ponds, which affect the pollutant removal efficiencies. A comparison between specific pond area and pollutant removal efficiency gave that the removal efficiency increases up to a certain level of surface/impervious area, 250 m^2 /ha, and above this level the increase is not as significant as below. Another factor that has an impact on the removal efficiency is the pond geometry.

Nkwonta et. al. (2010) discussed on roughing filtration is an important pre-treatment process for wastewater, because it efficiently separates fine solid particles over prolonged periods, without the addition of chemicals. For this study, a pilot plant was designed at Delmas Coal Mine in the Mpumalanga province of South Africa. The design and sizing of the pilot plant was guided by Wegelin's design criteria. Gravel was used as a control medium because it is one of the most commonly used roughing filter media and because it was used in developing the criteria. We compared the performance of gravel as a filter medium to that of another locally available material, charcoal, for the removal of turbidity in wastewater. The pilot plant was monitored continuously for 90 days from commissioning until the end of the project. The overall performance of the roughing filter in turbidity removal, using gravel or charcoal, was considered efficient for the pre-treatment of waste water. Charcoal performed slightly better than gravel as a filter medium for the removal of turbidity, possibly because charcoal has a slightly higher specific surface area and porosity than gravel, which could enhance sedimentation and other filtration processes, such as adsorption, respectively.

Khan et. al. (2013) focussed on multi-compartment, horizontal flow roughing filter (HRF) was designed, constructed and operated to evaluate its effectiveness against high turbidity surface water with and without coagulation. The objective was to evaluate the efficacy of the HRF in removing turbidity, total organic carbon (TOC), total coliform and particulate matter. The HRF was operated at filtration rates of 1.3, 1.0 and 0.7 m/hr. At 0.7 m/hr, plain HRF (PRF) reduced turbidity by 35%, TOC by 31%, coliform by 90% and particles with average diameter >4 μm. For coagulated roughing filtration (CRF), the optimum alum dose of 110 mg/L (L100) was determined using jar tests. In-line, CRF of the raw water using 25% (L25) and 50% (L50) of

L100 reduced turbidity by 87 and 98%, respectively. TOC removal at L50 was 41% and total coliform removal up to 99%. CRF was more effective in removing particles with average diameter >1 μm. CRF did not only help attenuating the turbidity shock loads but also consistently produced high quality effluent of 5–10 NTU at 55 mg/L vs 176 mg/L used by the plant. Over 98% reduction in coliform and removal of most particles of >1 μm diameter demonstrated that CRF would also be effective in removal of protozoa such as Giardia.

Sphesihle et. al. (2016) discussed important to have an understanding of public perception and attitudes towards the surface water purification because of the fact that the success of any use and application depends on the acceptance of the public. . The system consisted of three compartments containing different sizes of gravel that served as the filter media. This was done in order to investigate the effect of varying filter media size on the performance of the horizontal roughing filtration system in treating pond water. The system had an adjustable manual valve used in varying the filtration rate. The impact of varying filtration rate on the performance of the horizontal roughing filtration system in treating greywater was also investigated.

CHAPTER: 3

THEORETICAL CONCEPTS ON WATER FILTRATION

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3.1. Filtration

The process of filtration consists of passing water through a granular bed, of sand or other suitable medium, at low speed. The media retains most solid matter while permitting the water to pass, and the filtrate from a filter performing well will be crystal clear with a turbidity of around 0.1 nephelometric turbidity units (NTU). Except for treatment of high quality ground waters, filtration almost always follows a clarification stage. Thus there is a trade-off between the performance of the clarification and the performance of the filters; the more effective the clarification the less the filters have to do and vice versa. In order to achieve the required quality of filtered water, filtration has to remove particles far smaller than the sizes of the openings between the filtering media.

Two types of filters are commonly used for treating municipal water supplies. They are

I. The slow sand gravity filters; and
II. The rapid sand gravity filters.

A third type of a rapid sand filter works under pressure and is known as a pressure filter. This type of filters are generally used for small plants, such as for individual industrial supplies, or for swimming pools; and are generally not adopted for treating large scale municipal supplies. The slow sand gravity filters often called slow sand filters are useful in the sense that they can remove much larger percentage of impurities and bacteria from the water, as compared to what can be removed by rapid sand gravity filters (often called rapid gravity filters). However, slow sand filters yield a very slow rate of filtration (about 1/30 th of that given by rapid gravity filters) and require large areas, and are costly.

3.2. Theory of Filtration

The filters, in fact, purify the water under four different processes. These processes or actions are summarised below

i. Mechanical straining:

The suspended particles present in water, and which are of bigger size than the size of the voids in the sand layers of the filter, cannot pass through these voids and get arrested in them. The resultant water will, therefore, be free from them. Most of the particles are removed in the upper sand layers. The arrested particles including the coagulated flocs forms a mat on the top of the bed, which further helps in straining out the impurities.

ii. Flocculation and sedimentation:

It has been found that the filters are able to remove even particles of size smaller than the size of the voids present in the filter. This fact may be explained by assuming that the void spaces act like tiny coagulation-sedimentation tanks. The colloidal matter arrested in these voids is a gelatinous mass and, therefore, attract other finer particles. These finer particles thus settle down in the voids and get removed.

iii. Biological metabolism:

Certain micro-organisms and bacteria are generally present in the voids of the filters. They may either reside initially as coatings over sand grains, or they may be caught during the initial process of filtration. Nevertheless, these organisms require organic impurities (such as algae, plankton, etc.) as their food for their survival. These organisms, therefore, utilise such organic impurities and convert them into harmless compounds by the process of biological metabolism. The harmless compounds so formed, generally form a layer on the top, which is called schmutzdecke or dirty skin. This layer further helps in absorbing and straining out the impurities.

iv. Electrolytic changes:

The purifying action of filter can also be explained by the theory of ionisation. According to this theory, a filter helps in purifying the water by changing the chemical characteristics of water. This may be explained by the fact that the sand grains of the filter media and the impurities in water, carry electrical charges of opposite nature. When these oppositely charged particles and the impurities come in contact with each other, they neutralise each other, thereby changing the character of the water and making it purer. After a certain interval, the electrical charges of sand grains get exhausted and have to be restored by cleaning the filter.

3.3. Types of granular filter

There are three basic types of granular filter. It is useful to understand the differences between them before discussing them in more detail. The types are

- Slow sand filters
- Rapid gravity filters
- Pressure filters

3.4. Slow sand filters

3.4.1. Introduction:

A slow sand filter is a type of water filtration system designed to remove impurities and contaminants from water through a biological and physical process. It's one of the oldest and most effective methods for purifying drinking water, often used in both small-scale and community water supply systems.

3.4.2. **Construction and Design:**

A typical slow sand filter consists of the following components:

- **Filter Bed:** This is the core of the system, consisting of several layers of sand with varying sizes. The filter bed is usually several feet deep.
- **Underdrain System:** Located at the bottom of the filter bed, this system collects the filtered water and directs it out of the filter.
- **Supernatant Water:** The layer of water above the filter bed.
- **Cover:** Often, a cover or a layer of clean water is maintained above the filter bed to protect it from contamination and debris.

3.4.3. **Operation:**

The slow sand filter operates at a low flow rate, typically between 0.1 to 0.5 gallons per minute per square foot of filter surface area. The key processes involved include:

- **Physical Filtration:** Larger particles and sediment are physically trapped in the sand bed.
- **Biological Filtration:** A layer of microorganisms, known as the "schmutzdecke," forms on the surface of the sand bed. These microorganisms break down organic matter and pathogens, contributing significantly to the purification process.

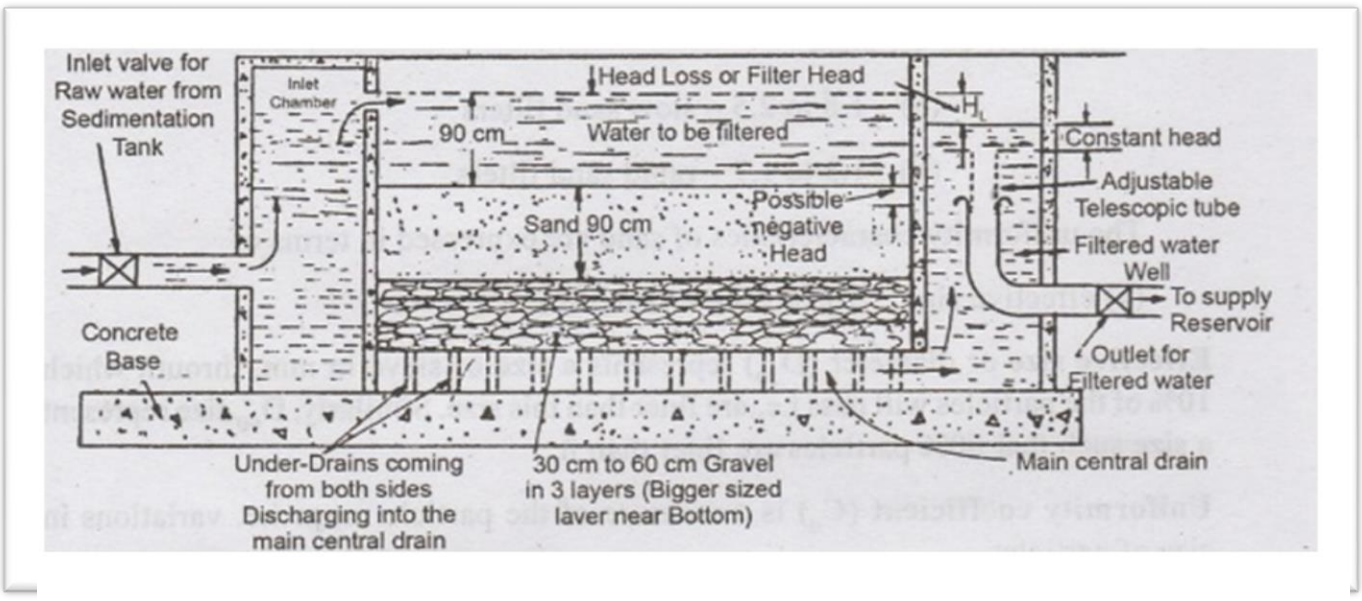


Figure 3.1 Typical section of Slow sand filter (Source: S. K Garg)

3.4.4. **Maintenance and Cleaning:**

- **Regular Inspection:** The filter bed should be inspected periodically for clogging and performance.
- **Backwashing:** Unlike rapid sand filters, slow sand filters do not typically undergo backwashing. Instead, they are cleaned by removing and replacing the top layer of sand, which accumulates the most contaminants.
- **Removal of Schmutzdecke:** In some cases, the schmutzdecke layer might need to be removed if it becomes too thick and starts to impede the flow.

3.4.5. **Advantages:**

- **Effective for Pathogen Removal:** Slow sand filters are highly effective at removing bacteria, viruses, and protozoa due to the biological activity within the filter bed.
- **Low Energy Requirements:** They operate without the need for high-pressure pumps, making them energy-efficient.
- **Simplicity:** The design and operation are straightforward, requiring minimal technical expertise.

3.4.6. **Limitations:**

- **Capacity and Flow Rate:** Slow sand filters have a lower flow rate compared to rapid sand filters and are thus less suitable for large-scale operations unless designed accordingly.
- **Clogging:** Over time, the filter bed can become clogged with particulates, necessitating periodic maintenance.

3.4.7. **Applications:**

- **Small Communities and Households:** Ideal for rural or small-scale applications where high-quality water is needed but resources are limited.
- **Emergency Situations:** Useful in disaster response scenarios where rapid deployment of water purification systems is necessary.

3.4.8. **Conclusion:**

Slow sand filters represent a reliable and sustainable method of water purification, particularly suited for applications where simplicity, effectiveness, and low energy consumption are essential. Their ability to produce high-quality water through a natural biological process makes them an invaluable tool in both developing and developed regions.

3.5. **Rapid sand filters**

3.5.1. Introduction

A rapid sand filter is an essential component in modern water treatment facilities designed to remove suspended solids and impurities from water quickly and efficiently. This type of filter is widely used in municipal water treatment plants to ensure the production of clean and safe drinking water.

3.5.2. Components and Structure

3.5.2.1. **Filter Tank**: The core of a rapid sand filter is a large, usually rectangular or cylindrical tank made of concrete or steel.

3.5.2.2. **Filter Media**: The tank is filled with layers of filtering media, typically composed of:

- **Coarse Sand**: The top layer is fine sand, which traps particles as water flows through.
- **Gravel Bed**: Below the sand, a coarser gravel layer supports the sand and helps with water distribution and flow management.

3.5.2.3. **Underdrain System**: At the bottom of the tank, an underdrain system collects the filtered water and ensures even distribution of the flow during backwashing.

3.5.2.4. **Influent and Effluent Channels**: These channels direct the incoming raw water to the filter bed and allow the filtered water to exit the system.

3.5.3. Operational Process

3.5.3.1. **Filtration**:

- **Water Inlet**: Raw water enters the filter tank and passes through the sand bed.
- **Particle Removal**: As the water moves through the sand, suspended particles are trapped by the sand grains, which removes contaminants from the water.

3.5.3.2. **Backwashing**:

- **Cleaning**: To remove accumulated debris and restore filter efficiency, the filter undergoes periodic backwashing. During this process, water flows in the reverse direction through the filter bed, lifting the sand and flushing out the trapped particles.

- **Maintenance**: Backwashing is crucial for maintaining the filter's performance and prolonging its lifespan.

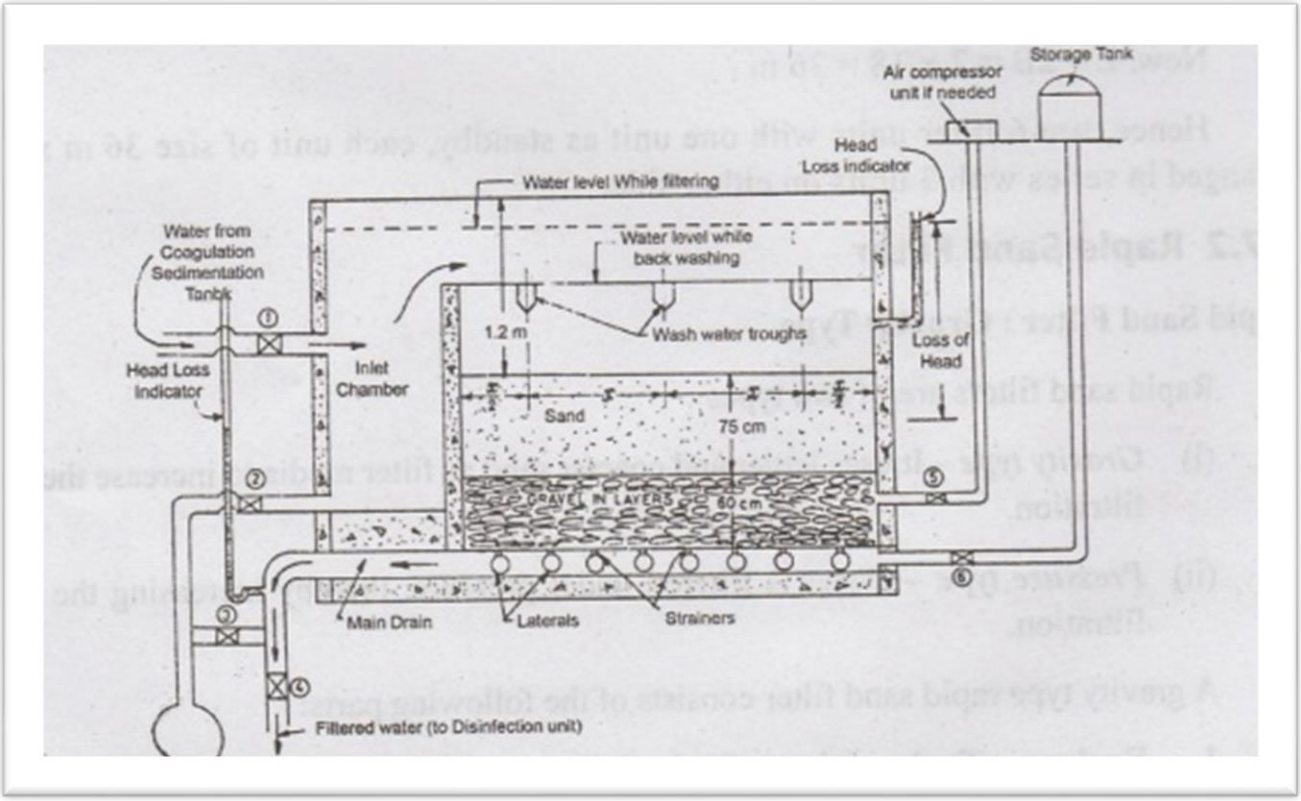


Figure 3.2 Typical section of Rapid sand filter (Source: S. K Garg)

3.5.4. Advantages:

- **High Flow Rates:** Rapid sand filters can handle large volumes of water quickly.
- **Compact Design:** They are more compact than slow sand filters, making them suitable for urban and high-demand settings.
- **Operational Efficiency**: They offer a good balance between filtration efficiency and operational simplicity, making them ideal for large-scale water treatment facilities.

3.5.5. Applications:

- **Municipal Water Treatment**: Commonly used in cities and towns to purify water for drinking and domestic use.
- **Industrial Processes**: Employed in various industries to ensure the quality of process water and protect equipment from particulate damage.

3.5.6. Conclusion:

Overall, rapid sand filters are an effective and efficient technology for large-scale water purification, balancing the need for high processing speeds with the ability to remove various contaminants.

3.6. Slow Sand Filters versus Rapid Sand Filters

The difference between these two types of filters are brought out in Table 3.1 (source: S. K Garg)

Sl. No	Items	**Rapid Sand Filtration**	**Slow Sand Filtration**
1	Improvement of water quality	With pre-treated water, filtrate quality is possible that has 1 NTU turbidity, 90% removal of coliforms, 50-90 %removal of cryptosporidium and Giardia cysts, 10 % removal of col our,5 % removal of total organic content.	With raw water, a filtrate quality impossible that has less than 1 NTU turbidity, 95 % removal of coliforms,99 % removal of cryptosporidium and Giardia cysts, 75 % removal of cColour10 % removal of total organic content.
2	Flow rate	Rate of filtration range between (3000-6000) $l/m^2/hr$.	Rate of filtration range between (100-200) $l/m^2/hr$.
3	Filtration medium	The effective size of sand is>0.55mm and the uniformity coefficient is between 1.2-1.6	Effective size of sand (0.15-0.35) mm and uniformity coefficient in between 3-5
4	Cleaning required	Cleaned through backwashing (using 2-5% of total filter water) and the process takes 15-30 min and a period of cleaning 1-3 days.	Frequency of cleaning (1-3) months.
5	Pre-treatment	Usually, necessary including coagulation and flocculation followed by sedimentation.	Plain sedimentation and roughing filters may be used to reduce the turbidity to below 20 NTU and Preferably below 5 NTU. Flocculation should not be used
6	Post-treatment	Chlorination is usually required.	Chlorination to be on the safe side
7	Filtration mechanism	Sedimentation, adsorption, straining, Chemical and microbiological processes.	Sedimentation, adsorption, straining, Chemical and microbiological processes.
8	Main filtering mechanism	Physical special adsorption	Micro bacterial
9	Principal Advantages	Substantially reduces pathogenic bacteria, viruses, and cysts, to	Relatively small and compact.

		produce potable water without further treatment. No machinery required.	
10	Principle Disadvantages	Can only effectively treat low turbidity Water.	Cannot produce potable water without further treatment. Backwashing water is required for cleaning the filter, this usually involves pumps.

3.7. Pressure filters

3.7.1. Introduction:

A pressure filter is a type of water filtration system designed to purify water by passing it through a filter medium under pressure. These filters are commonly used in various industries, including municipal water treatment, industrial processes, and wastewater management, due to their efficiency and high filtration rates.

3.7.2. Construction and Design:

Pressure filters generally consist of the following key components:

- **Filter Vessel:** A cylindrical or vertical chamber designed to withstand high pressure. It is usually made from materials like steel, fiberglass, or composite materials.
- **Filter Media:** The filtering medium placed inside the vessel, which could be sand, anthracite, granular activated carbon, or other materials, depending on the application.
- **Inlet and Outlet Ports:** Connections for inflowing and outflowing water. Water is introduced at the bottom or side of the filter and exits from the top or side.
- **Pressure Control System:** Includes gauges and valves to monitor and control the pressure within the filter.
- **Backwash System:** An integral part of pressure filters for cleaning the media. It typically involves reversing the flow of water to remove accumulated contaminants from the filter media.

3.7.3. Operation:

- **Filtration Process:** Water is pumped into the filter vessel under pressure, forcing it through the filter media. During this process, suspended solids and particulate matter are trapped within the media while the clean water exits the filter.
- **Pressure Maintenance:** The system operates at pressures typically ranging from 2 to 8 bar (30 to 120 psi), depending on the design and requirements.

- **Backwashing:** Periodically, the filter is backwashed to clean the media. This involves reversing the flow of water to dislodge and remove accumulated debris and contaminants from the filter media, restoring its efficiency.

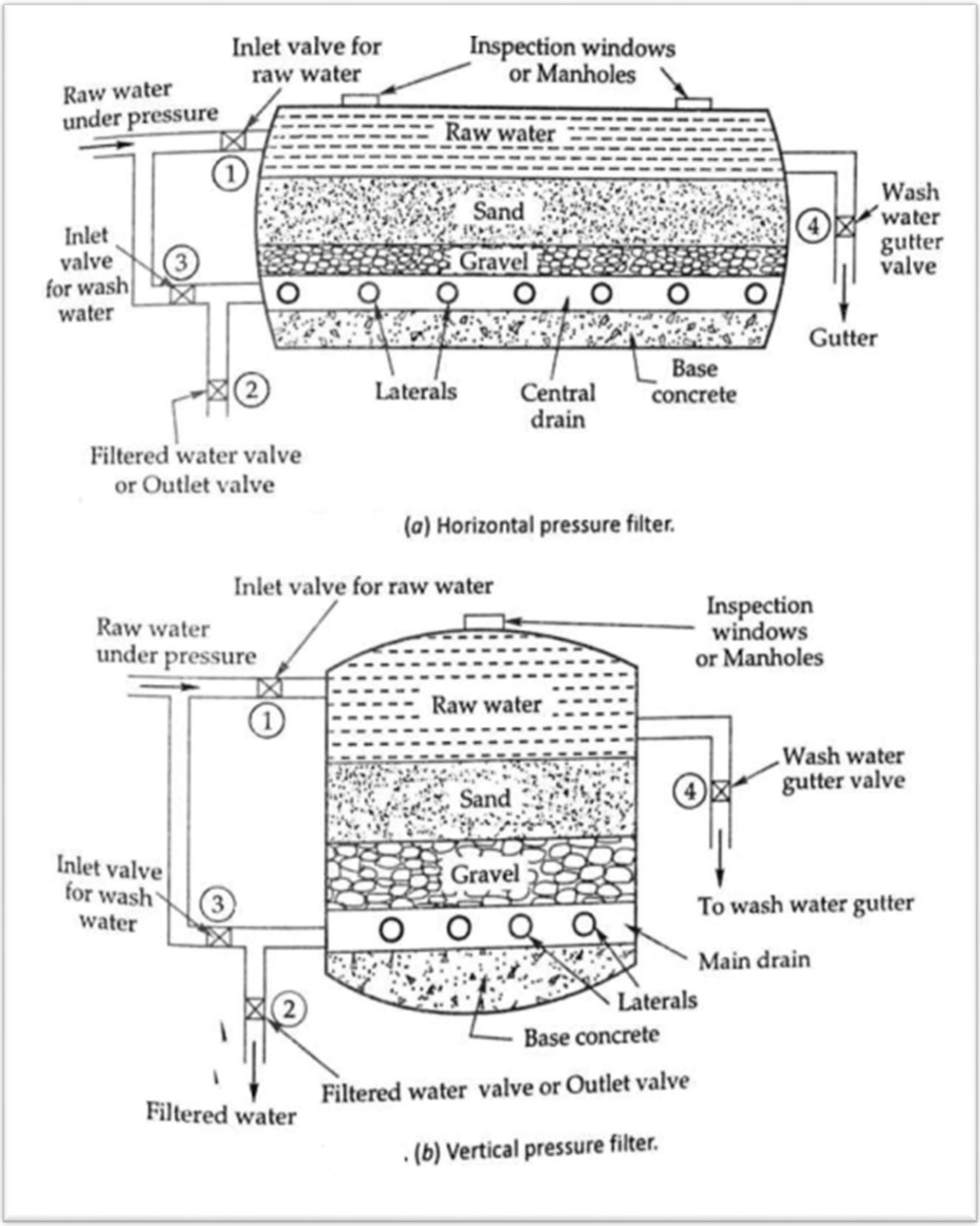


Figure 3.3 a) Horizontal pressure filter and b) Vertical pressure filter (source: S.K Garg)

3.7.4. **Advantages:**

- **High Flow Rates:** Pressure filters can handle large volumes of water and maintain a high flow rate, making them suitable for large-scale applications.
- **Compact Design:** Their vertical design and pressurized operation make them more compact and space-efficient compared to gravity filters.
- **Efficient Operation:** They offer effective filtration with less maintenance and operational complexity, thanks to their automated backwashing systems.
- **Versatility:** Capable of using various filter media to address different types of contaminants and water quality requirements.

3.7.5. **Limitations:**

- **Cost:** Pressure filters can be more expensive to install and maintain compared to simpler filtration systems due to their complexity and the materials used.
- **Energy Consumption:** Operating under pressure requires energy, which can increase operational costs, especially in large systems.
- **Maintenance Needs:** While generally efficient, pressure filters require regular maintenance and monitoring to ensure optimal performance and prevent issues related to clogging or pressure imbalances.

3.7.6. **Applications:**

- **Municipal Water Treatment:** Used for treating potable water in cities and towns to ensure safe drinking water.
- **Industrial Processes:** Employed in various industries to filter water used in processes, cooling systems, and product manufacturing.
- **Wastewater Treatment:** Utilized in wastewater treatment plants to remove suspended solids and improve water quality before discharge or further treatment.
- **Swimming Pools:** Used to maintain clean and clear water by filtering out debris and contaminants.

3.7.7. **Conclusion:**

Pressure filters are essential components in modern water treatment systems, offering high efficiency and effective filtration capabilities. Their ability to handle high flow rates and operate under pressure makes them a preferred choice for both large-scale and specialized filtration applications. Despite their higher initial costs and energy requirements, their performance and reliability often justify their use in demanding environments.

3.8. Other Types of Filters

The following two other types of filters are also used in certain special situations:

1. Roughing filters
2. Diatomaceous earth filters

3.8.1. Roughing filters

The slow sand filters normally yield a very small rate of filtration (100 to 200) litres per hour per sq. m) due to trapping of large amounts of suspended impurities. The rate of filtration of such filters can be considerably increased (almost doubled) by using a preliminary filter (a rapid gravity filter of a higher filtration rate) which is called the roughening filter. The raw water (generally without coagulants) is, therefore, first of all, passed through the roughening filter which partly removes impurities. The effluents are then passed through the ordinary slow sand filter, so as to get a good quality supply and also at a higher rate. The water is thus filtered twice.

The roughening filter is a rapid gravity filter, utilising coarser sand than what is used in an ordinary rapid gravity filter; thus giving a comparatively higher rate of filtration, of the order of 7000 litres per hour per sq. m. The roughening filter reduces the load on the slow sand filter, thereby increasing its filtration rate.

3.8.2. Diatomaceous Earth Filters or Diatomite Filters

This type of filters were basically developed by the Army for their field use to remove chlorine resistant dysentery cysts, and the cercariae of schistosomiasis which even passes through slow sand filters. They require very little space and hence can be used as portable units for field applications, or for industrial uses. They can also, though rarely, be used for treating municipal supplies for very small towns or colonies, besides their accepted use for swimming pools.

The filter Screen or Element consists of rigid cylindrical metal covered by a closely wound noncorrosive wire or fabric of metal, plastic or other material; or they may be cylinders of fused alumina or porous stone. While starting the operation of such a filter, a precoat layer of diatomaceous earth (diatomite) in the amount of about 0.3 kg/m² of filter area is allowed to get deposited on the filter screen to serve as an effective filter. The diatomite is kept in a precoat pot and raw water is allowed to enter through that pot. The diatomite mixed raw water, passing through the filter screen, will thus, help in providing a precoat layer of diatomite on the filter screen. The water coming out of the filter is wasted, till such a coating layer gets fully established on the filter screen or filter media. Thereafter, diatomite is added continuously as a slurry to the raw water to form a body coat. This keeps the mixture of turbidity etc. (removed from the water in filter) in porous condition, and allows longer runs between backwashings Body coat feed quantity is based on the turbidity present in raw water, and the diatomite used for this purpose may be about 2 to 3 mg/l per mg/l of turbidity contained in raw water. The raw water mixed with this quantity of diatomite is thus, allowed to pass through the filter element formed by the deposition of initial layer of diatomite on the filter medium/screen. Body coat, thus, helps in continuously building the filter, so that surface clogging is minimised. When

maximum pressure drop or minimum filtration rate is reached, the filter medium is backswashed by using filtered water by reversing the flow, discharging the dirty filter cake to wasted water. Backwashing may be done with or without the use of auxiliary water jets. Some manufacturers of such filters provide "air bumps" to dialodge the dirty material from the filter element. Runs between washings may vary from a few hours to several days, depending upon the characteristics (primarily turbidity) of raw water and operation skill used in back washings.

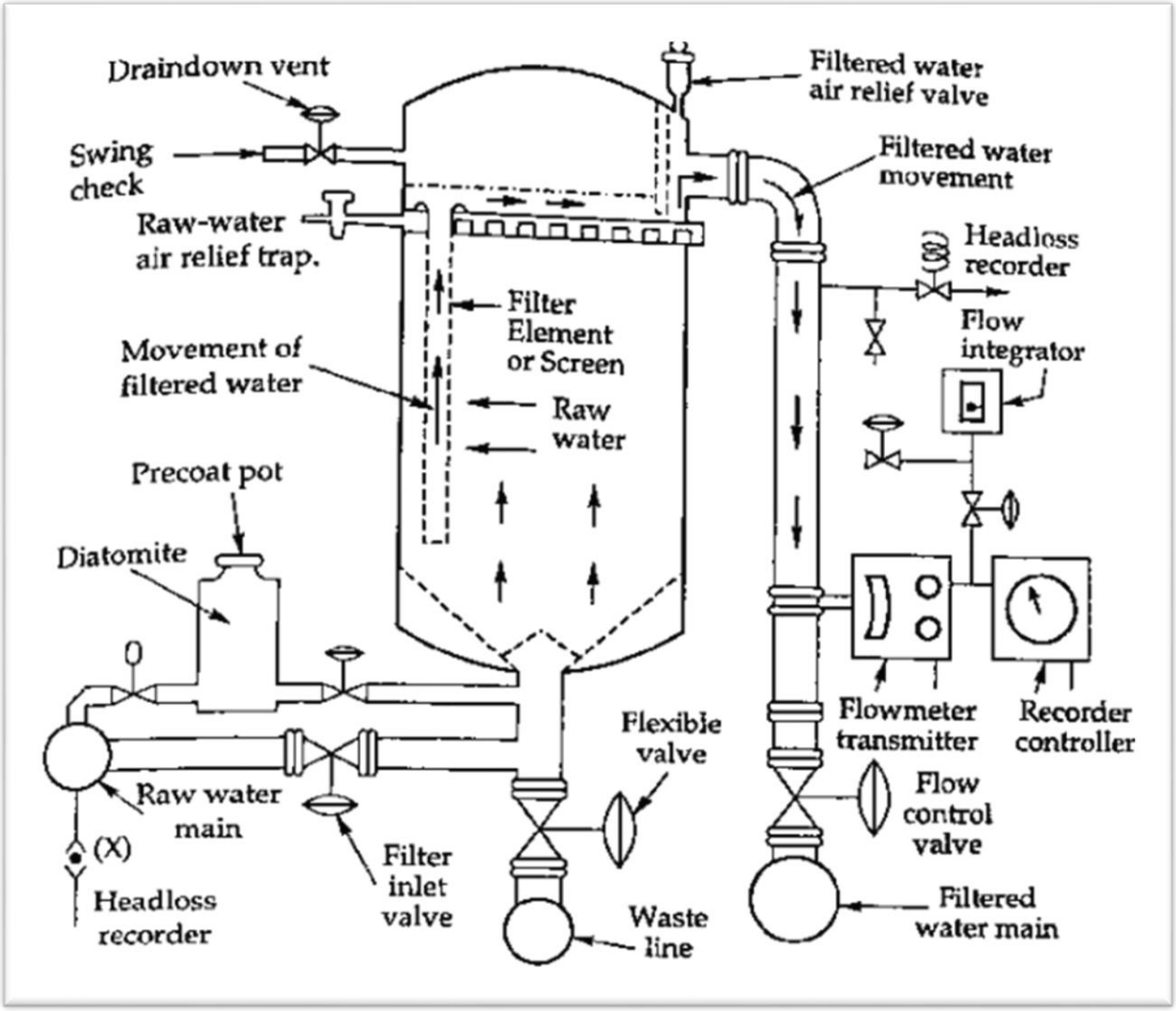


Figure 3.4 Schematic diagram of diatomite filter (source: S.K Garg)

Diatomite filters are not adapted to waters of high turbidity. The upper limit usually fixed on turbidity is 30 mg/l, although some what higher turbidities have been successfully treated. The raw water should also generally be chlorinated before application to the filter.

Most state Govts, and municipalities do not approve the use of such filters for public supplies, since there exists only a thin layer of diatomite on the filter element, and raw water might pass through. Moreover, only a metal wall separates the raw and filtered water, and there are chances of their mixing, particularly due to carelessness in backwashing of the filter unit.

3.9. Horizontal Roughing Filter

3.9.1. Introduction to Horizontal Roughing Filter

Water supply treatment plants generally use sand filters to produce clear water. Most sand filters have maintenance and operation problems due to lack of pre-treatment system for the reduction of turbidity and suspended solids. Gravel filtration has been used in water treatment since the early 1800s, when it was first used in Scotland to pre-treat water prior to sand filtration. Gravel filtration soon disappeared due to the advent of chemical and mechanical water treatment. However, gravel filtration merged in the 1970's and 1980's mainly in developing countries, because those roughing filters do not require sophisticated mechanical equipment or the use of chemicals (Cleary, 2005). Roughing filters are the most common type of pre-treatment system, which are used before slow sand filters in order to reduce the raw water turbidity and suspended solids (Wegelin, 1986; Ali, 1998; lngallinella et al., 1998).

Therefore, roughing filtration technology is used as pre-treatment to polish the raw water quality for the improvement of performance of slow sand filtration. But it may be used without slow sand filtration if raw water originates from well protected catchment area and having minor bacteriological contamination (Wegelin, 1996). Therefore in rural water supply systems roughing filtration becomes an appropriate technology. Besides that roughing filter can be maintained easily, does not need any ~ chemicals, has long operational time and can be operated and maintained by trained local caretakers (Wegelin, 1986).

3.9.2. Selection Criteria for Roughing Filter Application

Roughing filters are primarily used to separate fine solid matter which is only partly or not at all retained by grit chambers or sedimentation tanks. Roughing filters mainly act as physical filters and reduce the solid mass. However, the large filter surface area available for sedimentation, and the relatively small filtration rates also support adsorption as well as chemical and biological processes. Therefore, apart from solid matter separation, roughing filters also partly improve the bacteriological water quality and, to a minor extent, change some other water quality parameters such as colour or the amount of dissolved organic matter.

A great variety of different pre-filter types is available. Intake and dynamic filters, down-flow and up-flow roughing filters and finally horizontal-flow roughing filters makes the choice of the most appropriate pre-treatment method difficult. The selection of an adequate treatment scheme should be based on the following aspects:

- raw water characteristics
- type of surface water
- topography at the intake and treatment plant site
- operational aspects
- economic aspects

- **The raw water characteristics** determine to a large extent the type of pre-treatment to be applied. The variation of turbidity and of suspended solids concentration is thereby the most important required information. Average and maximum levels of turbidity and suspended solids concentrations, the settleability of the solids and the duration of peak concentrations are the most important raw water characteristics for the selection and

design of pretreatment units.

- **The type of surface water** also has a strong impact on the characteristics and amount of solids carried by the water. Small upland rivers, large lowland streams and stagnant surface water generally differ from each other. Small upland rivers draining erosion protected catchment areas are likely to have a small turbidity which, however, might increase to peaks of short duration during periods of heavy rainfalls. Such conditions favour the use of dynamic and intake filters. Large lowland streams are in general more turbid and change their quality only gradually following the annual climatic pattern. The use of roughing filters possibly combined with intake filters might represent an appropriate option for this situation. The suspended and colloidal matter as well as algae of a stagnant water source call for the application of probably fine graded roughing filters.

- **The topography** has to be taken into consideration especially in the layout of the water supply scheme. The location of the intake, the topographical conditions at that site and operational aspects are essential criteria for the conceptional layout of water supply schemes. Gravity schemes should be constructed whenever possible. This often requires remote intakes difficult to maintain. Nevertheless, favourable riverbed conditions should be used for the installation of intake and dynamic filters in order to reduce wastewater discharge problems at the treatment plant side, an aspect which needs careful attention with the use of roughing filters.

- **Operational and economic aspects** also influence the selection of the pretreatment scheme. Construction costs are related to operational costs and routine work increases the reliability of water treatment. Total costs might often be reduced through a sound treatment scheme design applying a sequence of different treatment steps. Routine maintenance work is essential for a good treatment plant performance.

Practical pilot plant tests are strongly recommended to evaluate treatment concepts. The design of treatment plants should not merely be based on the theoretical evaluation of the presented different criteria or on the application of general design guidelines and recommendations. This is applicable especially to large treatment schemes requiring considerable capital investments and where modifications cannot easily be realized at a later stage. Therefore, field tests with small pilot units are strongly recommended. Such tests should run over a year in order to cover the rainy as well as the dry season. The treatment plant design will certainly gain greater confidence if it is based on practical experience and on design values established by field tests.

3.9.3. Filter Materials

Graham (1988) described that filter material originally used in the roughing filter was gravel, later it was replaced by any inert, clean, insoluble and mechanically resistant material. Wegelin (1996) described that the filter material should have a large specific surface to enhance the sedimentation process in the roughing filter, and high porosity to allow the accumulation of the separated solids. According to Wegelin (1996), neither the roughness nor the shape or structure of the filter material have a great influence on the filter efficiency. Graham (1988) suggested that on the practical side, economic considerations besides availability of appropriate material are important factors in the selection of the filter media.

As filter media, gravel from a river bed or from the ground, broken stones or rocks from a quarry, broken burnt clay bricks, plastic material either as chips or modules, burnt charcoal and coconut fibre were used (Wegelin, 1996). In horizontal flow roughing filtration project implemented in Java, Indonesia, the coarse gravel fraction has been replaced by "injuk", a local palm fibre. Apparently, this fibre does not release taste or odour to the water. This interesting fibre might be a potential filter material due to its large specific surface area and high porosity (90-92%) which considerably increase retention time of the water in the filter and enhance filter efficiency (Graham, 1988).

3.9.4. Mechanisms of Removal in Roughing Filtration

The most influential mechanisms of removal in roughing filters are gravitational sedimentation, interception, and diffusion. The principle mechanism, as recognized by many authors, is gravitational sedimentation, where the settling velocity of the waterborne particle is greater than the hydrodynamic forces of the water flow.

Sedimentation and interception are most influential for particles greater than 1 µm, and the removal efficiency due to these mechanisms increases with increasing particle size (Collins et al., 1994b). Diffusion is the most influential removal mechanism for particles less than 1 µm, and the removal efficiency of diffusion increases with decreasing particle size (Collins et al, 1994b).

The roughing filter can be considered a sedimentation basin, where the filter media provides a large surface area and short settling distances for discrete and flocculant particle settling (Wegelin et al., 1986). In conventional sedimentation basins, particles have to reach a settling distance of 1 to 3 metres, whereas in roughing filters, the interstitial settling distance to the gravel surface is only a few millimetres (Wegelin and Schertenleib, 1993). Particles deposit onto media grains in dome-like formations. Eventually, particle accumulations drift and are allowed to migrate freely through the large pore spaces towards the bottom of the roughing filter (Boller, 1993). Thus most particle accumulation occurs in the bottom of the filter.

Compared to rapid filters with smaller media, roughing filters contain less collectors of a larger media size per unit volume, resulting in lower filtration efficiencies (Boller, 1993). Boller (1993) suggests that filter efficiencies similar to rapid filters can only be achieved in media less than 3 mm in diameter, where forces other than gravity become important. However, the advantage of the larger media in roughing filters is that it allows a higher probability of impaction, resulting in higher solids deposits. In addition, particles that are retained in solids deposits will act as additional collectors, increasing the interception of subsequent passing particles (Saidam and Butler, 1996). It is possible that as solids accumulate in the filter and interstitial pore space becomes smaller, interception and straining play an increasingly important role in removal (Saidam and Butler, 1996).

Furthermore, in rapid sand filters, the effects of van der Waals and double-layer forces on particle removal are more significant with decreasing media diameters and increasing particle diameters (Boller, 1993). However, in roughing filters with media diameters generally greater than 5 mm, these forces are negligible (Boller, 1993). Overall, although filtration is not as

efficient as rapid filters, solids storage capacity is much larger in roughing filters and headloss develops at a much lower rate, leading to very long filter run times (Boller, 1993).

The secondary mechanisms of particle removal in roughing filters are adsorption to biomass and biological degradation of captured particles (Schulz and Okun, 1984). Organic particles that are retained by the filter are assimilated into a sticky gelatinous biofilm on the media surfaces (Saidam and Butler, 1996). This sticky biofilm, otherwise known as zoogloea, further assimilates organic particles or adsorbs inert particles (Huisman and Wood, 1974). In fact, Collins et al. (1994b) found improved treatment with algae-ripened media compared to clean media. This suggests that the sticky nature of algae assists in particle attachment and solids retention.

It is important to note that, in absence of biomass, adsorption to clean media is not a significant mechanism in roughing filters. Wegelin (1996) found that removals were not greatly influenced by the surface properties of the filter media. This is confirmed by Mbwette 56 and Wegelin (1989) who found that the shape and surface texture of roughing filter media has a negligible influence on filtration coefficient.

3.9.5. Design Variables

The objective of a HRF design is the reduction of the suspended solids in the raw water from a certain, in many cases unknown concentration and hence assumed value, to a standard required by SSF. The characteristics of the raw water determine filter lay-out and its operation, whereas the required capacity only determines the cross-section area of the filter bed.

The following four design criteria have to be considered for HRF design:

1) The required effluent quality for a specific raw water quality in terms of separated suspended solids concentration ΔC in mg/1
2) The required daily output Q in terms of m^3/d
3) The required filter run period T_r in terms of weeks
4) The maximum allowable filter resistance ΔH in terms of cm.

The following four design variables determine the HRF 1ay-out:

1) The filtration rate V_p in m/h, which is the hydraulic load in m^/h on the filter's cross-section area in m^2
2) The individual sizes d_{gi} of the filter material in mm
3) The individual lengths I_{fi}, of each filter material in m
4) The cross-section area A of the filter in m^2

3.9.6. **Design Aspects**

HRF has to be dimensioned for extreme situations, i.e. for maximum suspended solids concentration in the raw water. As filter efficiency decreases with increasing filter load σ (g/1) defined as dry weight of accumulated solids (in g) per unit of filter volume (in 1), peak loads in the raw water should preferably be treated with a recently cleaned filter. The annual operational plan should therefore consider seasonal quality fluctuations of the raw water.

In order to guarantee an economic lay-out of HRF, moderately higher effluent concentrations of suspended solids might be permitted during extreme situations. Furthermore, the filtration velocity V_F can normally be increased when the mean suspended solids concentrations of the river water is moderate or low. Higher filtration rates permit smaller filter cross-sections although the filter length l_f may, as a consequence, have to be increased. The three design variables Vp, A and If are interrelated. An economic optimization of the filter bed volume by a variation of these three variables is possible within narrow limits only. The detention time of the water in the filter is one major operational filter characteristic since sedimentation remains the main process in HRF. However, a reduction of the filter run period T_r will not only reduce the required filter length 1_f but also the filter bed volume. Thus, economic filter optimization can more readily be achieved by a variation of T_r and l_f.

With respect to the grain size dg of the filter medium, one would primarily tend to use finer material as coarser filter aggregates have a lower efficiency. However, besides efficiency in the separation of suspended solids, other criteria such as final headloss H, filter run period T r and filter cleaning aspects have to be considered. With the use of only one fine filter material, it might be possible to pretreat the raw water sufficiently but at the expense of high head losses, short filter runs and difficulties in filter cleaning. Such problems arise with filter material of less than 4 mm in size. A graded filter bed with differently sized fractions overcomes the aforementioned difficulties.

$$Vf = \frac{Q}{H*W} = \frac{Q}{A}$$; V_f= 0.3 – 2 m/hr……eq.(4)

$$Vd = \frac{Qd}{L*W}$$; V_d= 60 -90 m/hr ……eq. (5)

Where,

V_f = filtration rate (m/hr)

V_d= drainage rate (m/hr)

The equation above to calculate the filtration rate Horizontal-flow Roughing Filter, by knowing the requirements of the two equations can be calculated the HRF dimension.

3.9.7. Height and width of HRF

Neither the height H nor the width W of a HRF are dependent on the raw water characteristics but are influenced by structural and operational criteria. The following aspects were taken into account for the recommendation of the respective dimensions:

- A convenient side walls height will allow for easier removal and refilling of gravel from and into the filter box respectively. In addition, a shallow height will also enable the construction of non-reinforced side walls and thus effectively reduce construction costs. On the other hand, too small structures require extensive land. Therefore, the height of the side walls should lie between 1.0 and 1.5 m.

  H_{max} = 1.5m

  $H_{Recommended}$ = 1- 1.5m

- The width (W) of a HRF depends on the required capacity of the treatment plant. In general, at least 2 HRF units should be provided in order to allow for treatment continuity during maintenance of any one unit. For hydraulic reasons and in order to limit the interruption period necessary for manual filter cleaning, the maximum width should not exceed 5 m, whereas the minimum width should be at least 1 m to ease cleaning.

W_{max} = 5m
$W_{recommended}$ = 1 – 4m

3.9.8. Factors Affecting Removal in Roughing Filters

The principal design parameters for roughing filtration are bed depth, filtration rate, and media size (Collins et al., 1994a). Generally, treatment performance increases with decreasing media size, increasing surface area, decreasing filtration rate, and increasing bed depth. In addition, the characteristics of the particulate matter, such as size and nature (organic or inorganic), have a significant influence on its removal in roughing filters. Bed depth is the most influential design variable (Collins et al., 1994b). As particles deposit in the filter bed, pore spaces become smaller and the solid deposits are subjected to higher shear forces, causing detachment and penetration of detached solids deeper into the filter bed. Thus, it is important to maximize the bed depth to capture particles that penetrate deeper into the filter. Filtration rate also has a significant influence on particle removal. Good removals in roughing filters are best achieved with low filtration rates (Boller, 1993). Boller (1993) suggests that low filtration rates are critical to retain particles that are gravitationally deposited or attached to the upper side of the media. It is important to maintain laminar flow conditions in the pores to limit the fluid shear stress on solids deposits. In Figure 3.5, Wegelin (1996) shows that removal efficiency increases with decreasing Reynolds Number (Re). For example, removal of turbidity was 40% at a Re of 8, whereas removal was greater than 80% at Re less than 3.

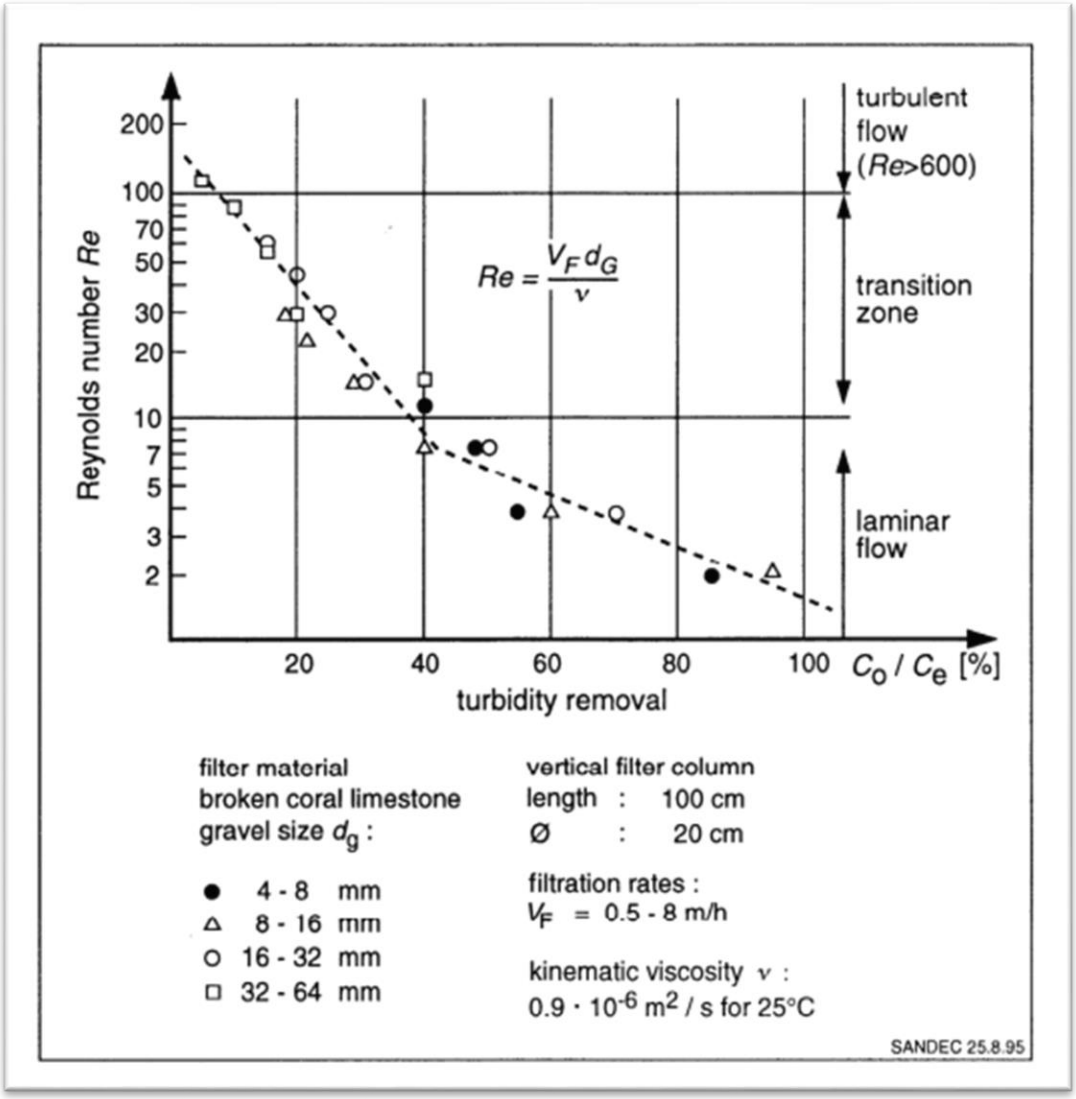


Figure 3.5 Removal Efficiency vs. Reynolds Number in Roughing Filters(Wegelin et al. (1986)

Furthermore, Wegelin et al. (1986) found that at increased filtration rates (2 m/h), coarse particles penetrated deeper into the bed, clogged the finer gravel media, and decreased the filter efficiency, resulting in more particle breakthrough. However, at 0.5 m/h, the bulk of the solid matter was retained by the coarse gravel, leaving the finer gravel sections unloaded. Whereas, at 1 m/h there was a good distribution of solids loading throughout the bed.

When treating high turbidity water, Wegelin (1983) found it necessary to use a filtration rate between 0.5 and 1 m/h to meet the influent requirements for slow sand filtration. In fact, a significant improvement in roughing filter removal efficiency was observed at filtration rates below 2 m/h, compared to over 2 m/h. In addition, Boller (1993) found that the removal of colloidal particles could only be achieved with filtration rates lower than 2 m/h, preferable lower than 1 m/h.

The media size is another important design variable. Gravity sedimentation on course media is more pronounced than in finer media, where a higher interstitial turbulence limits the gravitational accumulation of particulate matter (Clarke et al., 1996a).

Removal of particulate matter in roughing filters is also dependent on the particle characteristics. Thus, it is important to study the characteristics of the given source water when designing a roughing filter for a particular location. For example, Collins et al. (1994a) found that the removal of mineral particles (more dense, less sticky, and less uniformly sized particles) is most influenced by bed depth, followed by media size and filtration rate, in order of decreasing importance. Conversely, the removal of organic particles similar to algae (less dense, more sticky, more uniformly size particles) is most influenced by filtration rate, followed by media size and filter length in order of decreasing importance.

In addition, Collins et al. (1994a) found that sedimentation of particles was improved in the presence of "sticky" algal particles, which tend to aggregate with other particles and settle out faster. On the other hand, sedimentation of particles was compromised in the presence of stabilizing humic materials.

Furthermore, Wegelin et al. (1986) found that coarse particles are removed more efficiently and only smaller particles penetrate deeper into the roughing filter bed. However, near end of filter run, coarse particles penetrate deeper and smaller particles may breakthrough in the effluent.

The direction of flow can also have an impact on roughing filter performance. Particle trajectory models suggest that horizontal pores are more efficient particle collectors than vertical pores (Boller, 1993). In fact, particles 5 μm in diameter are three to four times more likely to become deposited in horizontal pores than vertical pores. Thus, it is suggested that horizontal filtration is more efficient than vertical filtration in sedimentation. In addition, Boller (1993) found that the use of smaller media (less than 4 μm in diameter) is not able to reach the same amount of solids deposits as larger media, without incurring a large headloss.

Finally, filtration efficiencies of roughing filters tend to decrease with time as particles are deposited in the filter, resulting in increased interstitial velocity due to decreasing pore space (Boller, 1993). In fact, the removal performance of roughing filters is constant until a critical solids deposit is reached, after which the filter coefficient decreases towards zero and may drop to negative values (Boller, 1993). Negative filter coefficient indicates a breakthrough or "washout" or solids in the effluent. Thus, roughing filters should not be operated past the point of critical solids deposit (Boller, 1993).

Overall, roughing filter performance depends on influent solids concentration, particle-size distribution, media size, bed depth, and filtration rate (Boller, 1993). Boller (1993) suggests that filter design becomes an "art" when attempting to determine the optimal combination of media size and bed depth for a particular source water. The ultimate goal of the design is to distribute the solids loading and headloss development evenly throughout the filter.

3.9.9. Cleaning of Roughing Filters

Roughing filters need to be periodically cleaned to remove accumulated particulate matter and replenish the solids storage capacity of the filter. Roughing filters are cleaned by opening a drain valve at the bottom of the filter and allowing the filter to drain freely under gravity, thereby flushing solids from the media. The height of roughing filters should be limited to 1.5 m to facilitate easy cleaning (Collins et al., 1994b).

A drainage velocity of 30 m/h (preferably 60-90 m/h) (Wegelin, 1996) is recommended to induce turbulent flow conditions in the media pores, thus dislodging solid deposits from the media. To achieve this drainage velocity, the difference in head between the initial water level in the roughing filter and the drain should be approximately 2.5 m (Galvis et al., 1998). In addition, the drainage pipes should be sized to allow the filter to drain at the recommended velocity. During draining, agitation and dislodgement of the solids can be aided by repeatedly opening and closing the drain valve to send pressure waves through the sand bed.

This method of cleaning has been proven effective, as recovery of initial filter headloss values is very good (Galvis et al., 1996). In fact, Galvis and Visscher (1989) found that cleaning of a roughing filter with a final headloss of 30 cm returned the headloss to 5 to 7 cm. Wegelin et al. (1986) found that filter drainage restores the filter efficiency to near the original value. Furthermore, Rajapakse and Ives (1990) found that draining the roughing filters twice resulted in the removal of greater than 70% of the deposited solids from the filter. Cleaning efficiency, however, can be hindered in filters that treat raw waters that are high in NOM (Collins et al., 1994b). This is most likely due to higher growth of sticky biomass and/or algae, which assist in the attachment and retention of solids on the media grains.

Collins et al. (1994b) examined the suspended solids concentration of the drainage water during filter cleaning. A large initial peak of suspended solids from accumulations in the bottom of the filter was followed by a second smaller peak due to flushing of the solids throughout the depth of the filter. Also, solids were more efficiently flushed from the finer gravel sizes, probably due to higher pore velocities.

The frequency of cleaning is dependent on the loading of particulate matter and biological activity in the filter (Wegelin, 1996), and there are no general recommendations available as water quality conditions are site specific. However, field experience shows that roughing filters are usually cleaned on a weekly to monthly basis. For example, Wegelin (1996) mentions that cleaning should occur once every one or two weeks during months of high precipitation and runoff, and once every one or two months during dry seasons. Generally, cleaning of roughing filters is not labour intensive. In fact, it is estimated that cleaning can take only 2.4 to 4.6 hours per m^2 of filter area per month (Galvis et al, 1996).

Another method of cleaning is the “upflow method” where an increased upward flow of water induces turbulent conditions in the interstitial pore space and dislodges deposited particles, flushing them from the media. This method is effective in removing solids from the filter, however it is more energy intensive due to pumping requirements. Thus, it may not be suitable for some rural areas where energy supply is limited.

3.10. PRACTICAL EXPERIENCES WITH ROUGHING FILTERS

In a study conducted in the Middle East, a pilot scale horizontal roughing filter was constructed for use in Al-Wehda water treatment plant which treats the raw water of Tigris River in AlKarradah in Baghdad city. The horizontal roughing filter design characteristics were 5.5 m length x 1 m width x 1 m depth with inlet and outlet weirs of lengths 0.5 m and 0.5 m, respectively. The filter had three compartments of 2 m, 1.5 m and 1 m length, filled with three different sizes of gravel from the first to the last compartment, 15 mm, 10 mm and 5 mm, respectively. The filter was continuously operated for 24 hours for a period of 3 months of 2007. In the first stage, raw water free from any addition was treated using three different flow rates, 1.3, 1.1 and 0.9 m3 /h. 27 Turbidity, S.S, temperature, pH and bacteriological tests were performed. The mean removal efficiency of turbidity for 1.3, 1.1 and 0.9 m3 /h was found to be 92%, 94% and 95%, respectively while in the second stage raw water with alum addition was used and the filter was operated with a filtration rate of 1.3 m/h. A high performance in turbidity removal of 97% was achieved (Nkwonta, 2010).

In Northern region Ghana (NRG), a pilot horizontal roughing filter at Ghanasco dam in Tamale was used to treat highly turbid dugout water of 305 NTU. The pilot horizontal roughing filter was run for the period of 52 days to test a pilot horizontal roughing filter effectiveness in reducing turbidity from 305 to a value of 50 NTU or less which would have met a criteria for a use of slow sand filtration possible. In this pilot study, a 7 m length horizontal roughing filter with three compartments was used. The compartments were filled up with granite gravel, local gravel and broken pieces of ceramic arranged in order of decreasing size. At a performance level, granite gravel was found to be the best performing media by achieving an average of 46% removal of the influent turbidity and the effluent turbidity of 51 NTU was achieved which is slightly above the 50 NTU value required. The filter coefficient was 0.002/min. The granite gravel removal of 46% was twice as much turbidity removal than plain settling which can only be 25% (Nkwonta, 2010).

In another study conducted in South Africa, Mpumalanga province, a pilot horizontal roughing filter was designed for use by Nkwonta and Ochieng (2009) at Delmas coal. Gravel was used as the filter media. The objective of the pilot horizontal roughing filter was to investigate the ability of removing magnesium and iron in acid mine water. The horizontal roughing filter was designed according to Wegelin design criteria. The filtration rate of 1 m/h was used in the horizontal roughing filter. The filter removed magnesium and iron by 52% and 72%, respectively.

In India a pilot scale horizontal roughing filter was constructed in Jadavpur University in the Department of Water Resources Engineering. The study aimed to investigate the possibility of using a horizontal roughing filter to treat wastewater. A horizontal roughing filter with three compartments was designed. The compartments were filled with gravel medium of average sizes of 12.5 mm in the first compartment, 7.5 mm in the second compartment and 2.5 mm in the third compartment. A 0.75 m/h flow velocity was selected and maintained throughout the filter. The filter was operated for the period of 70 days during dry and rain seasons. The influent raw water 28 used had a concentration of suspended solids in the range 40 -150 mg/l. The removal efficiency is summarized in Table 3.2.

Table 3.2: Filter removal efficiency (Nkwonta, 2010)

Effective size (mm)	Filtration velocity (m/h)	Length of compartment (m)	E-value (%)	Total E-value
5	0.75	0.45	21.3	0.026
10	0.75	0.45	19.6	
15	0.75	0.45	26.0	

Table 3.3 presents studies conducted on horizontal roughing filters by different researchers and the percentage removal of pollutants obtained. In the pilot study conducted by Pacini (2005), a percentage removal of 85% and 90% was obtained using a filtration velocity of 1.20 m/h for iron and manganese reduction. Jayalath (1994) however obtained 50% and 80% removal of coliforms and turbidity at a filtration rate of 1.5 m/h. In the other study conducted by Dome (2000), where a filtration velocity of 0.3 m/h was used and 95% and 90% for algae and turbidity removal, respectively in the waste water was achieved. The same percentage removal of algae and turbidity were also obtained in the study conducted by Ochieng et al. (2004) at a slightly reduced filtration velocity of 0.7 m/h, however, Mukhopadhay (2009) obtained a reduced percentage removal of 75% at the same filtration velocity of 0.75 m/h which is the same as that used in the study of Ochieng et al. (2004). Rabidra (2008), however obtained 95% removal for both turbidity and total suspended solids by maintaining 1 m/h filtration velocity.

Table 3.3: Studies on HRF by different researchers (Affam and Adlan, 2013)

Filtration Rates (m/h)	Parameters	Percentage Removed (%)	Reference
1.2	Iron and Manganese	85 and 95	Pacini (2005)
0.3	Algae and turbidity	95 and 90	Dome (2000)
1.5	Turbidity	90	Mahvi (2004)
0.75	Turbidity and algae	90 and 95	Ochieng et al. (2004)
1.8	Turbidity, TSS and coliforms	63.4, 89 and 94	Dastanaie (2007)
1.5	Coliforms and Turbidity	50 and 80	Jayalath (1994)
1.0	TSS and Turbidity	95 and 95	Rabindra (2008)
0.75	Turbidity	75	Mukhopadhay (2009)

CHAPTER: 4
METHODOLOGY

CHAPTER: 4

METHODOLOGY

4.1. Flow Chart

In this chapter, various activities of the study objectives are discussed. The various activities carried out in the study are shown through the flowchart.

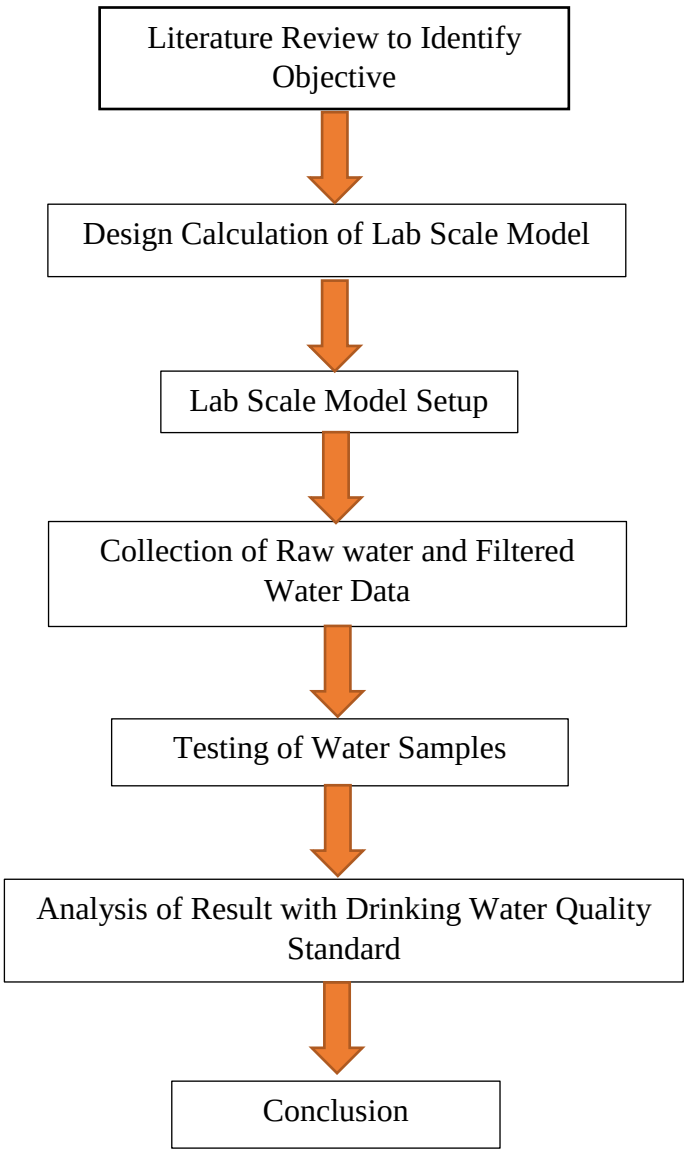


Figure 4.1 Flow chart of Methodology

4.2. Literature Review

Based on the literature reviewed, various research studies have indicated that roughing filters have the ability of reducing the turbidity and Suspended Solids. It also played a significant role in both Faecal and Total coliform reduction. It was also noted that HRF units also played a crucial role in both Iron and manganese reduction. Connecting the HRF units in series yielded very high efficiencies in terms of Turbidity and Suspended solids removal. Hence the current study investigates the performance and reliability analysis of Horizontal Roughing Filter in surface water treatment. The methodological approach to the study is presented on Chapter 4.

4.3. Lab Scale Model Setup

4.3.1. Overview of the Treatment Model

The design of this model was done based on the water quality analysis of surface water sources in geogenic contaminated rural areas. This multistage filter system, comprises of a combination of distinct treatment processes, for water purification and to ensure the delivery of safe drinking water (conforming to IS 10500:2012). This integrated approach involves several key components:

- **Horizontal Roughing Filter:** This initial stage of the filtration system involves passing raw water through a bed of coarse gravel and sand. It serves to remove larger particles, sediments, and turbidity from the water.

- **Step Aerator:** Following the roughing filter, the water enters a step aerator. This component introduces air into the water, which helps in the oxidation of certain impurities and improves the overall quality of the water.

- **Slow Sand Filter:** In this stage, the water passes through a bed of fine sand at a slow rate. The slow sand filter effectively removes smaller particles, pathogens, and microorganisms, providing additional purification.

- **Activated Carbon Filter: The** Activated carbon has a high adsorption capacity and is effective at removing organic compounds, taste, odor, and certain chemicals from the water.

- **Chlorine Dosing Tank:** The final stage involves the addition of chlorine to the water. Chlorine is a disinfectant that helps to kill remaining bacteria and pathogens, ensuring the water is safe for consumption.

This multistage filtration system combines various physical, chemical and biological processes to provide comprehensive water treatment.

4.3.2. Overview of the Treatment Process

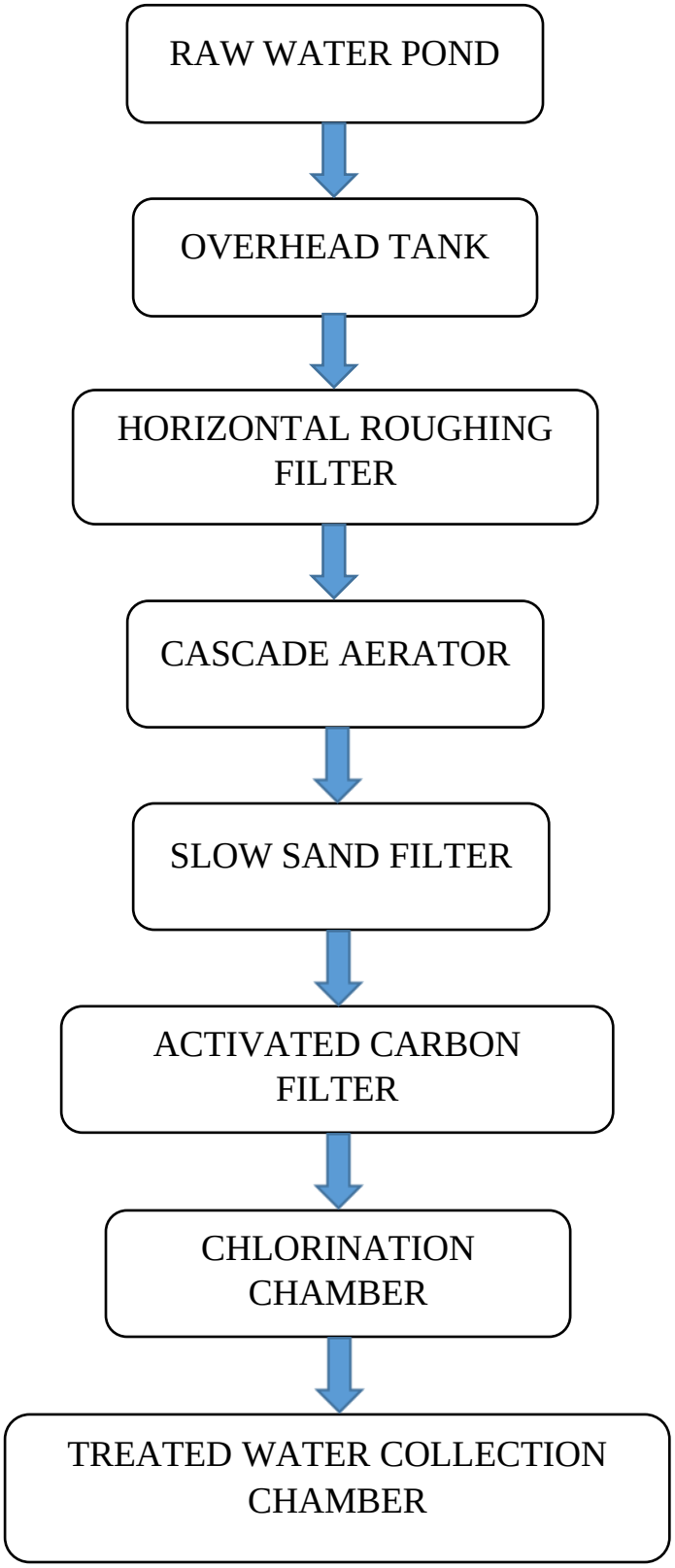


Figure 4.2 Filtration Process

4.3.3. Description of HRF Model

Three prototype HRFs was developed at the Department of Water Resources Engineering at Jadavpur University, Kolkata, India to examine the aim of the study is to performance and reliability analysis. The framework of HRFs was built out of acrylic sheets of 10 mm and each HRF comprised of four chamber each having dimensions as shown in figure 4.1. The overall length of the entire filter could be expanded in scale, and this would result in greater turbidity removal, henceforth reducing the particle storage capability of the chambers. As a result, flushing intervals would be exceedingly frequent. The research was conducted consistently for 90 days. Physical parameters like temperature, pH, TDS, turbidity, and DO were measured daily and chemical parameters like nitrate, phosphate, sulphate, iron, and ammonia were monitored twice weekly. The three HRFs were filled up with sand gravel (HRF1), a composite of gravel and granite chips in 1:1 ratio (HRF2) and only granite chips (HRF3). Each HRF consisted of 4 chambers having media size 10mm, 5mm, 3mm and 2mm respectively. The chambers have been marked as A (10mm), B (5mm), C (3mm) and D (2mm). Perforated acrylic sheets were used to divide each chamber so as to prevent the sand gravels from different chambers from mixing. The HRF filter bed was constructed with an under-drainage mechanism to allow flushing after a predetermined running time interval of 20 days for the extraction of the hydraulic sludge in the system. A flow rate of 7.5 l/hr (0.3m/hr) was kept consistently through the HRFs utilizing water from an overhead raw water tank. The water quality parameters of raw water for all the HRFs at the inlet of the system and the water quality parameters at the outlet was consistently measured using standard procedures as described in the Standard methods (Standard Methods for the Examination of Water, 2023). During a 90-day period, the experiment was conducted in both low flow (dry conditions) as well as high flow (monsoon conditions) conditions. Raw water was obtained from a nearby pond under natural circumstances.

4.3.4. Gravel Specification:

Gravel used in the bottom layer up to 0.07m of size varies from 4.75mm to 30mm. after sieving with a different sieve which is retained in 4.75mm and passing through 30mm sieve is used. At the bottom layer grave size 20-30 mm is used. in the 2^{nd} layer 10-20 mm is used then in the 3^{rd} layer 5-10 mm gravel size is used.

4.4. Experimental Design of Horizontal Roughing Filter:

Output Flow rate (Q_0) = 0.18 m^3/day = 0.0075 m^3/hr

Filtration Rate (Fr) = 0.3 m/hr = 0.3 - 1.5 m / hr (Range= 0.3 - 1.5) (Wegelin, 1996)

Required Filter Area = (Q_0 / Fr)

= (0.0075/0.3) m^2

= 0.025 m^2

Providing 3 chambers area of 0.025 m^2

Considered,

Filter Depth (d_f) = 0.17 m

Filter Width (W_f) = 0.025/0.17

= 0.147 m ~ 0.15 m

Considered four compartment of gravel size 10 mm, 5 mm, 3 mm and 2 mm are placed accordingly,

So, L_1 = 0.35 m for 10 mm Gravel

L_2 = 0.35 m for 5 mm Gravel

L_3 = 0.25 for 3 mm Gravel

L_4 = 0.25 m for 2 mm Gravel

So, Filter Length (L_f) = $L_1 + L_2 + L_3 + L_4$

= 1200 mm + 200 mm (inlet and outlet chamber)

= 1400 mm

= 1.4 m

Filter Depth (D_f) = 0.2 m

Average Drainage velocity (V_d) = 60 m/hr (range= 60 – 90 m/hr)

Drainage Rate (Q_d) = V_d x (d_f x W_f)

= (60 x 0.17 x 0.15) m^3/h

= 1.53 m^3/h

= 0.0255 m^3/min

For cleaning gravel of HRF 0.0255 m^3/min flow rate will be required

Now, Considered Head loss = 0.05 m

Total Depth of HRF (H_h) = h_h + Head loss + free Board

= 0.17 + 0.05 + 0.03

= 0.25 m

Roughing filter Dimension (L_h x W_h x H_h)

= (1.4 x 0.15 x 0.25) m for each chamber which include 4 compartments of different size of Gravel.

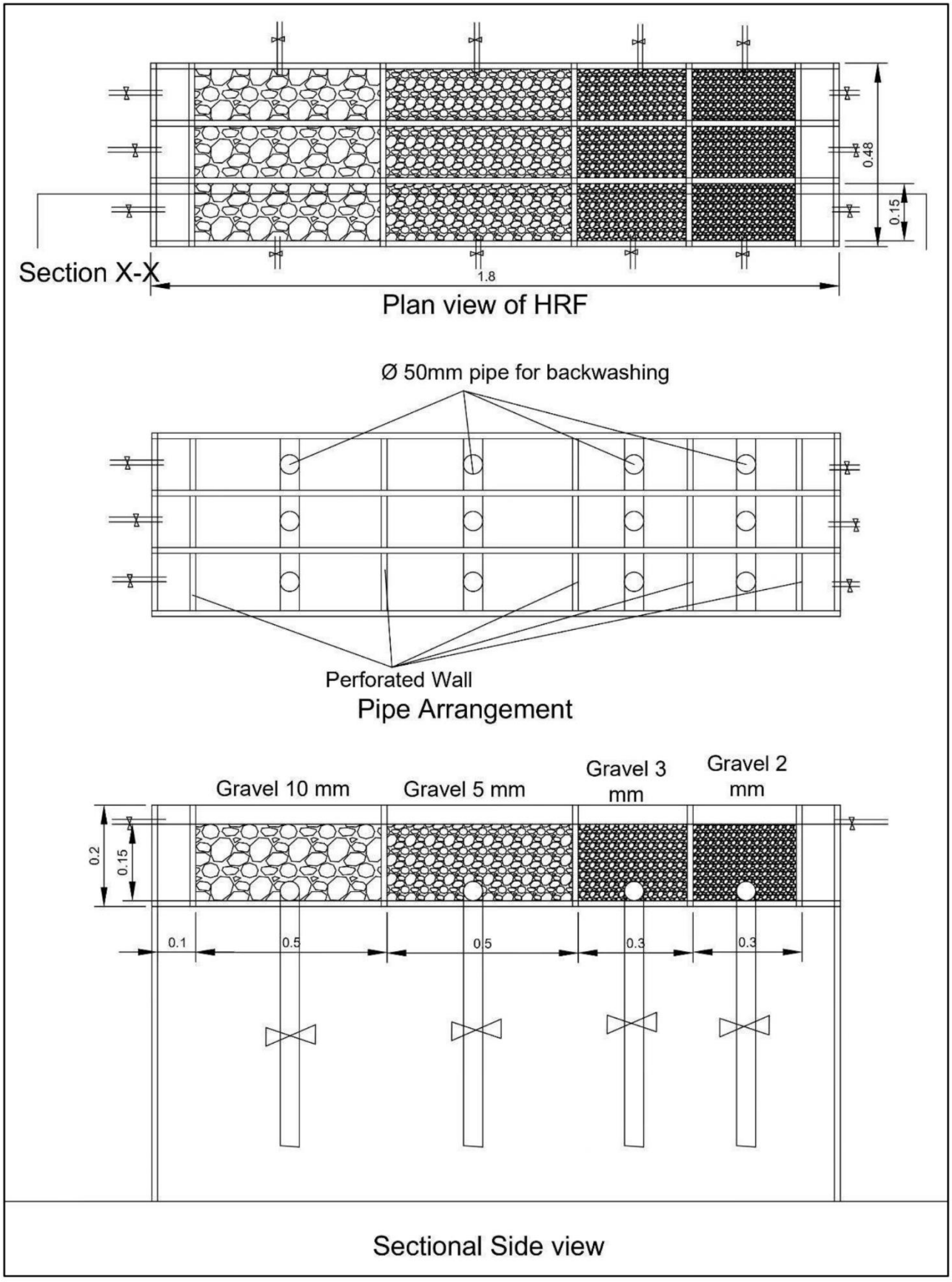


Figure 4.3 Detailed diagram of Horizontal Roughing Filter (source: working manual for MSF model)



Figure 4.4 HRF materials sieving and Filling



Figure 4.5 Raw water supply pump



Figure 4.6 HRF units are filled by appropriate materials

4.5. Filter run procedure

The inlet water management system consists of a 1-horsepower inlet pump positioned at a depth of one meter within the pond, two meters away from the pond's southern bank. Its role is pivotal in ensuring a continuous and reliable water supply. This pump is connected to an outlet pipe that directs the water flow into a 300-liter capacity overhead tank, which serves as the central storage reservoir for the supplied water.

The reassurance of this system lies in its full automation, which is achieved through the integration of sensors and controllers. When the water level within the overhead tank reduces, a signal is triggered by the sensor. This signal serves as a command to the controller system, causing the pump to start automatically. The pump draws water from the pond and channels it into the tank, refilling it to its optimal level.

Once the water level in the tank reaches its upper limit, a top-level sensor promptly detects this change. In response, the motor is automatically stopped, ensuring that the tank does not overflow. The overhead tank is also equipped with a mechanical overflow system to ensure safety from any unwarranted failure of electronic equipment.

In storage tank consists of 3 flow control valves which control the rate of flow. We collect water from three outlet of the HRF and test that water. The HRF outlet water dropped to Cascade Aerators then Slow Sand Filter and then passing by Activated Carbon Filter. After that chlorination is done for disinfection and store clear water tank for supply to consumers. It is a complete Setup of Multi-Stage Filter and I'm focusing on performance and reliability analysis of Horizontal Roughing Filter.

4.6. Sample collection

At inlet of HRF take the sample and determine water quality parameters. At various flow rate take the sample in three chambers. Each chambers has four sub parts and taking samples of each sub parts. The samples are taking two times in a day. Then check the physical and chemical parameters of water.



Figure 4.7 Sample Collection

4.7. Water quality test

The collected water samples underwent a rigorous testing process. Physical parameters, such as turbidity and temperature, were measured. Chemical composition, including pH, dissolved oxygen, and chemical contaminants, was analysed. Pesticide and Bacteriological levels in the water samples were also assessed. In order to ascertain the quality of water, it is subjected to various tests. These tests can be divided into the following three categories:

- **Physical tests**
- **Chemical tests**
- **Bacteriological test**

4.7.1. Physical Test

Under this category, tests are carried out to examine water from the following:

4.7.1.1. Temperature

The test for temperature of water has no meaning in the sense that it is not possible to give any treatment to control the temperature in any water supply project. The temperature of water to be supplied from storage reservoir depends on the depth from which it is drawn. The desirable temperature of potable water is 10°C while temperature of 25°C is considered to be objectionable.

The multiplication of bacteria in the waters is more rapid at higher temperatures than in the waters at lower temperature. Hence, when waters with a temperature of about 15°C are collected for bacteriological analysis, they should be cooled down as quickly as possible. It should further be remembered that the air temperature at the time of taking the water sample should always be recorded.

Test is conducted by HM-200 instrument.

4.7.1.2. Turbidity

The colloidal matter present in water imparts turbidity to water. The turbidity in water may also be due to clay and silt particles, discharges of sewage or industrial wastes, presence of large numbers of micro-organisms etc., and the cloudy appearance developed in water due to turbidity is aesthetically unattractive and it may also be harmful to the consumers.

The turbidity is expressed in terms of parts of suspended matter per million parts of water or shortly written as ppm. It is to be noted that the expression ppm is equivalent to mg per litre. The standard unit of turbidity is the form of finely divided silica in a million parts of distilled water. As per IS10500:2012 refer that the turbidity of drinking water should not be more than 5 NTU, and should ideally be below 1 NTU. Turbidity of the water is conducted by HACH 2100Q instrument is use. Figure 4.6 is depicted the instrument of HACH 2100Q.

Figure 4.6 Sample Testing



Figure: 4.8 HACH 2100Q Turbidity meter

4.7.2. Chemical tests

Under this category, tests are carried out to examine water for the following

4.7.2.1. Dissolved Oxygen

The water contains various gases from its contact with the atmosphere and ground surfaces. The usual gases are nitrogen, methane, hydrogen sulphide, carbon dioxide and oxygen. The contents of these dissolved gases in a sample of water are suitably worked out.

Oxygen in the dissolved state is obtained from atmosphere and pure natural surface water is usually saturated with it. The simple test to determine the amount of dissolved oxygen present in a sample of water is to expose water for 4 hours at a temperature of 27°C with 10% acid solution of potassium permanganate. The quantity of oxygen absorbed can then be calculated. This amount, for potable water, should be about 5 to 10 ppm. Dissolved Oxygen is measured by DO meter. The test is conducted by HACH HQ40d instrument.



Figure 4.9 Chemical Test of Samples



Figure 4.10 HACH HQ 40d

4.7.2.2. Hydrogen ion concentration (pH)

The acidity or alkalinity of water is measured in terms of its pH value or H-ion concentration. It is desirable to maintain pH value of water very close to 7. The acidic water causes tuberculation and the alkaline water causes incrustation. For potable water, the pH value should be between 7 and 8.50 Following are the two methods which are employed to measure the pH value of water:

- **Electrometric method:** In this method, potentiometer is used to measure the electrical pressure exerted by positively charged H-ions. The pH value is then correspondingly expressed. Instrument use for this test is HM-200.

4.7.2.3. Total dissolved solids

In this test, the amounts of dissolved in water is determined. The highest desirable level of total solids is 500 mg/l and its maximum permissible level is 2000 mg/l. TDS is measured by HM-200 instrument as shown in Figure 4.11.



Figure 4.11 HM-200

However, if the TDS level exceeds the acceptable limit but remains below 2000 NTU, it is considered permissible for drinking water purposes. TDS levels above this permissible limit may indicate a higher concentration of dissolved substances, which can affect the taste and quality of the water. To accurately measure TDS levels and determine compliance with these standards, the recommended testing procedure can be found in IS 3025 Part 16. This standard outlines the proper methodology and equipment to assess TDS levels in water, ensuring that the water meets the required quality standards for safe drinking water.

CHAPTER: 5

RESULTS & DISCUSSION

CHAPTER: 5

RESULTS & DISCUSSION

5.1. Turbidity Measurements and Interpolation

Raw water samples from a pond were collected and tested for turbidity over a period of 41 days. The measured turbidity values (in NTU) were recorded at regular intervals. Linear interpolation was applied to estimate turbidity values at intermediate points between actual measurements to provide a smoother representation of turbidity changes throughout the filtering process. The efficiency of turbidity removal was recalculated based on interpolated data points to ensure accurate estimation of performance at intermediate stages. The error between actual and interpolated turbidity values was evaluated to assess the accuracy of linear interpolation.

5.2. Raw Water From Pond

The Table 5.1 shows that the turbidity value of raw water is measured in the range of 12.40 NTU and 57.40 NTU. Now the turbidity value is calculated by linear interpolation for every four gap (yellow shade values in column 3 are taken as reference for linear interpolation). Interpolated turbidity value is in the range of 14.20 NTU and 40.10 NTU. The mean raw water turbidity measured value is 26.27 NTU where we get 24.64 NTU from interpolation, which is only 6.2% error. The standard deviation of interpolated value is only 6.66. Figure 5.1 shows that the visual representation of measured value and interpolated values according to successive days.

Table 5.1 Actual and Interpolated turbidities' Value of Raw Water

Day	Measured Raw Water Turbidity (NTU)	Interpolated Turbidity (NTU)	Difference Between Measured Turbidity and Interpolated Turbidity	Percentage error in Interpolated value w.r.t measured value
1	28.90	28.90	0.00	0.00
2	42.60	25.33	17.27	40.54
3	29.60	21.76	7.84	26.49
4	18.20	18.20	0.00	0.00
5	36.60	18.40	18.20	49.73
6	28.00	18.60	9.40	33.57
7	47.40	18.80	28.60	60.34
8	19.01	19.01	0.00	0.00
9	14.90	23.83	8.93	59.93
10	25.10	28.65	3.55	14.14
11	42.30	33.47	8.83	20.87
12	38.30	38.30	0.00	0.00
13	54.90	35.95	18.95	34.52
14	57.40	33.60	23.80	41.46
15	27.20	31.25	4.05	14.89
16	28.90	28.90	0.00	0.00
17	21.20	28.77	7.57	35.71
18	19.80	28.65	8.85	44.70
19	35.97	28.52	7.45	20.71
20	28.40	28.40	0.00	0.00
21	30.70	28.43	2.28	7.41
22	26.80	28.45	1.65	6.16
23	21.92	28.48	6.56	29.90
24	28.50	28.50	0.00	0.00
25	26.60	25.45	1.15	4.32
26	29.60	22.40	7.20	24.32
27	32.00	19.35	12.65	39.53
28	16.30	16.30	0.00	0.00
29	19.74	16.73	3.01	15.25
30	31.55	17.16	14.39	45.61
31	47.93	17.56	30.37	63.36
32	18.02	18.02	0.00	0.00
33	16.52	23.54	7.02	42.49
34	53.80	29.06	24.74	45.99
35	12.40	34.58	22.18	178.87
36	40.10	40.10	0.00	0.00
37	12.68	33.62	20.94	165.14
38	13.80	27.15	13.35	96.74
39	17.20	20.67	3.47	20.17
40	14.20	14.20	0.00	0.00
41	18.53	18.53	0.00	0.00
Mean	26.27	24.64	1.63	6.2
Standard Deviation	12.13	6.66		
Min	12.40	14.20		
Max	57.40	40.10		

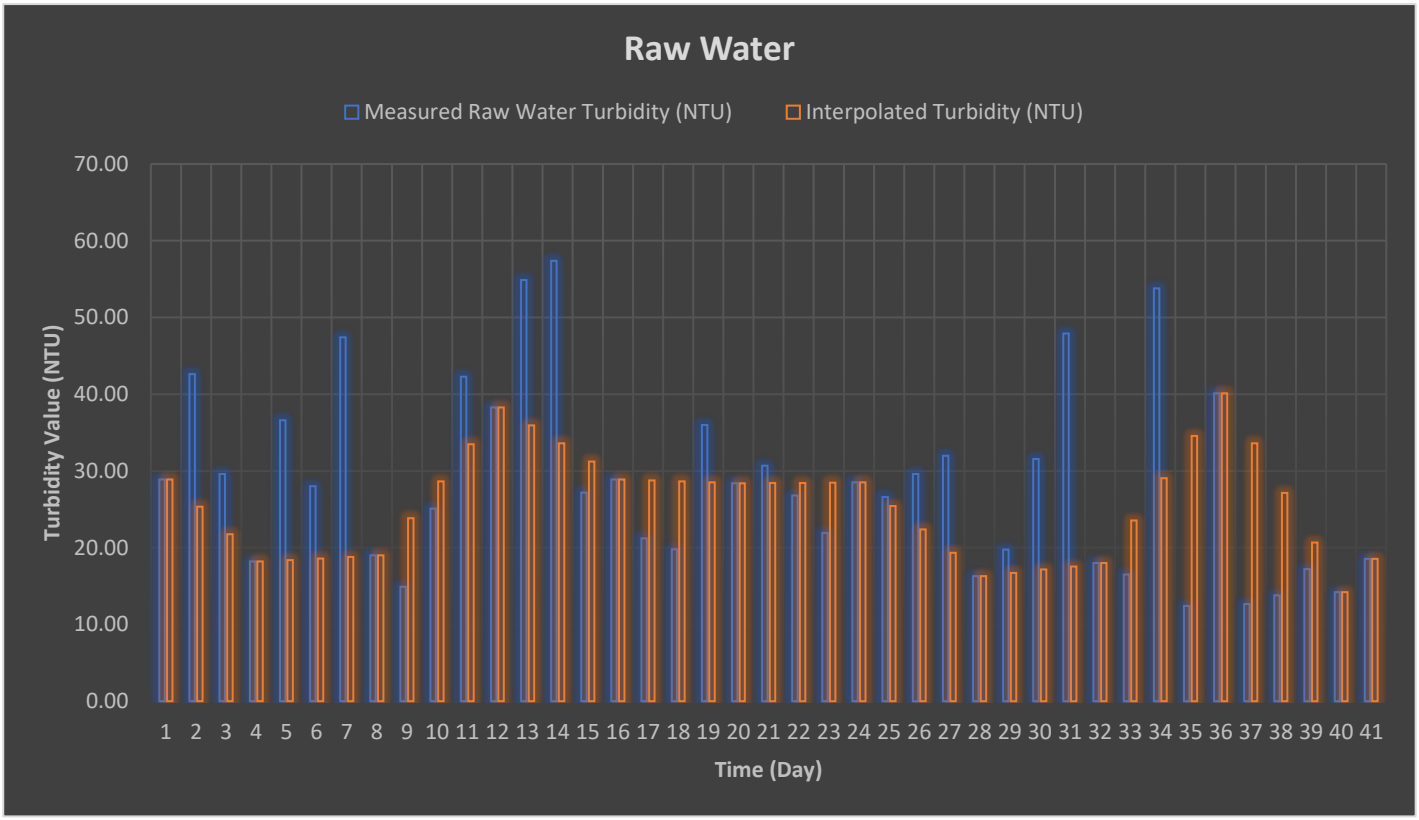


Figure 5.1 Variation of Measured and Interpolated Turbidities' Value

5.3. Sample from HRF Chamber 1

The Table 5.2 shows the values of Chamber 1 of HRF setup. The water is collected from HRF chamber 1. The measured maximum and minimum value is 20.32 NTU and 1.31 NTU respectively. Whereas the maximum and minimum value of interpolation is 14.33 NTU and 1.94 NTU respectively. The mean measured and interpolated turbidity value is 6.35 NTU and 5.62 NTU respectively. The mean error value is 11.33%. The standard deviation of interpolated value is only 3.01.

Table 5.2 HRF Chamber 1 Turbidity Values

Day	Measured Turbidity of HRF 1 (NTU)	Interpolated Turbidity (NTU)	Difference Between Measured Turbidity and Interpolated Turbidity	Percentage error in Interpolated value w.r.t measured value
1	14.33	14.33	0.00	0.00
2	20.32	12.20	8.12	39.96
3	13.59	10.07	3.52	25.90
4	7.95	7.95	0.00	0.00
5	16.40	7.80	8.60	52.43
6	11.82	7.66	4.17	35.24
7	17.30	7.51	9.79	56.60
8	7.36	7.36	0.00	0.00
9	5.54	7.78	2.24	40.43
10	8.18	8.20	0.02	0.24
11	12.52	8.62	3.90	31.15
12	9.04	9.04	0.00	0.00
13	12.02	8.33	3.69	30.70
14	11.25	7.63	3.62	32.18
15	5.55	6.93	1.38	24.86
16	6.23	6.23	0.00	0.00
17	4.73	6.42	1.69	35.69
18	4.71	6.61	1.90	40.23
19	9.30	6.79	2.51	26.99
20	6.98	6.98	0.00	0.00
21	7.27	6.80	0.47	6.44
22	6.12	6.63	0.51	8.25
23	4.89	6.44	1.55	31.70
24	6.27	6.27	0.00	0.00
25	5.80	5.48	0.32	5.52
26	6.15	4.68	1.47	23.90
27	6.30	3.89	2.41	38.25
28	3.10	3.10	0.00	0.00
29	3.67	3.01	0.66	17.98
30	16.43	2.93	13.50	82.17
31	7.92	2.85	5.07	64.02
32	2.77	2.77	0.00	0.00
33	2.35	2.22	0.13	5.53
34	6.48	2.77	3.71	57.25
35	1.31	3.32	2.01	153.28
36	4.96	4.96	0.00	0.00
37	1.76	4.20	2.44	138.64
38	1.96	3.45	1.49	76.02
39	2.57	2.69	0.12	4.67
40	1.94	1.94	0.00	0.00
41	14.19	14.19	0.00	0.00
Mean	6.35	5.62	0.72	11.33
Standard Deviation	4.79	3.01		
Min	1.31	1.94		
Max	20.32	14.33		

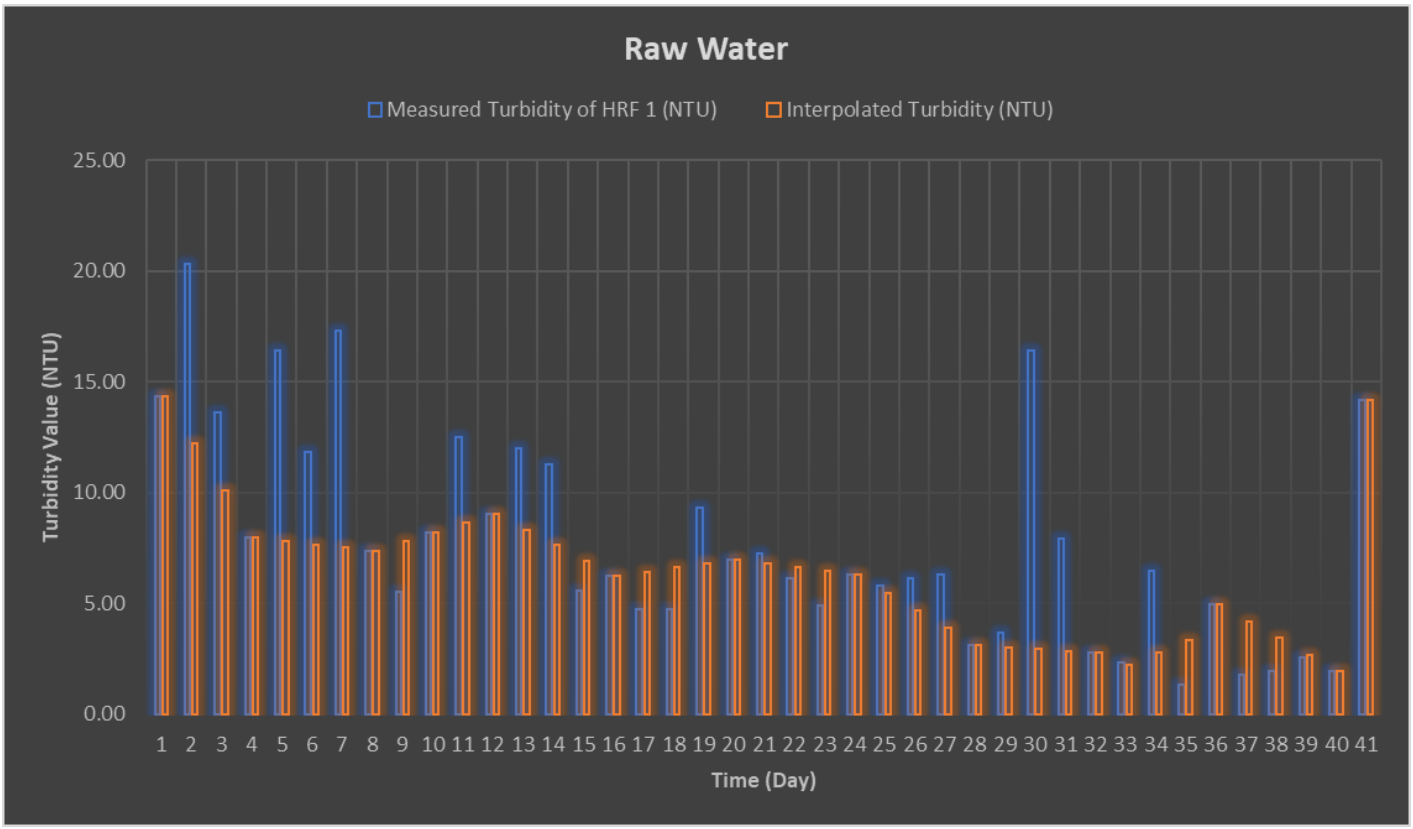


Figure 5.2 HRF Chamber 1 Turbidity variation

5.4. Sample from HRF Chamber 2

The Table 5.2 shows the values of Chamber 2 of HRF setup. The water is collected from HRF chamber 2. The measured maximum and minimum value is 21.44 NTU and 1.66 NTU respectively. Whereas the maximum and minimum value of interpolation is 14.84 NTU and 2.18 NTU respectively. The mean measured and interpolated turbidity value is 7.18 NTU and 6.39 NTU respectively. The mean error value is 11%. The standard deviation of interpolated value is only 2.99.

Table 5.3 HRF Chamber 2 Turbidity Values

Day	Measured Turbidity of HRF 2 (NTU)	Interpolated Turbidity (NTU)	Difference Between Measured Turbidity and Interpolated Turbidity	Percentage error in Interpolated value w.r.t measured value
1	14.84	14.84	0.00	0.00
2	21.44	12.77	8.67	40.44
3	14.76	10.71	4.05	27.44
4	8.65	8.65	0.00	0.00
5	17.82	8.43	9.39	52.69
6	12.97	8.22	4.75	36.62
7	20.08	8.01	12.07	60.11
8	7.80	7.80	0.00	0.00
9	5.98	8.41	2.43	40.64
10	9.50	9.02	0.48	5.05
11	14.23	9.63	4.60	32.33
12	10.24	10.24	0.00	0.00
13	13.46	9.53	3.93	29.20
14	13.39	8.82	4.57	34.13
15	6.62	8.10	1.48	22.36
16	7.39	7.39	0.00	0.00
17	5.67	7.49	1.82	32.10
18	5.45	7.60	2.15	39.45
19	10.67	7.71	2.96	27.74
20	7.82	7.82	0.00	0.00
21	8.14	7.55	0.59	7.25
22	6.79	7.28	0.49	7.22
23	5.39	7.01	1.62	30.06
24	6.74	6.74	0.00	0.00
25	6.32	5.95	0.37	5.85
26	6.75	5.15	1.60	23.70
27	7.05	4.36	2.69	38.16
28	3.57	3.57	0.00	0.00
29	4.17	3.51	0.66	15.83
30	18.64	3.45	15.19	81.49
31	9.27	3.39	5.88	63.43
32	3.34	3.34	0.00	0.00
33	2.88	3.83	0.95	32.99
34	8.24	4.33	3.91	47.45
35	1.66	4.82	3.16	190.36
36	5.32	5.32	0.00	0.00
37	1.97	4.53	2.56	129.95
38	2.30	3.75	1.45	63.04
39	3.09	2.96	0.13	4.21
40	2.18	2.18	0.00	0.00
41	13.95	13.95	0.00	0.00
Mean	7.18	6.39	0.79	11
Standard Deviation	5.18	2.99		
Min	1.66	2.18		
Max	21.44	14.84		

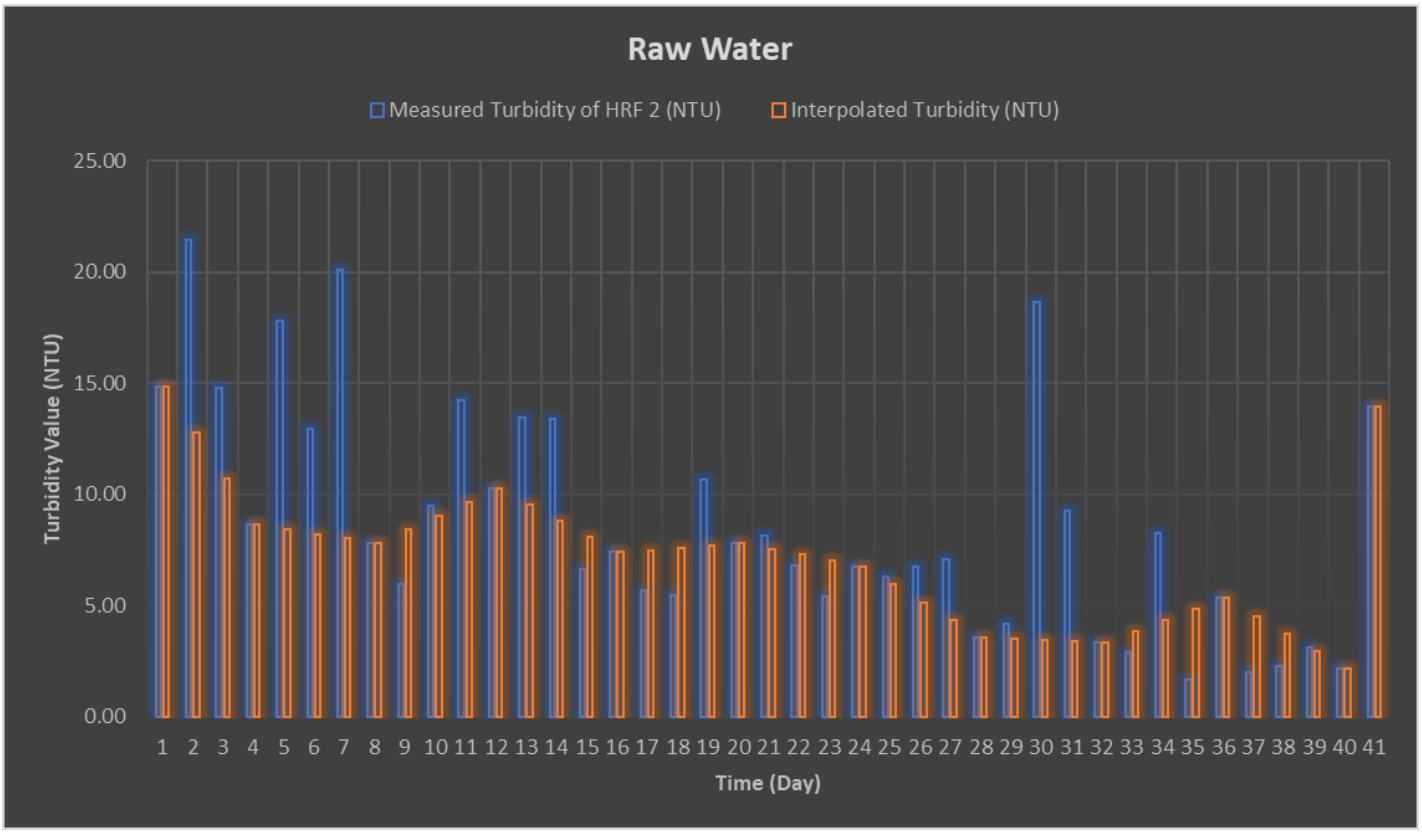


Figure 5.3 HRF Chamber 2 Turbidity Variation

5.5. Sample from HRF Chamber 3

The Table 5.4 shows the values of Chamber 3 of HRF setup. The water is collected from HRF chamber 3. The measured maximum and minimum value is 23.52 NTU and 2.02 NTU respectively. Whereas the maximum and minimum value of interpolation is 16.59 NTU and 2.94 NTU respectively. The mean measured and interpolated turbidity value is 8.35 NTU and 7.45 NTU respectively. The mean error value is 10.77%. The standard deviation of interpolated value is only 3.40.

Table 5.4 HRF Chamber 3 Turbidity Values

DAY	Measured Turbidity of HRF 3 (NTU)	Interpolated Turbidity (NTU)	Difference Between Measured Turbidity and Interpolated Turbidity	Percentage error in Interpolated value w.r.t measured value
1	16.29	16.29	0.00	0.00
2	23.52	14.11	9.41	40.01
3	16.19	11.94	4.25	26.25
4	9.76	9.76	0.00	0.00
5	19.42	9.54	9.88	50.88
6	14.66	9.32	5.34	36.43
7	22.93	9.11	13.82	60.27
8	8.89	8.89	0.00	0.00
9	6.71	9.76	3.05	45.45
10	10.83	10.64	0.19	1.75
11	16.28	11.52	4.76	29.24
12	12.39	12.39	0.00	0.00
13	15.79	11.47	4.32	27.36
14	15.81	10.55	5.26	33.27
15	8.07	9.63	1.56	19.33
16	8.71	8.71	0.00	0.00
17	6.68	8.78	2.10	31.44
18	6.41	8.85	2.44	38.07
19	12.14	8.92	3.22	26.52
20	8.99	8.99	0.00	0.00
21	9.32	8.77	0.55	5.90
22	7.97	8.55	0.58	7.28
23	6.22	8.33	2.11	33.92
24	8.11	8.11	0.00	0.00
25	7.30	7.10	0.20	2.74
26	7.79	6.09	1.70	21.82
27	8.36	5.08	3.28	39.23
28	4.08	4.08	0.00	0.00
29	4.56	4.00	0.56	12.28
30	21.45	3.94	17.51	81.63
31	10.71	3.86	6.85	63.96
32	3.79	3.79	0.00	0.00
33	3.45	4.45	1.00	28.99
34	9.98	4.91	5.07	50.80
35	2.02	5.46	3.44	170.30
36	6.02	6.02	0.00	0.00
37	2.39	5.25	2.86	119.67
38	2.79	4.48	1.69	60.57
39	3.80	3.71	0.09	2.37
40	2.94	2.94	0.00	0.00
41	16.59	16.59	0.00	0.00
Mean	8.35	7.45	0.90	10.77
Standard Deviation	5.78	3.40		
Min	2.02	2.94		
Max	23.52	16.59		

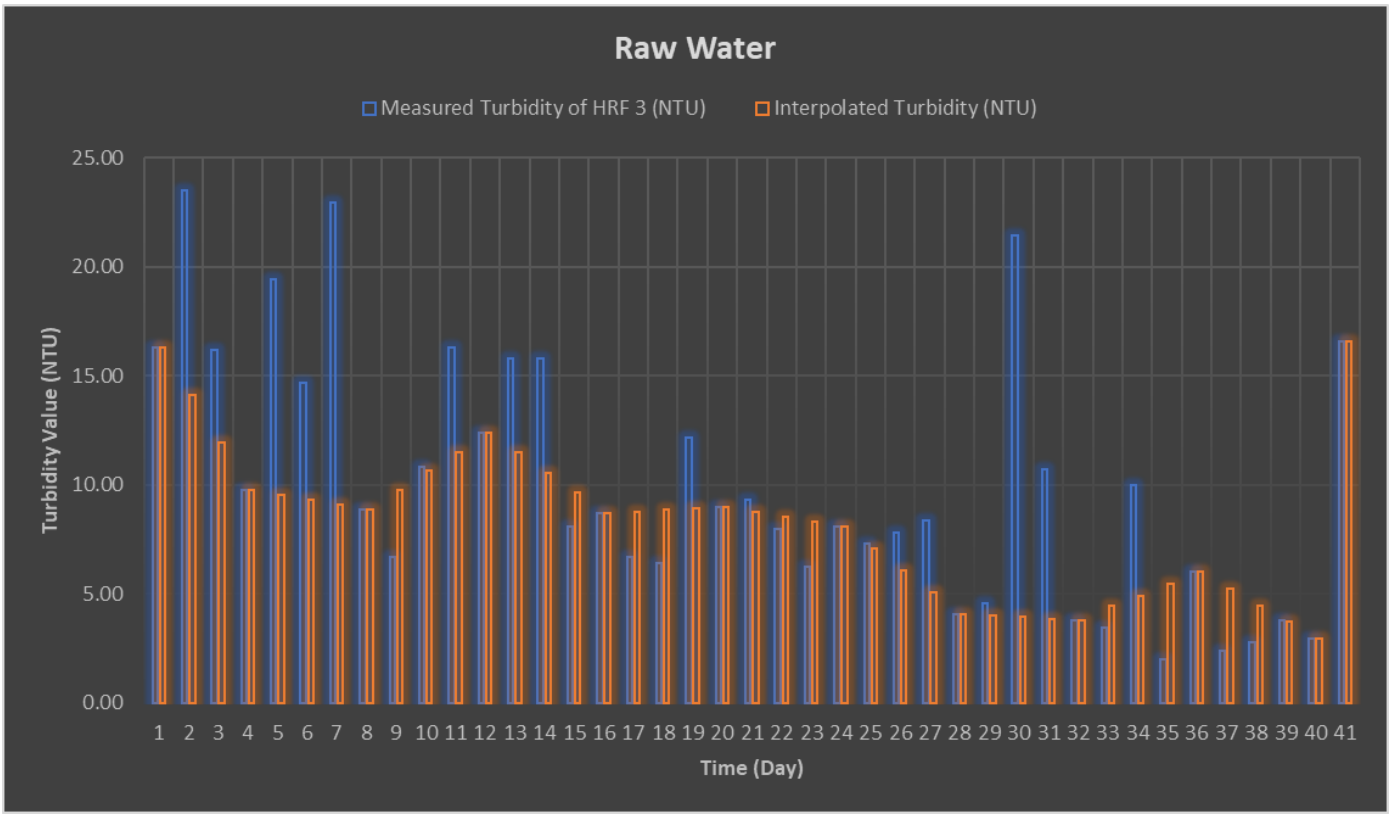


Figure 5.4 HRF Chamber 3 Turbidity Variation

5.6. Comparison Between Actual and Interpolated Data

The results indicate a high degree of agreement between the actual turbidity removal data and the interpolated estimates. The error in average turbidity value derived from interpolated data is 9.8%, which is very close to that of the actual data. The minor discrepancies observed can be attributed to the inherent variability in turbidity removal efficiency due to experimental conditions or measurement errors.

5.7. Error Analysis

The low percentage error value reflect that linear interpolation is a suitable method for estimating turbidity levels when direct measurements are sparse. These errors are relatively minor, suggesting that the interpolated data is a reliable representation of the actual turbidity levels. However, it's important to note that while linear interpolation works well for gradual changes, more complex interpolation methods might be needed for highly variable data or when the actual turbidity reduction behavior deviates from linearity.

CHAPTER: 6

CONCLUSION

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CONCLUSION

This thesis provides a comprehensive analysis of the effectiveness of a horizontal roughing filter (HRF) in removing turbidity (82.92%) from water at Jheel of Jadavpur University and evaluates the reliability of linear interpolation for estimating missing turbidity data. The experimental results confirm that the HRF is proficient in reducing turbidity, demonstrating significant improvements in water clarity through its filtration process. The performance of the HRF varies with initial turbidity levels, highlighting the importance of optimizing filter conditions to achieve the best possible results. In addressing the issue of missing data, linear interpolation was utilized to estimate turbidity values for gaps in the dataset. The analysis of interpolated values compared to actual measurements indicates that linear interpolation is a viable and effective method for estimating missing turbidity data. The percentage errors observed (9.825%) were generally within acceptable limits, suggesting that linear interpolation provides a reliable approximation for incomplete data points in turbidity studies.

6.1. Future scope of the study

Building upon the findings of this study, several future research and development in the field of turbidity removal and data analysis emerge:

1. **Optimization of Filter Design**: Future studies could explore modifications to the horizontal roughing filter (HRF) design to enhance its turbidity removal efficiency. This includes experimenting with different filter media, configurations, and flow rates to optimize performance across a wider range of water quality conditions.
2. **Integration with Advanced Technologies**: Investigating the integration of HRFs with advanced filtration technologies, such as membrane filtration or advanced oxidation processes, could offer a more comprehensive solution for turbidity and contaminant removal. Hybrid systems could potentially provide superior water treatment outcomes and address a broader spectrum of water quality issues.
3. **Performance Under Variable Conditions**: Additional research could examine the performance of HRFs under varying operational conditions, including different types of influent water quality, temperature fluctuations, and flow rates. Understanding how these variables affect filter performance could lead to more adaptable and robust filtration systems.
4. **Cost-Benefit Analysis**: Future research could focus on conducting a detailed cost-benefit analysis of implementing HRFs compared to other turbidity removal technologies. This includes evaluating initial costs, operational expenses, and maintenance requirements to determine the most cost-effective solution for various applications.
5. **Environmental Impact Assessments**: Investigating the environmental impact of HRFs, including the sustainability of filter materials and the disposal of spent media,

could contribute to more eco-friendly water treatment solutions. Research in this area could focus on minimizing the environmental footprint of filtration systems.

6.2. Limitation of the Study

While this study provides valuable insights into the performance of horizontal roughing filters (HRFs) and the effectiveness of linear interpolation for estimating missing turbidity data, several limitations should be acknowledged:

- The study's findings are based on a specific set of 41 experimental conditions and water samples.
- Linear interpolation assumes a linear relationship between data points, which may not always accurately reflect the true behaviour of turbidity changes.
- The experiments were conducted on a laboratory scale, which may not fully capture the complexities and operational challenges of large-scale or field implementations of HRFs.
- The study was conducted over a relatively short period, which may not capture long-term performance and maintenance needs of the HRF.
- The accuracy of turbidity measurements and the precision of the linear interpolation method are subject to measurement errors.

Overall, the findings underscore the HRF's capability as an effective water treatment solution for turbidity removal. Additionally, the successful application of linear interpolation enhances the robustness of data analysis in water treatment research, making it a useful tool for managing and interpreting incomplete datasets.

REFERENCES

1. Sittivate, 2000. How to Estimate and Design the Filter Run Duration of a Horizontal-Flow Roughing Filter, Thammasat Int. J. Sc. Tech., Vol.5, No.2, 45

2. Wegelin, 1986. Horizontal-Flow Roughing filtration (HRF) a design, construction and operation manual, International Reference Centre for Waste Disposal (IRCWD) -Report No. 06/86, 48

3. Mistoro and Saraswati, 2019. Design and modification of horizontal-flow roughing filter as water treatment at UGM retention pond. E3S Web of Conferences 76, 02002, 45-49

4. Wegelin, Boller and Schertenleib, 2016. Particle Removal by Horizontal-Flow Roughing Filtration, Research Gate, 5

5. Dastanaie et al. 2007.Use of horizontal flow roughing filtration in drinking water treatment. Int. J. Environ. Sci. Tech., 4 (3): 379-382, 21-26

6. Patil V.B., Kulkarni G.S. and Kore V.S. 2012. Performance of Horizontal Roughing Filters for Wastewater: A review, International Research Journal of Environment Sciences, Vol. 1(2), 53-55. 29-32

7. Hopman et al. 2019. The prediction and optimization of pesticide removal by GAC-filtration, Research Gate,

8. Sittivate, 2001. How to estimate the run duration of a horizontal-flow roughing filter, Transactions on Ecology and the Environment vol 49,

9. Khazaei et al, 2014. Nitrogen and phosphorous removal from aerated lagoon effluent using horizontal roughing filter (HRF), Desalination and Water Treatment 57

10. Cahyana et al, 2021. Effectiveness of combined up-flow roughing filter and up-flow slow sand filter to reduce turbidity in Citarum water as a source of drinking water, IOP Conf. Series: Earth and Environmental Science 896 (2021) 012020,

11. Guidice, 2020. Enhancing gravel roughing filter performance with zero valent iron and anion exchange resin,

12. Lebsir, 1992. Factors controlling the performance of horizontal flow roughing filters,

13. Nkwonta and Ochieng, 2009. Roughing filter for water pre-treatment technology in developing countries: A review, International Journal of Physical Sciences Vol. 4 (9), pp. 455-463, https://www.researchgate.net/publication/237827490

14. Adel, Negm and Razik, 2014. The Use of Roughing Filters in Water Purification, Sci. Journal of Oct. 6Uni. (SJO6U), ISSN: 2314-8640: Vol. 2(1): 50-58,

15. Syazwan, 2020. Removing Iron and Manganese by Using Cascade Aerator and Limestone Horizontal Roughing Filters, IOP Conf. Series: Materials Science and Engineering 864 (2020) 012006

16. Nkwonta and Ochieng, 2010. Total Dissolved Solids Removal in Wastewater Using Roughing Filters, Chemical Sciences Journal, Volume 2010: CSJ-6

17. Nabizadeh et al, 2015. Upgrading the effluent quality of an aerated lagoon with horizontal roughing filtration, DOI: 10.5277/epe150309

18. Goswami et al. 2017. Seasonal variations of water characteristics in three urban ponds with different management practices at Kolkata of West Bengal, India, Journal of Entomology and Zoology Studies 2017; 5(6): 1449-1454

19. Singh et al, 2015. Drinking water, sanitation and health in kolkata metropolitan city: contribution towards urban sustainability, DOI: 10.15356/2071-9388_04v08_2015_07

20. Chhoden & Manchanda, 2015. Impact assessment of ponds on groundwater quality in vicinity area of district ropar, Punjab

21. Mahvi et al. 2004. Performance of a Direct Horizontal Roughing Filtration (DHRF) System in Treatment of Highly Turbid Water, Iranian J Env Health Sci Eng, Vol.1, No. 1, pp.1-4,

22. Maung, 2006. a study on the performance of limestone roughing filter for the removal of turbidity, suspended solids, biochemical oxygen demand and coliform organisms using wastewater from the inlet of domestic wastewater oxidation pond

23. Indian Standard drinking water — specification (Second Revision), IS 10500 : 2012

24. Chowdhury, 2019. Determining the effectiveness of direct horizontal-flow roughing filtration, Determining the effectiveness of direct horizontal-flow roughing filtration - Environmental Science & Engineering Magazine.

25. Lin et al. 2020, Occurrence and risk assessment of emerging contaminants in a water reclamation and ecological reuse project, DOI: 10.1016/j.scitotenv.2020.140977

26. Wang et al. 2021. Research on drinking water purification technologies for household use by reducing total dissolved solids (TDS), PLoS ONE 16(9): e0257865. https://doi.org/10.1371/ journal.pone.0257865.

27. Sphesihle et al. 2016. Performance of a horizontal roughing filtration system for the pre-treatment of greywater.

28. Karki et al. 2020. A Comparative Study of Water Turbidity Removal Efficiency of Anthracite and Gravel in Roughing Filter, Journal of Innovations in Engineering Education, Vol: 3,Issue: 1

29. Boller, 1993. Filter mechanisms in roughing filters, J Water SRT-Aqua Vol. 42, No.3, pp. 174--185, 1993, https://www.researchgate.net/publication/287547492

30. Amin et al. 2023, Performance Evaluation of a Simple Ceramic Filter (SCF) Combined with Roughing Filter for Pond Water Treatment, https://www.researchgate.net/publication/378125196

31. Al-Bayati et al. 2009, Evaluation of Horizontal Flow Roughing Filtration Performance, Eng.& Tech. Journal ,Vol.27, No.15,

32. Ahsan et al. 2016. Direct horizontal-flow roughing filtration. Part I: Optimisation of process parameters, Journal of Water Supply: Research and Technology https://www.researchgate.net/publication/287556987 ,

33. Baidhani et al. 2017, Pre-Treatment of Water by using Broken Marble and Ceramic Wastes as Up-Flow Roughing Filter Media, International Journal of Current Engineering and Technology, https://www.researchgate.net/publication/359025036

34. Khafajy et al. 2016. Treatment of Water and Wastewater by using Roughing Filter Technology of Local Materials, International Journal of Current Engineering and Technology, https://www.researchgate.net/publication/359025061

35. Onyeka, Olufisayo and Olufayo et al. 2010. Turbidity removal: Gravel and charcoal as roughing filtration media, South African Journal of Science, Article No 196,

36. Khan, Riaz and Ishtiaq et al. 2013. Comparing plain and coagulated horizontal flow roughing filtration for high turbidity water, Water Science & Technology: Water Supply 13.2,