Development of Design Criteria for Multi Stage Filtration Units for Surface Water Treatment

by

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

August, 2010 A.H.M. KHALEQUR RAHMAN

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ABBREVIATIONS AND ACRONYMS

AWWA	American Water Works Association
BUET	Bangladesh University of Engineering and Technology
COD	Chemical Oxygen Demand
DANIDA	Danish International Development Agency
DFID	Department for International Development
DO	Dissolve Oxygen
DyRF	Dynamic Roughing Filter
EC	Electric Conductivity
EQS	Environmental Quality Standard
EC	Escherichia Coli
FM	Fineness Modulus
ITN	International Training Network
MS	Mild Steel
MSF	Multistage Filter
NGO	Non Government Organization
NTU	Nephelometric Turbidity Unit
Pt.Co.Unit	Platinum Color Unit
PSF	Pond Sand Filter
SSF	Slow Sand Filter
TTC	Thermotolerant Coliform
Unicef	United Nations Children’s Fund
URF	Up-flow Roughing Filter

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ABSTRACT

Surface water with proper treatment can be an effective alternative to groundwater in salinity and arsenic affected areas since surface water sources i.e. ponds, canals and rivers are available in many places of the country. However, exposed to direct contamination, surface water is a vulnerable carrier of water-borne diseases. Multi Stage Filtration (MSF) is a community based low cost and simple technology for treating surface water. The thesis work has been done in quest of determining appropriate design criteria for Multi Stage Filtration (MSF) units for use in Bangladesh. The MSF system considered under the study comprised of three units, i.e. Dynamic Roughing Filter (DyRF) unit, Up-flow Roughing Filter (URF) unit and Slow Sand Filter (SSF) unit.

In the study, one MSF model unit was set up in the laboratory and three field MSF units were installed in three districts of the country. Necessary design data were collected regarding roughing pre-filtration and slow sand filtration system by reviewing the relevant literatures. The performance of different units of MSF were monitored and investigated regarding improvement of different physical, microbial and chemical water quality parameters both in the laboratory and field. For this the effect of different process variables i.e. bed material, rate of filtration, role of different filtration stages, flow condition, exposure condition of filter bed etc were considered in several experimental runs. Finally the optimum criteria of different design parameters have been developed through rigorous analysis of the performance of MSF units which are summarized below.

‘Coarse media size range’ and ‘depth of bed’ in DyRF and URF are more important design parameters for the reduction of turbidity. A coarse media size range from 4.75 mm to 25 mm for DyRF, and 6.3 mm to 25 mm for URF placed in three layers have been found suitable. Slow sand filter bed materials size range and grading, particularly on the top layer of filter bed, are very important design parameters for efficient microbial removal performance. Filter sand having following characteristics have been found appropriate:

FM = 1.8-2.0, D_{10}*=0.21-0.22 mm, D60 = 0.45-0.47 mm, U = 2.14 -2.16 and Filter Media Size Range = 0.15 mm to 1.1 mm.*

A moderate influent turbidity limit of around 20 NTU may be proposed for SSF. In case of raw water turbidity level greater than 150 NTU, pre-settling arrangement should be made and if the raw water level turbidity remains within 60 to 150 NTU both DyRF and URF units will be required. However, for turbidity values below 60 NTU, DyRF unit may be omitted.

To maintain slow sand filter influent turbidity value within 20 NTU and Color value within 25 Pt.Co.Unit, slow sand filtration rate should be within 0.20-0.25m/h. To maintain this flow rate at SSF, the corresponding flow rates at URF and DyRF were in a range of 0.43-0.54 m/h and 1.6-2.00 m/h respectively. Beyond slow sand filtration rate of

0.20-0.25 m/h, microbial quality deteriorates significantly. For a maximum slow sand filtration rate of ≤ 0.1m/h, an acceptable level of microbial quality of water may be obtained and at a filtration rate up to 0.15 m/h, TTC and E.Coli may appear occasionally. Reduction of Dissolved oxygen level inversely related to the flow rate of water and average reduction of organic matters is approximately independent of rate of flow.

Intermittent operation affected the color removal performance, not the turbidity removal performance. Effluent of consistently satisfactory microbial quality was obtained in MSF system operated without interruption and a definite deterioration in microbiological quality was noticed in intermittent operation. Therefore, to obtain a better removal performance uninterrupted flow condition should be maintained.

For a slow sand filtration rate of around 0.20 m/h, a maximum of 40 cm head loss may be permitted before cleaning of bed within 6-8 weeks operation period. Therefore, provision of total height of water level of about 60 cm (10 cm Initial Water Depth + 40 cm Head Loss + 10 cm Free Board) should be kept over sand bed. For an up-flow coarse media filtration rate of 0.43 m/h and a down-flow coarse media filtration rate of 1.6 m/h, a maximum of 10 cm and 2 cm head loss may be permitted, respectively before cleaning of bed after about 8 weeks operation period.

Approximately 7 to 10 days are required to improve the removal performances for ripening of the “Schmutzdecke” on filter sand (SSF). Twin bed filter chambers may be used and cleaning may be performed alternatively after 7 to10 days interval using the method known as “harrowing” after every 6-8 weeks period. However, complete removal of filter sand, washing and replacing may be necessary after every 5 to 6 months of operation.

Filter bed should be kept covered to avoid the unnecessary growth of algae particularly on slow sand filter bed. The scouring action of falling water on sand bed can be reduced by installing homogenous flow distribution arrangement.

CHAPTER ONE

INTRODUCTION

1.1 Background

Contamination of arsenic in excess of acceptable limit in groundwater mainly from shallow tube wells is a major public health problem in the country. This has been an unforeseen consequence of a large scale program to replace contaminated surface water source by ‘safe’ ground water, never suspecting the presence of arsenic in the aquifer. However, extraction of the groundwater from the swallow tube wells have been found to be the best option for rural water supply and Bangladesh has achieved a remarkable success by providing 97% of the rural population with tube well water. It is unfortunate that the presence of arsenic in drinking water has emerged as a serious threat to public health challenges.

The alternative options available for water supply in the arsenic affected areas include avoidance of shallow tubewell through use of alternative water sources or treatment of arsenic contaminated groundwater. In either case, the drinking water supplied must be free from harmful bacteriological and chemical contaminants. The use of alternative water sources will require a major technological shift in water supply. It would be a serious mistake to revert back to use of unsafe surface water sources without proper treatment. Surface water sources are abundantly available in many places of the country.

For developing simple treatment technologies for water taken from ponds, a number of Technologies have been developed. Slow Sand Filtration has become a most appropriate surface water treatment technology in developing countries on account of its simple construction and operation. The Pond Sand Filter (PSF) already designed on the principle of Slow Sand Filtration for the arsenic problem areas are performing for the last decade without any major modification.

In addition to ponds, Bangladesh has many rivers, canals and streams that could be used as a source of water supply. However, exposed to contamination, these sources of water are an excellent carrier of waterborne diseases, moreover, during the rainy season concentration of suspended particles in the flowing water sources increases tremendously. In order to make this water safe for drinking, some kind of treatment is necessary. Very little work has been done for the treatment of these surface water sources. Slow Sand Filter (SSF), on account of its simple construction and operation has become a most appropriate surface water treatment technology in developing countries.

1.2 Statement of the Problem

Although slow sand filter (SSF), on account of its simple construction and operation has become a most appropriate water treatment technology in developing countries, direct use of high turbid and contaminated water sources on SSF bed may not be feasible without pretreatment. Slow sand filtration (SSF) accomplishes its treatment primarily through biological activity, with the bulk of this activity taking place on the surface of the sand bed; as a result SSF is very sensitive to particulate matter which, at high concentration, clogs the filter after short time. SSF therefore operates only satisfactorily with raw water of low turbidity.

Filtration of raw waters with higher turbidities particularly during rainy season causes a rapid increase of the filter resistance and short filter runs. Obviously, frequent cleaning are the consequence of poor raw water quality. Moreover, the most desired biological activities of the filter required for microbial water quality improvement are therefore seriously affected, and application of SSF becomes very questionable under such conditions.

In addition the presence of algae in the source water reduces filter run lengths. Therefore, it is prudent to reduce algae content in source water to as low a level as possible to limits its effect on the filter performance. Source water color should also be limited as high colored water is not acceptable due to aesthetic reason and gives undesirable taste.

1.3 Rationale of the Study

Flocculation and sedimentation is the conventional way of pretreatment through separating suspended solids from surface water sources. But these processes, which involve high cost and skilled personnel to apply chemicals, are difficult to implement in developing countries. Roughing pre-filtration processes using coarse materials as filter media eventually will be required to improve the influent water qualities of SSF and is a sound technique in handling highly turbid waters. Two stages pre-filtration may be required if the raw water quality is very unsatisfactory; first down-flow and then up-flow. In corporation of all such units into a multistage filtration process and optimization of their operations demand further intensive study.

1.4 Objectives

Roughing pre-filtration processes using coarse materials as filter media will be designed to improve the influent water qualities of SSF in handling highly turbid waters and make the unit capable to survive in shock load condition. It is expected that a properly designed and carefully operated Multistage Filtration systems should have the effluent water quality, which would be acceptable to most of the consumers and satisfy the international and local recommended water quality standards.

Specific objectives of the study are as follows:

- To investigate the physical, chemical and microbial quality improvement performance of the laboratory MSF units under variable experimental conditions.
- To investigate the physical and microbial quality improvement performance of the field MSF units under different water quality conditions.
- To compare the performance of field units with that of laboratory model unit.
- To determine the appropriate design criteria for MSF units for use in Bangladesh.

1.5 Organization of the Thesis

The thesis is structured in seven chapters. First chapter of the thesis gives an overview of the problem statement with rationale of the study and specific objectives of the thesis work. In second chapter literature review has been presented. The third chapter describes the methodology i.e. working procedures for both laboratory and field works. In fourth chapter physical water quality improvement performance of field and model MSF units including their comparison in performance have been presented.

The fifth chapter provides microbial water quality improvement performance of field and model MSF units including their comparison in performance. In sixth chapter chemical water quality improvement performance of laboratory MSF units has been described. In chapter seven the design criteria of multi stage filtration units for treating surface water have been finalized and summarized. Finally conclusion and some recommendations have been noted in chapter eight.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

There are normally two types of impurities in water, suspended and dissolved. The surface water are characterized by the suspended impurities whereas the ground water are generally free from the suspended matter but are likely to contain a large amount of dissolved impurities. Suspended solids in water may consist of inorganic or organic particles or of immiscible liquids. Inorganic solids such as clay, silt and other soil constitute are common in surface water. Organic materials such as plant fibers and biological solids (algae cells, bacteria etc.) are also common constituents of surface waters. These materials are often natural contaminants resulting from the erosive action of water flowing over surfaces. The suspended matter often contains pathogenic or disease producing bacteria; as such surface water are not considered to be safe for water supply without the necessary treatment (Peavy, et al., 1985).

Recently various methods have been adopted to make water potable and attractive to the consumers. In the case of surface waters, the treatment procedure involves removal of silt or turbidity, color, taste, odor and bacteria. Moreover, the method of water treatment has to be selected on the basis of the character of the raw water to be treated.

2.2 Background of the Development of Water Treatment Processes

Ancient water supply systems did not have proper treatment methods. Although some cities were able to collect safe water from uninhabited regions and thereby reduced water-borne diseases to some extent, many others found their supplies dangerously polluted. Accordingly, some treatment method, such as sedimentation was developed, which when properly applied, reduced the hazard to some extent.

Water filtration was conceived in the early 19th century. When slow sand filters were introduced in England in 1906, an immediate reduction of typhoid fever occurred. At the beginning of the 19th century, the first water treatment plants for public water supplies were constructed in Britain and France (Wegelin, 1996). They generally comprised settling basins followed by gravel and sand filters. In the course of time, slow sand filters were developed as an efficient water treatment process, and used by many water authorities at the end of 19th century. By this time however, the Industrial Revolution came up with the mechanical filters, initially called rapid sand filters. The growing demand for water and the subsequent discovery of chlorine to disinfect the water enhanced the use of rapid sand filters.

In 1940, there were about 2,275 rapid filter plants in the United States compared to about 100 slow sand filter plants (Wegelin, 1996). Another outstanding feature with regard to the water treatment technology was the use of aluminum and iron salts as coagulants in water treatment. Since the beginning of this century, coagulation and flocculation combined with sedimentation, rapid filtration, and final chlorination are now commonly used in water treatment.

In Bangladesh, Nawab Sir Abdul Gani first started the water supply in Dhaka city with the establishment of Dhaka Water Works (DWW) in 1874. But in coastal areas the crucial situation in water supply due to excessive salinity, has made it very hard for people to get access to safe and sweet drinking water. In addition to this, arsenic contamination of ground water in Bangladesh has been recognized as major problem from 1993. However, to ensure the safe water for drinking & all other household usage, the concerned persons and organizations (DPHE, Danida, Unicef, WHO, NGO Forum etc.) are searching for appropriate alternative technology for the salinity and arsenic affected areas. (Islam, 2002)

2.3 Water Borne Diseases

Pathogenic microorganisms cause water borne diseases. A variety of different microorganisms are found in untreated water. Only a small fraction of these microorganisms poses health hazards to human and is generally known as pathogens. Pathogens are not native to aquatic systems and usually require an animal host for growth and reproduction. They can however be transported by natural water systems, thus becoming a temporary member of aquatic community. Many species of pathogens are able to survive in water and maintain their infectious capabilities for significant periods of time. Microorganisms posing health hazard includes species of bacteria, virus and protozoa. Pathogenic microorganisms are transmitted primarily through the feces of infected persons. Water that shows evidence of such contamination is thus considered to be unfit for consumption. Determining the number of coliform bacteria usually assesses the possibility of such contamination. Pathogens are found in far smaller numbers and tend to die off more rapidly than the Coliforms under the conditions found in natural waters and in water and wastewater treatment plants. Thus, while the presence of Coliform does not proof that the water is dangerous, the absence of this group is taken as evidence that is free of pathogens.

2.4 Different Treatment Processes for Surface Water

2.4.1 Sedimentation Process

In water and wastewater treatment, sedimentation or removal by gravitational settling of suspended particles heavier than water is perhaps the most widely used operation. When the impurities, held in suspension are separated from the fluid by the natural force alone i.e. by gravitational and natural aggregation of the settling particles, the operation is called plain sedimentation.

This operation is used for grit removal, particulate matter removal, biological and chemical floc removal. In most cases, the primary purpose is to produce a clarified effluent. The factors that effect sedimentation are, density of particles, density of water, size of particle, velocity of settling particle, drag coefficient and acceleration due to gravity. Increasing particle size can accelerate sedimentation or decreasing the distance a particle must fall prior to removal. The first can achieve by coagulation and flocculation prior to sedimentation. The second is achieved by making the basin shallower or by providing tube settlers.

Sedimentation may be classified into four general ways depending upon the characteristics and concentrations of suspended materials (Peavy, et al., 1985). First type of settling refers to the sedimentation of discrete particles that settle as individual entities and there is no significant interaction with neighboring particles. This is also called as discrete particle settling. Second type called flocculent settling refers to a rather dilute suspension of particles that coalesce, or flocculate, during the sedimentation operation. By coalescing, the particles increase in mass and settle at a faster rate. The third type of settling occurs in suspension of intermediate concentration, in which inter-particle forces are sufficient to hinder the settling of neighboring particles. Hence it is called hindered settling or zone settling. When the rising layer of settled solids reaches the interface a compression zone occurs, this is the fourth type of settling, known as compression settling. It is common to have more than one type of settling taking place at a given time during a sedimentation operation, and it is possible to have all four occurring simultaneously.

2.4.2 Filtration Process for Water Treatment

2.4.2.1 Introduction

Filtration in water treatment is a major cleaning process where water is passed through a porous medium and particulate materials either accumulate on the surface of the medium or are collected through its depth. In this process the water quality is improved partly by removal of suspended and colloidal matter, by reduction in the number of bacteria and other organisms and by changes in its chemical constituents.

Basically there are two methods of filtration:

a) Surface filtration - in which thin media are used, such as screens or membrane, which works by simple mechanism of mechanical straining, where some characteristic size of particulate is larger than the opening in the filter medium. Larger floc particles can be removed by simple straining at the bed surface, but much of the flocculated matter will pass through the bed and clog the openings.

b) Depth filtration- In the case of deep bed filters, particulate can penetrate into the depth of the filter medium, and the mechanisms of removal are more complex. Generally the particulate matter must be transported from the fluid streamline to the surface of the media or collector. Particles will deviate from fluid streamline due to gravitational forces, diffusion gradients and interfacial effect of momentum. Particles removed in filters are much smaller than the passages between adjacent grains, so the process of filtration is not straining only. Filters are also divided into two types based on flow rate namely rapid sand and slow sand filters.

2.4.2.2 Filtration Mechanisms

The mechanisms involved in removal of impurities by a filter are very complex. The overall removal is brought about by a combination of different phenomenon. Many workers have discussed the various factors, which may play an important role in removal of impurities (O'Melia and Stumm, 1967). The dominant phenomenon depends on the physical and chemical characteristics of the suspension and the medium, the rate of filtration and the chemical characteristics of the water. The removal mechanisms such as straining, interception, impaction, flocculation, sedimentation and adsorption are shown schematically in Figure-2.1. However, to simplify the discussion different mechanisms are discussed separately.

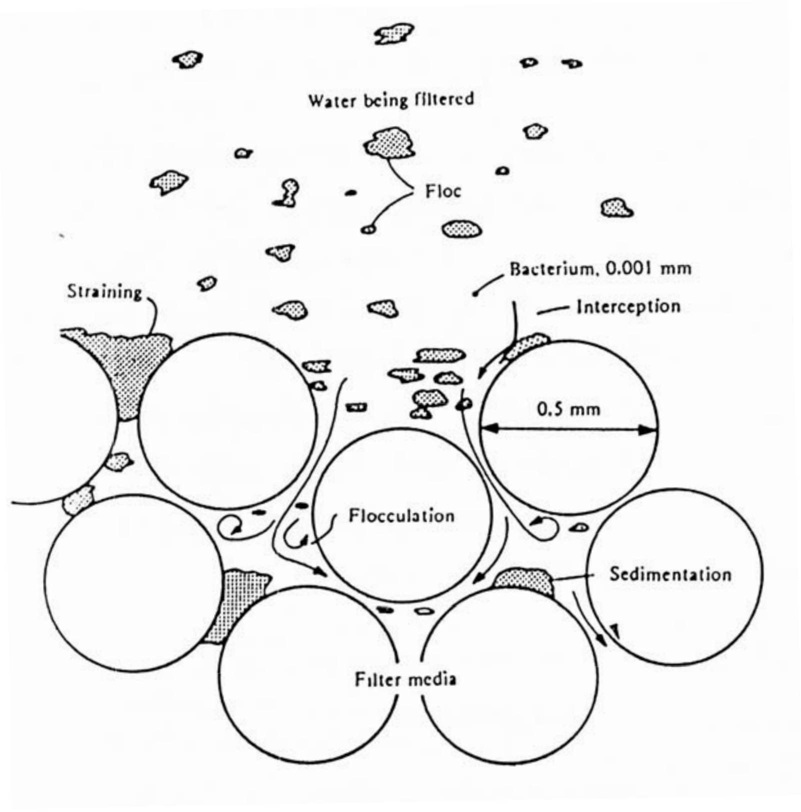


Figure-2.1: Schematic diagram illustrating straining, flocculation and sedimentation action in a granular media filter (Source: Warren and Hammer, 1998)

Straining: Suspended particles bigger than the pore space between sand grains are removed at the surface of the filter bed. The process is therefore independent of the filtration rate. As gradual clogging reduces pore space, the straining efficiency increases with time and forms permeable layer at the surface, which is known as cake filtration. This mechanism is of little significance in a filter bed composed of coarse material.

Sedimentation: Sedimentation occurs when particles settle on the filtering medium within the filter. Interstices of filter media act as minute sedimentation basins with comparatively large surface area.

Interception: Many particles that move along in the streamline are removed when they come in contact with the surface of the filtering medium. This phenomenon is known as interception.

Impaction: Heavy particles present in the water will not follow the flow streamlines and will settle on the filtering medium, this is known as impaction.

Physical and Chemical Adsorption: Removal of impurities such as small-suspended particles, colloidal and dissolved substance depends on two mechanisms. First, a transport mechanism must bring the small particles from the bulk of the fluid within the interstices close to the surface of the media. Transport mechanisms include interception, settling, diffusion and hydrodynamic action.

Second, as the particle approaches the surface of the medium or previously deposited solids on the medium an attachment mechanism is required to retain the particle (<0.01μm). The attachment mechanisms may include Vander Walls forces, electro kinetic interactions, chemical bridging and surface tension.

Flocculation: Large particles overtake smaller particles, join them, and form still larger particles. This is known as flocculation.

Adhesion: Flocculent particles become attached to the surface of the filtering medium, some materials are sheared away before it becomes firmly attached and is pushed deeper into the filter bed. Interstices of the filtering medium get gradually narrowed down by accumulating deposits, which further carry out mechanical straining action. Moreover, some chemical flocs have good adsorbing properties, which can even remove micro-precipitates.

Biological Growth: Biological growth within the filter also can reduce the pore volume. This mechanism indicates the possibility of use of a coarse filter medium in place of fine filter medium. A schematic of an isolated spherical collector developed by Yao, et al., is shown in Figure 2.2. Particulates are transported past the spherical collector and must deviate from the streamline to be removed from the suspension.

The collection efficiency throughout the depth of granular media is the summation of the efficiency of all individual collectors in the filter bed (Montgomery, et al., 1985).

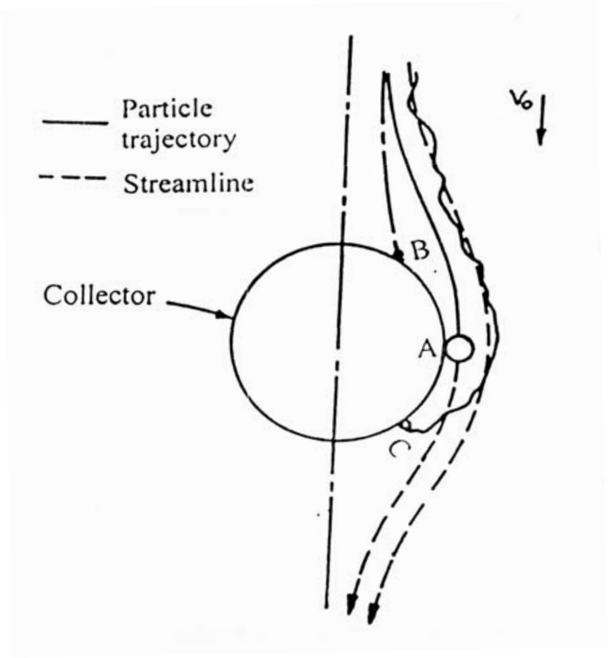


Figure 2.2: Modes of action of the basic transport mechanisms, A-interception, B-sedimentation; C-diffusion. (Source: Montgomery, et al., 1985)

2.4.3 Filtration with Slow Sand Filter

2.4.3.1 Theoretical Considerations

Slow sand filtration is a purification process in which the water to be treated is passed through a porous bed (preferably sand bed) of filter medium. During this passage the water quality improves considerably by-

- removing the number of microorganisms present the water.
- retaining fine organic and inorganic solid matters and
- oxidize organic compounds dissolved in water.

Slow sand filters perform best under continuous operation and constant flow conditions. The biological activities must first be allowed to develop in a newly installed filter bed. This ripening period will take two to four weeks after first installation. Later on, filters will regain their full biological activities within two to three days after cleaning provided the cleaning procedure is of few hours duration. The flow rate is adjusted by the inlet valve at the start of the filtration operation. The water depth on the filter bed will gradually increase with the running of the filter and development of head loss.

Filter cleaning is required once the supernatant water reaches the highest permissible level. The proven method of cleaning a slow sand filter is by scraping off the sand surface with hand shovels to remove the top dirty sand. The scraped-off mixture of sand and impurities may be discarded and replaced by new sand or washed for re-use if it is cheaper than buying new sand. The thoroughly washed, scraped sand may be applied during the next cleaning operation. The cleaning frequency for well-operated slow sand filters is approximately one to three months depending upon the load on the filter. After removal of the top layer the filter operation is immediately started in order to minimize interference with the biological activity within the filter bed.

2.4.3.2 Removal Mechanism

Physical water quality improvement

Slow Sand Filtration accomplishes its treatment primarily through biological activity, with the bulk of this activity taking place on the surface of the sand bed. A layer develops on the sand surface that is called “Schmutzdecke,” an accumulation of organic and inorganic debris and particulate matter in which biological activity is stimulated. It has been found that some biological activity also extends deeper into the bed, where particulate removal is accomplished by bioadsorption and attachment to the sand grains (AWWA, 1996).

Microbial water quality improvement

The removal mechanisms of particles in a Slow Sand Filter (SSF) include mechanical straining, sedimentation, adsorption, and chemical and biological activities. Large and fine particles of suspended matter are deposited at the surface of the filter bed by the action of mechanical straining and sedimentation respectively. The sedimentation process is enhanced by the flocculation of fine particles during sinusoidal/converging flow across the interstices of filter media while colloidal and dissolved impurities are removed by the action of adsorption. By chemical and biological oxidation, the deposited organic matter is converted into inorganic solids and discharged with filter effluent (Schulz and Okun, 1984).

Chemical water quality improvement

In addition to physical and microbiological activities, changes in chemical constituents also take place through slow sand filtration processes. When raw water enriched with inorganic and organic matters passes over the microbial layers developed on filter media, soluble and colloidal materials are utilized by bacteria and other microorganisms as food. Organic and inorganic pollutants are dissociated in to simple end products and some of them are adsorbed on filter bed, rests are discharged with filter effluent, resulting changes in effluent water quality. Moreover, zooplankton grazing occurs and continuous respiration of entire biomass causes depletion of dissolved oxygen level.

2.4.4 Roughing Filtration for Pretreatment

2.4.4.1 Theoretical Considerations

Rouging filters are often used before slow sand filters because of their effectiveness in removing suspended solids. Roughing filters usually consists of differently sized coarse gravel or crushed stones as filter material decreasing successively in size in the direction of flow. Roughing filter is a more effective process for solids removal than plain sedimentation since the filter material drastically reduces the settling distance. The subsequent medium and fine filter media reduce the suspended solids concentration. Roughing filters are operated at small hydraulic loading. There are different types of roughing filters classified on the basis of flow through filter media. These are:

- Horizontal roughing filters
- Vertical down flow roughing filters and
- Vertical up-flow roughing filters
- Dynamic roughing filters

The main advantage of horizontal-flow roughing filtration (HRF) is that, when raw water flows through it, a combination of filtration and gravity settling takes place, which invariably reduces the concentration of suspended solids. At the same time, biological mechanisms similar to those in slow sand filtration help remove some pathogens. HRF is subjected to lower filtration rates, and they generally require manual cleaning of the filter media.

In a single compartment vertical up-flow or down-flow roughing filter, gravel layers of different sizes are installed one above the other in the same compartment with gravel size decreasing in the direction of flow. The vertical up-flow filtration is one of the improved methods of water treatment. In this process, the raw water is fed at the bottom in the upward flow direction and course to fine media filtration is achieved with a single medium in the direction of filtration, which makes better use of the entire filter bed. Structural constraints limit the depth of the filter bed in up-flow filters, but higher filtration rates and back washing of the filter media are possible.

There also exists a combination of down flow roughing filter and sedimentation zones called Dynamic Roughing Filter (DyRF). DyRF performance is described by its adjective "dynamic" which applies to the continuous washing or cleaning of the upper filter layer by the water flow (Wegelin, 1996). A balance is sought between the settling of small particles in the upper layer and re-suspension of these particles by the water flow. The dynamic characteristics also refers to the fact that as particles settle continuously on top of this filter bed, others are washed out and flushed away by the water flow (Pardon, 1989). It includes a shallow layer of medium size filter media in their upper part and coarse media that covers the under-drains. With moderate levels of suspended solids in the source water, DyRF gradually clogs. If quick changes in water quality occur, the clogging may be much faster. Eventually the gravel bed will be blocked and the total water volume will just flow over the clogged surface area to waste, protecting the subsequent treatment steps that are more difficult to maintain. A combination of down-flow at the beginning and an Up-flow at the end may be advantageous.

2.4.4.2 Removal Mechanism

Physical water quality improvement

The Roughing Filters allow deep penetration of suspended materials in to a filter bed and they have large silt storage capacity. When raw water flows through a packed bed of coarse media, a combination of filtration and gravity settling takes place which invariably reduces the concentration of suspended solids. Moreover, sinuous flow of water through the interstices of coarse media provides repeated contacts among the small suspended particles to form compact settleable flocs (Schulz and Okun, 1984). A portion of the agglomerated floc settle on the surface and within the interstices of coarse media, which further helps in adsorbing finer particles as they come into contact with the settled flocs. Again in an up-flow system as the flow emerges from the coarse media, due to sudden drop of velocity, agglomerated flocs settle on the top of coarse media bed forming a layer of sludge blanket which is also effective in the removal of finer particles.

Microbial water quality improvement

Roughing Pre-filtration by coarse media can certainly provide the requisite protection for slow sand filtration in adverse raw water conditions as already been explained; but, in addition, it may contribute valuable improvements in microbiological quality. While some of this microbial removal may be assumed to be solids-associated and, therefore, removed from water by physical processes of adsorption and sedimentation, the contribution of the gravel pre-filter to overall microbial improvement is clearly significant. Examinations of the microfauna colonizing the mature gravel media confirmed that organisms were in fact identical to those usually associated with slow rate, finer grain filters such as slow sand filters (Gerado, et al.). This is an important observation because in many small scale water supplies in developing countries where reliable disinfection is rare, the addition of an extra dimension of biological treatment that the multiple barrier principle may be truly applied even on a very small scale.

Chemical water quality improvement

In addition to physical and microbiological activities, changes in chemical constituents also take place through roughing filtration processes. When raw water enriched with inorganic and organic matters passes over the microbial layers developed on filter media, soluble and colloidal materials are utilised by bacteria and other microorganisms as food. Organic and inorganic pollutants are dissociated in to simple end products and some of them are adsorbed on filter bed, rest are discharged with filter effluent, resulting changes in effluent water quality. Moreover, zooplankton grazing occurs and continuous respiration of entire biomass causes depletion of dissolved oxygen level.

2.5 Design Data

Reviewing the relevant literatures necessary design data have been collected regarding roughing pre-filtration and slow sand filtration systems which have been explained in the following articles.

2.5.1 Design Parameters

Following are the fundamental design parameters of roughing pre-filtration and Slow Sand Filtration systems:

Type, size and gradation of filter media; Filtration rate or Face velocity; and Depth and length of filter bed. The rate of filtration and size of coarse materials depend on the desired degree of turbidity removal.

(a) Size and Grading of Filter Media

Recent designs used gravel filter materials that decreases in size with flow direction and size range is between 5 mm to 50 mm (AWWA, 1996). Schulz and Okun have recommended coarse media size range between 4 mm to 15 mm (Schulz and Okun, 1984) for up-flow roughing filter. AIT study recommended an effective size(D_{10}) of coarse media varying from 2.8 mm to 9.1 mm (ENSIC, 1983).

The International Research Center manual recommends filter sand with effective size(D_{10}) of 0.15 mm to 0.30 mm with a uniformity coefficient between 3 and 5 (AWWA, 1996). Schulz and Okun have recommended an effective size(D_{10}) of sand in between 0.15 mm to 0.35 mm. McGhee has indicated that effective sizes of 0.10 mm to 0.3 mm and uniformity coefficient of 2 to 3 are commonly employed for slow sand filtration.

(b) Filtration Rates

Good turbidity reductions were obtained at filtration rates less than 2 m/h through coarse media (Gerado et al.). In AIT a horizontal flow roughing filter operated at a filtration rate of 0.6m/h produced a filtrate of 10 -15 NTU from raw water turbidity range of 20 -120 NTU(ENSIC, 1983). The acceptable range of filtration rate for up-flow roughing filter has been found in the range of 0.5 m/h to 4 m/h (Schulz and Okun, 1984).

AWWA has recommended typical roughing filtration rate in the range of 0.3 m/h to 1.5 m/h and slow sand filtration in the range of 0.09 m/h to 0.24m/h (AWWA, 1996). McGhee has proposed that the filtration rate of SSF should be normally less than 0.4 m/h (Mc.Ghee, 1991). SSF operated at 0.3 m/h always produced a filtrate of lowest turbidity while those operated at 0.2 m/h and 0.3 m/h gave filtered waters of higher turbidity but less than 1 NTU (Paramasivam and Sundaresan, 1978). Although the normal flow rate for SSF is between 0.1 m/h and 0.4 m/h, a conservative filtration rate of 0.29 m/h was chosen in North Haven (Abernethy, 2004).

(c) Depth of Filter Media and Under-drainage System

McGhee has also indicated that sand bed depth around 1000 mm should bed be used for slow sand filtration (Mc.Ghee, 1991). The American Water Works Association (AWWA) has suggested that the sand bed depth should generally be between 460 mm and 800 mm, however, the minimum depth before resanding should be 460 mm (AWWA, 1996).

The sand layer of SSF is supported by a layer of coarse media of about 300 mm thick which is graded from effective size of about 5 mm at the top to 50 mm at the bottom. Under drains are normally constructed of perforated pipes (Mc.Ghee, 1991). Regarding the under-drainage system plastic piping system has been proposed in some study (AWWA, 1996).

2.5.2 Source Water Quality Considerations

Treatment capacity of SSF and effect of environmental conditions on the removal performance have been investigated by many investigators to determine the source water quality parameters with recommended limits. Degree of pretreatment through coarse media should attain these recommended limits for better performance of SSF.

(a) Turbidity and Color Values

Infiltration gallery has been proved a simple and efficient method of pretreatment before SSF and raw water turbidity as high as 500 NTU could be reduced to a uniform low level of less than 5 NTU (Joshi et al., 1985).

It has been observed that most of the existing Slow Sand Filter(SSF) plants successfully treat surface water having turbidity of less than 10 NTU which is recommended for an upper limits in designing new facilities. A high level will block the bed after a short time (AWWA, 1996). Similarly source water color should be limited within 15 to 25 Platinum color units (AWWA, 1996).

(b) Presence of Algae

In a few instances, it has been found that the presence of certain types of algae(filamentous species) actually enhances the filtration process by providing greater surface area for biological activity. In general, however, the presence of algae in the source water reduces filter run lengths. Therefore, it is prudent to reduce algae content in source water to as low a level as possible to limit its effect on the filter performance through shading of bed (AWWA, 1996).

(c) Dissolved Oxygen Level

The presence of dissolved oxygen (> 6 mg/l)in source water is critical for stimulating a healthy "schmutzdecke" for proper SSF operation and to reduce taste and odors. Reduction of dissolved oxygen levels commonly occurs following algal blooms. Some SSF plants use aeration of the water as a pretreatment (AWWA, 1996).

2.5.3 Effluent Water Quality

It is expected that a properly designed and carefully operated Multistage Filtration systems should have the effluent water quality which would be acceptable to most of the consumers and satisfy the international and local recommended water quality standards. Improvement of effluent water quality from MSFs observed in various research projects have been highlighted below:

(a) Physical Water Quality

- Coarse media filters have normally been specified to produce an effluent with turbidity less than 10-20 NTU (Gerado et al.).

- SSF effluent turbidities in the range of 0.1 to 0.2 NTU were typical for high-quality source waters. However, in general effluent turbidities less than 1 NTU can be achieved (AWWA, 1996).

- Under varying condition of operation, SSF treating raw waters of turbidity 5-30 NTU produced a good quality filtrate with turbidity well below 1 NTU (Joshi, 1982).

(b) Chemical Water Quality

- Under varying conditions of raw water quality, there was a marginal reduction in the pH value of water due to filtration (Joshi, 1982).

- Under tropical conditions, shading of SSF did not materially influence the length of filter run and produced a filtrate with a more or less uniform Dissolved Oxygen(DO) throughout the day (Joshi, 1982).

- Removal of organic substances was generally in the range of 15% to 25% (AWWA, 1996).

- The DO in the filtrate was found to be lower with lower rates of filtration (Paramasivam and Sundaresan, 1978).

- The organic content (COD) of raw water ranged from 4.5 to 10.5 mg/L reduced from 50% to 72% through filtration process and this reduction was independent of rate of filtration (Joshi, 1982).

- 33% to 66% TOC removal was achieved through multistage filtration units (Abernethy, 2004).

(c) Microbial Water Quality

- Slow Sand Filtration has been shown to be effective in achieving removal of Giardia and viruses (AWWA, 1996).

- The bacteriological results clearly showed that when the filter was run without interruption, a filtrate of consistently satisfactory quality was obtained. However, when switched over to intermittent operation, a definite deterioration in bacterial quality occurred (Paramasivam et al., 1980).

- It was observed that the slow sand filter operated at 0.1 m/h delivered water free from E,Coli on 66 occasions out of total 71 samples tested and when it was operated at 0.2 m/h delivered water free from E,Coli on 72 occasions out of total 76 samples tested (Paramasivam and Sundaresan, 1978).

- In a study in Latin America 69.5 to 75.2 percent reduction of faecal coliform densities were achieved through coarse media filtration.

- To evaluate the effectiveness of SSF for rural water supply schemes it has been proposed to provide extra filter area or stand by units for allowing sufficient time for the growth of biological layers on sand surface (Rao et al., 2003).

2.6 Concluding Remarks

The selected literature sited here gives an overview of the thesis approaches in the field of filtration process for the treatment of surface water. Surface waters with high turbidity and bacteriological impurities are primarily responsible for early failure of the treatment system. Slow sand filtration applied as surface water treatment is particularly effective in improving the microbiological water quality. However, effective application of this treatment process requires raw water of low turbidity. To protect the pond sand filter from premature break down, pretreatment of raw water has been suggested. Conventional pretreatment systems such as sedimentation, flocculation for solid matter separation is generally inappropriate in rural water supplies of developing countries for a number of reasons, such as unavailability of chemicals, inadequate dosing equipment, difficult operation and maintenance, as well as lack of local technical skills and trained operators. Therefore, simple techniques are preferable for pre-filter design in treating the surface water.

Slow sand filters in combination with roughing filters may present a reliable and sustainable treatment process particularly for developing country like Bangladesh. Practical experience shows (Wegelin, 1996) that roughing filters can achieve a particulate matter reduction of 90% or more. Furthermore, pre-filters and roughing filters can improve the bacteriological water quality. Roughing filters also reduce color to some extent, dissolved organic matter and other substances found in surface waters.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

Initially a model MSF unit was developed in the concrete laboratory of Civil Engineering building, BUET. Raw water was collected from nearby ponds and simulated to the water quality of field condition. Raw water and filtered water samples were tested from the various stages of treatment in order to determine the effectiveness of the unit process of the model MSF for selected water quality parameters. The head loss and filter run length of the model MSF were also measured. The effectiveness of different operational units of model MSF was examined and the findings were analyzed along with experimental and theoretical basis.

On the basis of few findings of the model MSF units and literature review, a field design of MSF units had been developed and three Multistage Filters were constructed to treat pond water in three different areas of Jessore, Comilla and Chandpur districts of the country. Effectiveness of the Multistage Filtration Units was monitored very closely for a period of over six months. After careful evaluation of the field data and making comparison to the laboratory data obtained from model MSF units, finally, design criteria have been developed for fundamental design parameters and a cost effective new Multistage Filtration Units for surface water treatment have been proposed.

3.2 Experimental Run of the Model MSF Units

3.2.1 Design and Set Up of Model MSF Units

a) Number of Filter Units

As shown in the Figure-3.1 the laboratory experimental set up consisted of a dynamic roughing filter (DyRF) chamber at the beginning, followed by an up-flow roughing filter (URF) chamber before final slow sand filter (SSF) chamber to cope with high turbidity and microbial load in the raw water. Figure-3.2 and 3.3 show the laboratory multistage filtration units with water feeding arrangement.

b) Construction Materials

These chambers were made of MS sheet welded with MS angle at the edges and supported on MS angle legs to allow the influent water flowing by gravity from inlet to outlet end. All chambers were fitted with interconnecting pipes, water sample collection port and drainage outlet.

c) Size and Shape

Cross sectional area, height and other particulars are listed below in Table-3.1

Table-3.1: Detail Description of Laboratory Experimental Units.

MSF units	Shape	Size (mm) and Area	Height (mm)
DyRF	Rectangular	(250+150) x 250 = 0.0625 m^2	800
URF	Circular	500 Dia = 0.23 m^2	1200
SSF	Rectangular	500 x 1000 = 0.50 m^2	1200

d) Number of Experimental Run and Duration

Total four experimental runs were conducted under different environmental and filter bed conditions during a period of six months. Particularly, during the 4th experimental run, variable flow conditions were maintained. Table-3.2 shows the variable conditions and the duration of experimental runs.

Table-3.2: Details of Experimental Runs- Duration, Bed and Flow Condition

MSF Units	Duration	Bed Materials & Bed Exposure Condition	Flow Rate & Type of Flow
1st Run	28 days	Comparatively Coarser & Bed Unshaded	Fixed Flow (0.2 m/h) Uninterrupted Flow
2nd Run	40 days	Moderately Coarse & Bed Shaded	Variable Flow Rates Intermittent/Uninterrupted
3rd Run	21 days	Moderately Coarse & Bed Shaded	Variable Flow Rates Intermittent /Uninterrupted
4th Run	40 days	Comparatively Finer & Bed Shaded	Variable Flow Rates Intermittent /Uninterrupted

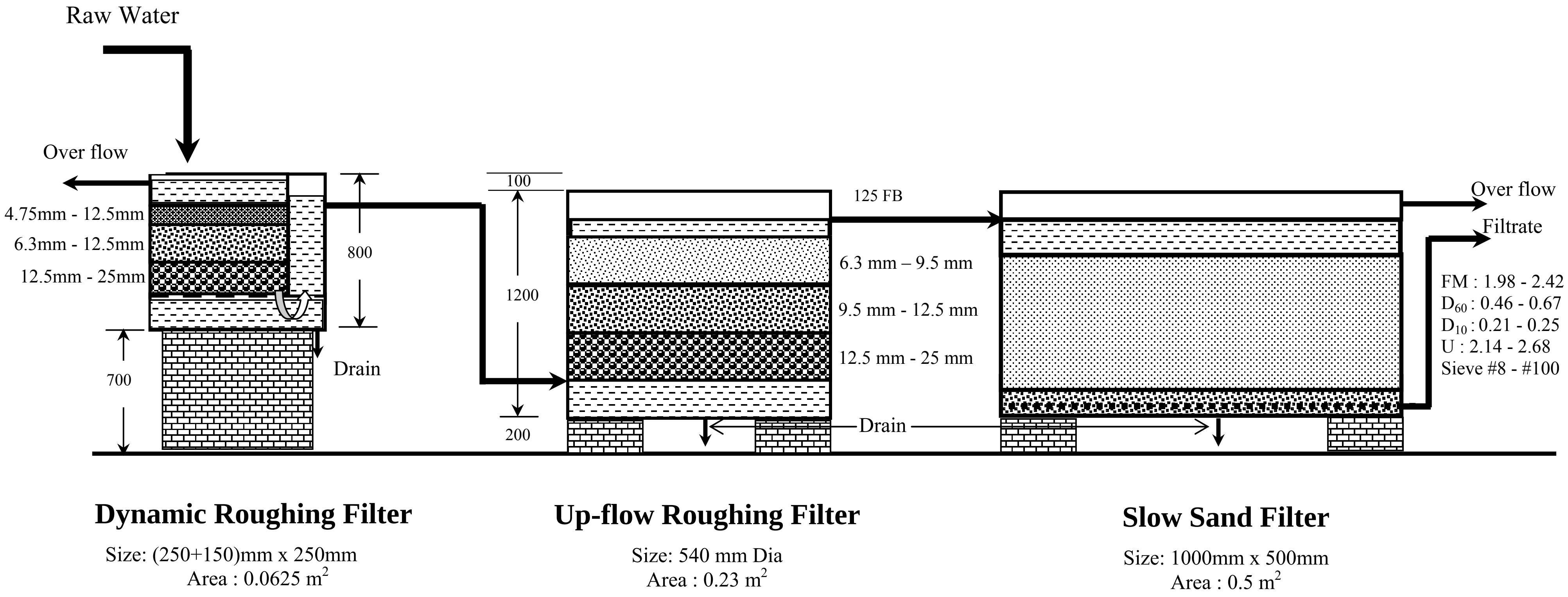


Figure-3.1: Layout Diagram of Experimental Set up of Model Multi stage Filtration Units

Figure-3.2: Front View of the Laboratory Multistage Filtration Units

Figure-3.3: Laboratory Raw Water Feeding Arrangement to MSFs

e) Filter Materials Characteristics

The DyRF and URF chambers were filled with different sizes of brick chips as shown in the Table-3.3 and Table-3.4. The SSF chamber was also filled by graded sand layers placed on graded brick chips under drainage system as shown in Table-3.5. The filter materials were washed to remove all dust before use. During the 1st run, coarser sand materials compared to other experimental runs were used and during the 2nd and 3rd runs, comparatively finer sand materials were used. However, two different sand layers were maintained during the 4th run.

Table-3.3: Characteristic of Coarse Media in Dynamic Roughing Filter

Position in Filter Bed	**Sieve Analysis Results**	**1st Run* (28days)**	**2nd Run# (40days)**	**3rd Run# (21days)**	**4th Run # (42 days)**
Top Layer (50 mm thick)* (125mm thick)#	Passing through Sieve #	½ " (12.5 mm)	¼ " (6.3 mm)	¼ " (6.3 mm)	¼ " (6.3 mm)
	Retaining on Sieve #	¼ " (6.3 mm)	# 4 (4.75 mm)	# 4 (4.75 mm)	# 4 (4.75 mm)
Middle Layer (225 mm thick)	Passing through Sieve #	½ " (12.5 mm)	½ " (12.5 mm)	½ " (12.5 mm)	½ " (12.5 mm)
	Retaining on Sieve #	¼ " (6.3mm)	¼ " (6.3mm)	¼ " (6.3mm)	¼ " (6.3mm)
Bottom Layer (225 mm thick)	Passing through Sieve #	1 " (25 mm)	1 " (25 mm)	1 " (25 mm)	1 " (25 mm)
	Retaining on Sieve #	½ " (12.5 mm)	½ " (12.5 mm)	½ " (12.5 mm)	½ " (12.5 mm)

Table-3.4: Characteristic of Coarse Media in Up-flow Roughing Filter

Position in Filter Bed	**Sieve Analysis Results**	**1st Run* (28days)**	**2nd Run** (40days)**	**3rd Run** (21days)**	**4th Run** (42 days)**
Top Layer (250 mm thick)* (350 mm thick)**	Passing through Sieve #	⅜ " (9.5 mm)	⅜ " (9.5 mm)	⅜ " (9.5 mm)	⅜ " (9.5 mm)
	Retaining on Sieve #	¼ " (6.3 mm)	¼ " (6.3 mm)	¼ " (6.3 mm)	¼ " (6.3 mm)
Middle Layer (250 mm thick)* (350 mm thick)**	Passing through Sieve #	½ " (12.5 mm)	½ " (12.5 mm)	½ " (12.5 mm)	½ " (12.5 mm)
	Retaining on Sieve #	⅜ " (9.5 mm)	⅜ " (9.5 mm)	⅜ " (9.5 mm)	⅜ " (9.5 mm)
Bottom Layer (250 mm thick)* (100 mm thick)**	Passing through Sieve #	1 " (25 mm)	1 " (25 mm)	1 " (25 mm)	1 " (25 mm)
	Retaining on Sieve #	½ " (12.5 mm)	½ " (12.5 mm)	½ " (12.5 mm)	½ " (12.5 mm)

Table-3.5: Characteristic of Filter Sand Materials in Slow Sand Filter

Characteristic of Sand Materials	**1st Run (28days)**	**2nd Run (40days)**	**3rd Run (21days)**	**4th Run (42days)**	
				Top 15 cm	**Top 15-150cm**
Fineness Modulus (FM)	2.42	2.26	2.21	1.84	1.98
D_{60}	0.67	0.60	0.56	0.46	0.47
D_{10}	0.25	0.25	0.25	0.21	0.22
Uniformity Coefficient (U)	2.68	2.40	2.24	2.16	2.14
Passing through Sieve #	8	16	16	16	16
Retaining on Sieve #	100	100	100	100	100
Filter Bed Exposure	Unshaded	Shaded Filter Bed			

f) Rate of Filtration Range-

Six different ranges of filtration rate were maintained for three filtration steps as follows:

Table-3.6: Various Range of Filtration Rates Maintained in Multistage Filter Units

MSF Units	Range and Rate of Filtration (m/h)					
	1st	2nd	3rd	4th	5th	6th
DyRF	0.80	1.20	1.60	2.00	2.40	3.20
URF	0.22	0.33	0.43	0.54	0.65	0.87
SSF	0.10	0.15	0.20	0.25	0.30	0.40

3.2.2 Preparation of Surface Water Sample

a) Collection of Surface Water Samples from Field

Prior to the laboratory experiment work, water samples from three rivers located in the arsenic affected areas were collected during rainy season and were tested for turbidity, color and Thermotolerant Coliforms (TTC) concentrations to assess the water quality of the field in worst situation. The results have been summarized in the Table-3.7 which indicates that flowing waters of river and streams contain more suspended particles causing more turbidity than still water of pond. The water quality data of pond water collected for laboratory use have been shown in Table 3.8.

Table-3.7: Water Quality of River Water in the Arsenic Affected Areas

Water quality Parameters	Sampling Location			Average Range of Conc.
	River Gomoti (Muradnagar)	River Dakatia (Hajigonj)	River Dhaleswari (Sirajdikhan)	
Turbidity (NTU)	55 – 65	85 – 95	100 – 110	80 – 90
Color (Pt.Co.Unit)	40 – 45	50 – 55	50 – 60	46 – 53
TTC (CFU/100ml)	250 – 300	300 – 350	400 – 500	320 – 550

b) Preparation of Laboratory Raw Water

During the experimental run everyday sample water collected from nearby ponds was mixed with tap water and a small portion of silt/clay at desired proportions for the simulation of field surface water quality and to obtain a concentration within the average range of values shown in the Table-3.7. Continuous mixing was done with electric motor driven propeller to maintain homogenous condition and to keep the turbid particles in suspension. From the mixing tank, water was pumped to an elevated tank provided with overflow pipe and flow control valves to maintain fixed head flow conditions. Desired rate of flow was maintained through regular measurement of flow rate. The flow rate was measured by measuring the volume of water flowing during a specific time period.

Table-3.8: Water Quality of Sample Water Collected from Nearby Pond

Pond Location	**Water Quality Parameters**		
	Turbidity (NTU)	Color (Pt.Co.Unit)	TTC (CFU/100ml)
Azimpur Colony	30 – 35	90 – 110	5000 – 6000
Jagannah Hall, DU	10 – 18	35 – 60	300 – 1100

3.2.3 Collection of Water Samples for Laboratory Analysis

a) Sampling Procedure and Water Quality Analysis

Water samples were collected from different sampling points after certain interval from the starting of the process, determining the average detention times of water in each unit on the basis of flow rate and pore volume of the media.

For physical and chemical quality investigation, water samples were analyzed for turbidity and color regularly, however, frequent samples were analyzed also for pH, EC, DO, NH_4, and COD. Visible Range Spectrophotometer was used to measure color value and ammonia concentration. Portable Turbidimeter, pH meter, DO meter and EC meter was used to determine the results directly at the experimental set up point.

For microbial quality analysis TTC concentration was determined regularly using membrane filter technique and occasionally E. Coli concentration was also determined.

b) Duration of Experimental Run and Interpretation of Data

Experiments were conducted under variable flow rates, types of flow, different range of impurities concentrations in raw water and filter bed conditions. For a particular experimental condition, turbidity and color were tested at least for two weeks; microbial and chemical water quality parameters were tested for at least one week period. At least three water samples were collected daily with some interval from each sampling point to get an average value.

3.3 Construction and Monitoring of the Field Multi Stage Filters

3.3.1 Location of the Field MSF Units

Table-3.9 shows the locations of the field MSFs. Performance of all the MSFs was monitored regularly for over a six months period through the collection and analysis of water samples from different locations.

Table-3.9: List of Multi Stage Filters in the Field

ID No.	Name of the Caretaker	Name of the Village	Thana	District
1	Md. Liaqat Ali	Palua	Chowgacha	Jessore
2	Hafez Sulaiman	Karba	Saharasti	Chandpur
3	Sisir Babu	Madha Nagar	Muradnagar	Comilla

3.3.2 General Features of the Field Multi Stage Filters

3.3.2.1 Main Components

The field MSF treatment plants consist of three chambers- (i) Up-flow Roughing Filter Chamber, (ii) Slow Sand Filter Chamber and (iii) Clear Water Storage Chamber. The Dynamic Roughing Filter chamber has been omitted for treating pond water which contained a turbidity level less than 50 NTU. The flow diagram of the treatment unit is shown in Figure-3.4. Hand pump spout is connected with the up-flow roughing filter chamber bottom through a 50 mm PVC pipe and the pumped water flows upward through the coarse media (graded brick khoa placed symmetrically in three different layers) and enters the slow sand filter chamber through two interconnecting slotted water distribution pipes. The slow sand filter chamber is divided into two independent compartments to allow alternative cleaning and washing of filter materials. Water trickles down the filter sand and the filtrate is collected in a clear water storage chamber through the under-drainage system made of two slotted PVC manifold pipes and surrounded by brick chips and coarse sand/gravel. The interconnecting pipes between the filter chamber and clear water chamber are provided with flow control gate valves and arranged in such a way that filter beds never get dry. The Clear Water Chamber is connected with a pot chlorinator through a PVC tube and chlorine solution adjustment valve, which is placed on the top of the Clear Water Chamber.

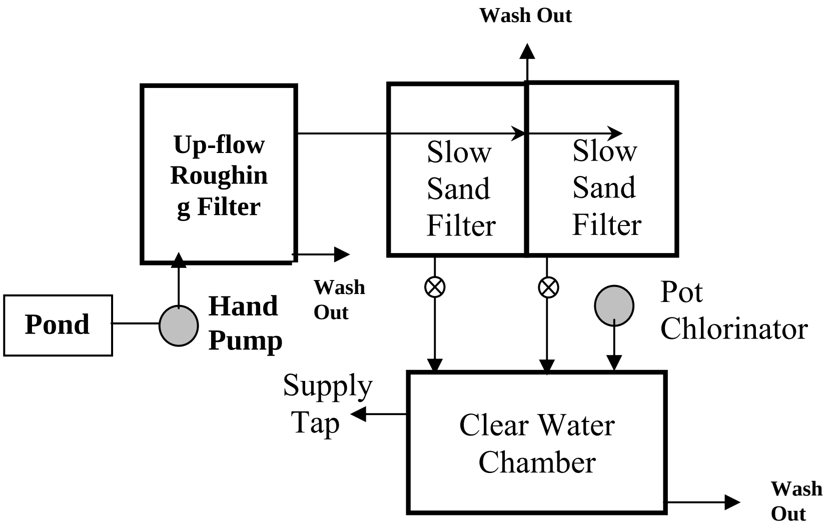


Figure-3.4: Flow Diagram of the Field Multi Stage Filters

Top lid of the filter chamber is made of 20 gauge MS sheet welded on MS angle to avoid the entrance of insects and dust. Both the roughing filter chamber and slow sand filter chambers are provided with bottom wash out pipes and valves. Surface drain has been constructed around the MSFs to dispose off the roughing filter and slow sand filter wastewater during cleaning. Figure-3.5 to 3.7 shows the plan and different views of the field Multistage Filters.

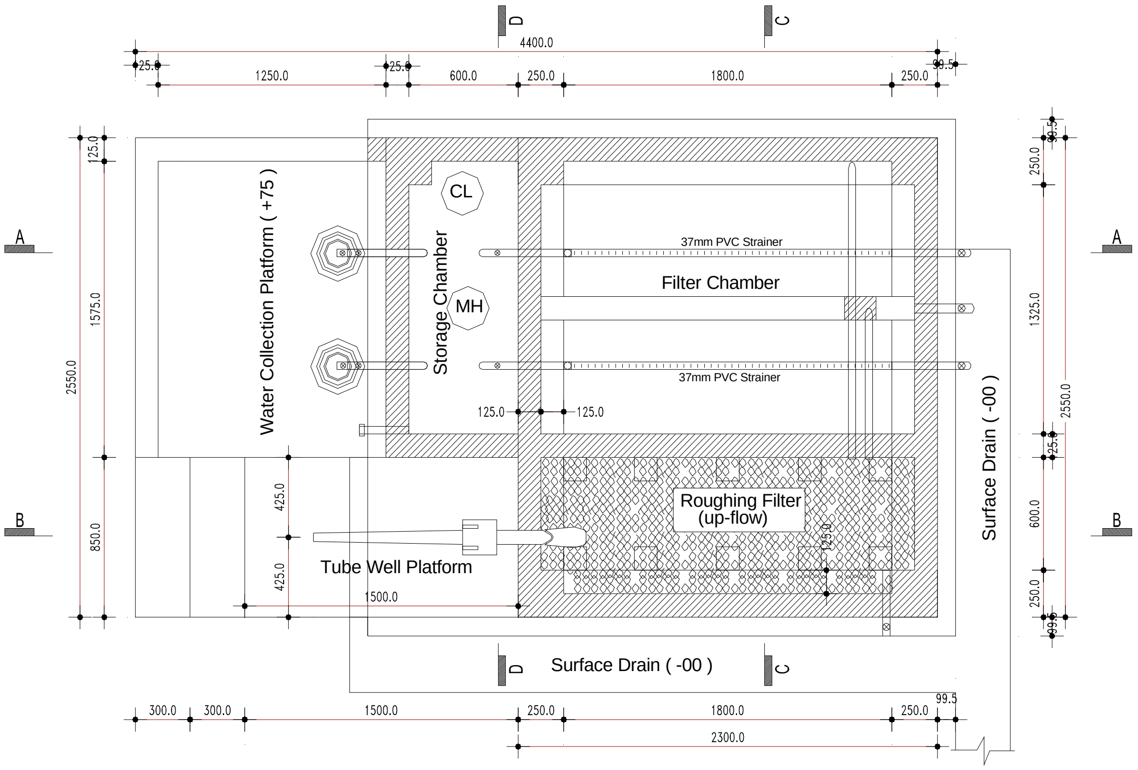


Figure-3.5: Plan of the Field Multi Stage Filter

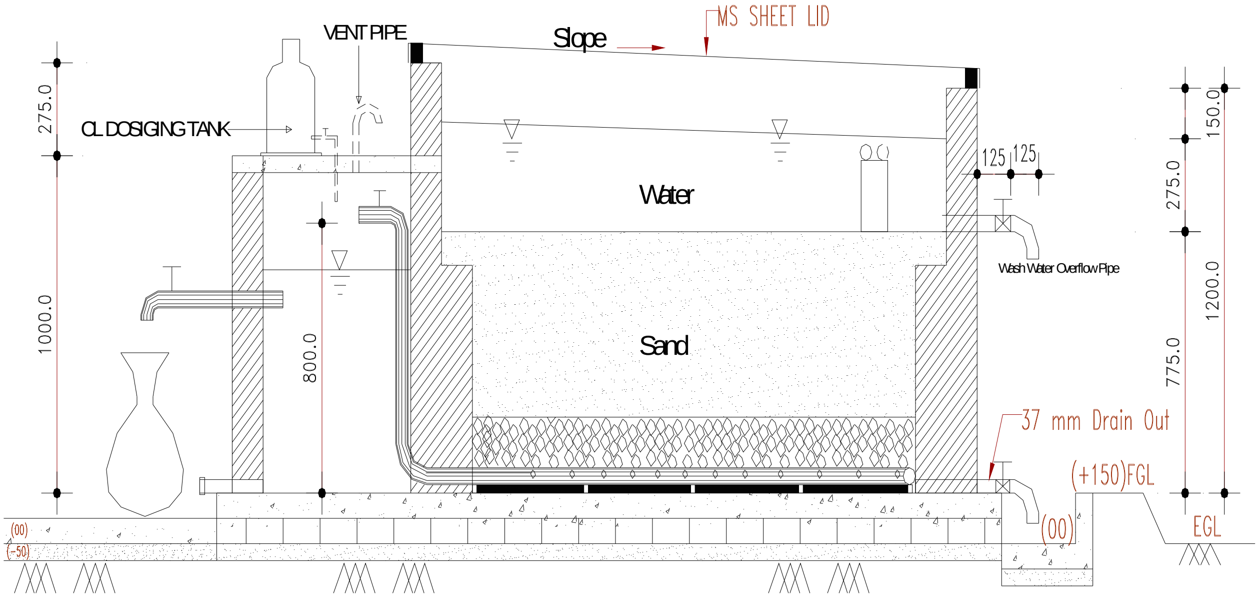


Figure-3.6: Longitudinal Section of field MSFs

Figure-3.7: Different Views of the field MSFs

3.3.2.2 Design Considerations

The size of the Up-flow Roughing Filter bed has been made about 1.46 m^2 to maintain an average face velocity of around 0.79 m/h. The average rate of flow across the roughing filter bed is around 1.15 m^3/h.

The size of the slow sand filter bed has been made about 2.92 m^2 to maintain an average rate of filtration of around 0.20 m/h. (maximum rate of flow across the slow sand filter bed is around 0.78 m^3/h); however, actual rate of filtration is much lower due to intermittent operation of hand pumps attached to the field MSFs.

The size of sand materials has been selected (D10 = 0.20 – 0.25 mm, U = 2 – 3, passing sieve # 16 and retaining on sieve # 100, FM = 1.8 - 2.0) to ensure the use of standard slow sand filter materials. The depth of the sand bed is 600 mm and it is placed on 175 mm thick under-drainage system. The under-drainage system is made of two numbers 37 mm ϕ PVC Strainers surrounded by two layers of 175 mm thick brick chips (size range: 2 mm to 10 mm).

3.3.3 Monitoring of Performances and Testing of Water Samples

Performances of MSF units were monitored time to time through measuring flow rate, recording variation of head loss, collecting and analyzing water samples from various points of MSF units. Effectiveness of MSF units were determined in terms of impurities removal as a percent of influent water quality. Moreover, length of run between cleaning was also recorded.

The following water quality parameters were monitored regularly:

(a) Turbidity, (b) Color, (c) Faecal Coliform

Samples were tested at the BUET Environmental Engineering Laboratory. Standard Methods were followed for analysis of water samples. Field kits from BUET and ITN (Portable Turbidity meter, Spectrometer and Membrane Filter Unit) were also used to monitor the effluent quality directly at the field.

3.4 Problems Encountered During the Experimental Runs

During the experimental runs following problems were encountered. However, measures were taken to solve those problems:

- Collected Pond water quality was not uniform and organic pollutant and TTC concentration were sometimes very high.
- Overnight storage of pond water in the mixing tank enhances the growth of microbial load which gave high TTC counts.
- Maintaining uniform raw water turbidity level through the experimental period was very difficult.
- Trapping of air inside the interconnecting pipes sometimes stopped the flow of water.
- Bulking of sand filter chamber during high head loss caused cracks in the filter bed.
- Ponds, having no external protection, were found to be highly polluted by microbial loading which were difficult to use in MSF units as raw water.
- To maintain specific TTC and turbidity load in raw water mixing of tap water was required which changed the actual constituent of the pond water

CHAPTER FOUR

PHYSICAL WATER QUALITY IMPROVEMENT IN LABORATORY AND FIELD MSF UNITS

4.1 Introduction

In assessing the performance of a surface water treatment system, physical quality of effluent water, particularly turbidity and color is important. These two physical water quality parameters are also important from aesthetic considerations, particularly acceptability to consumers for domestic consumption. This chapter describes the removal performance of turbidity and color through different units of MSF both in laboratory and field considering the effect of different process variables and role of different filtration stages including the comparison of performance between field and laboratory model.

4.2 Performance of Laboratory MSF Units

4.2.1 Performance of Different Filtration Stages

Water quality improvement performance of different filtration stages i.e. DyRF, URF were investigated closely through different experimental runs. The contribution of different zones of DyRF in removing turbidity and the performance of URF bypassing the flow through DyRF were determined with separate batch studies.

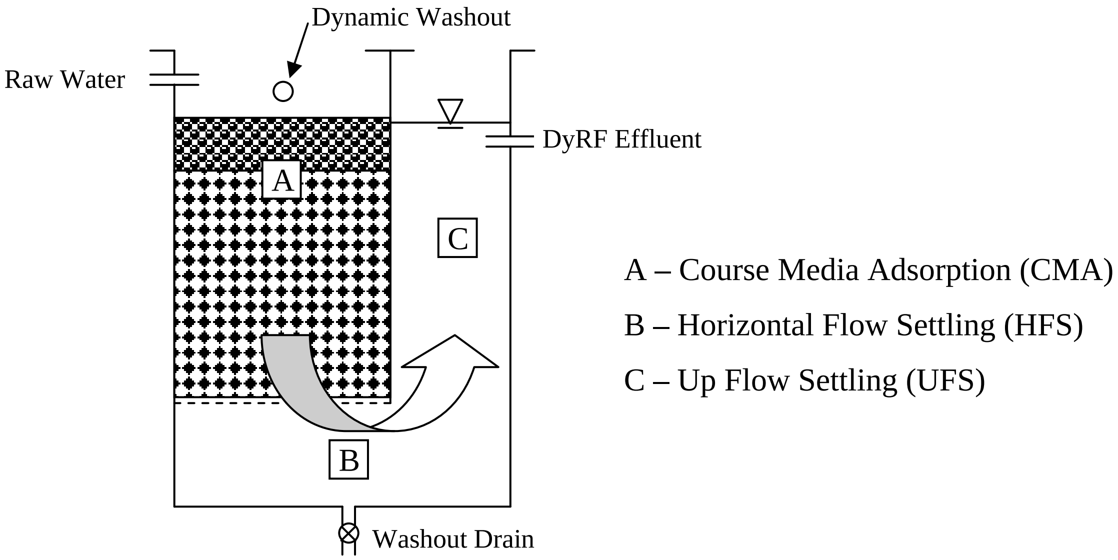


Figure-4.1: Schematic Diagram Showing the Different Zones of DyRF.

4.2.2.1 Performance of Different Zones of DyRF

The dynamic roughing filtration unit comprises of three active zones which are mentioned as course media adsorption, horizontal flow settling and up flow settling as sketched in the figure-4.1. The turbidity removal contribution of these zones of DyRF were investigated through different experimental runs observing the effects of flow rate and filter bed materials to identify appropriate design criteria. The average removal contribution of these zones of DyRF with different flow rates in the final setup of bed material is presented in figure-4.2. This illustration indicates that removal contribution of different zones decrease with flow rate; removal contribution of up flow settling zone drops significantly with flow as the increasing flow prohibited the gravity setting of finer particles. However, no significant difference in removal contribution of course media adsorption zone was observed with flow rate ranging 0.8 m/h to 1.6 m/h.

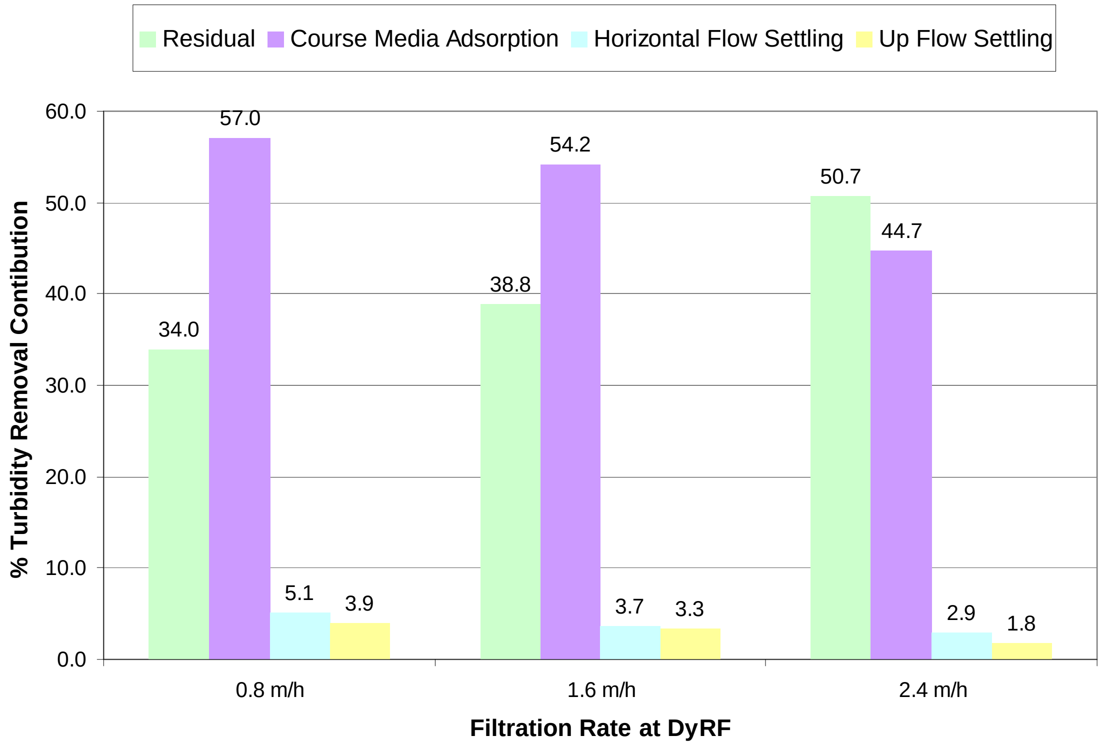


Figure-4.2: Turbidity Removal Contibution of Different Zones of DyRF with Flow Rates

It has been explained already in the Article 3.2.1, that for the DyRF and URF, comparatively smaller sizes coarse media with higher depth were used in the 2nd, 3rd and 4th experimental setup, being called final setup here, compare to the 1st experimental setup. As a consequence better turbidity removal was observed in course media adsorption zones of DyRF and which was further enhanced with operation period, which is presented in Figure-4.3, however, removal contribution decreased in HFS and UFS.

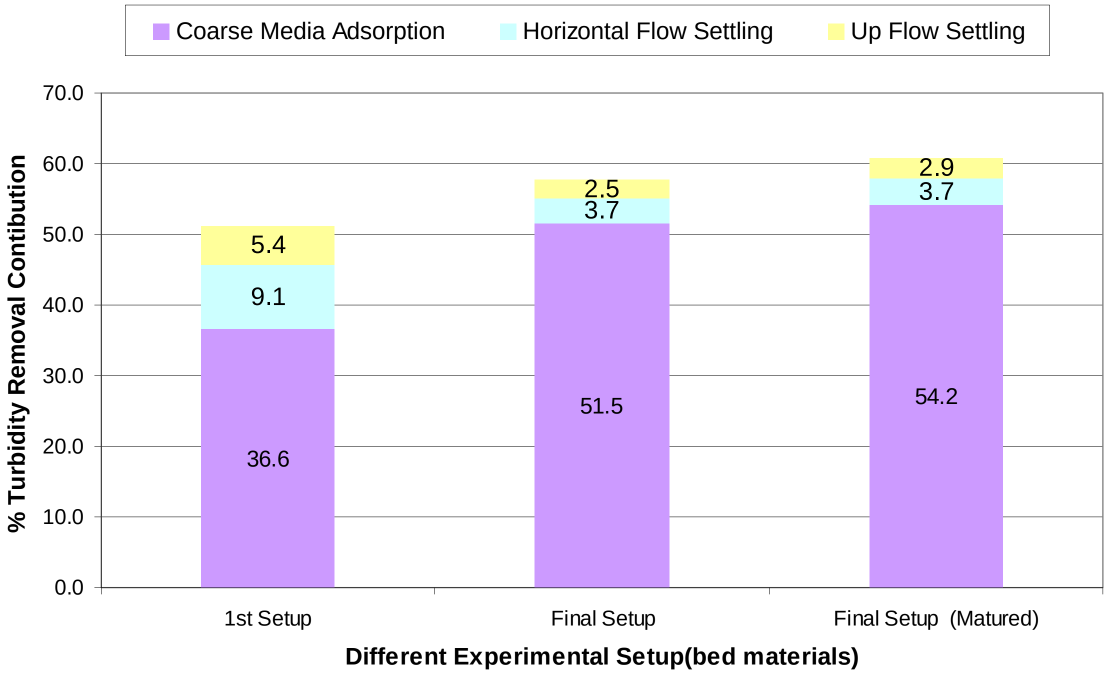


Figure-4.3: Turbidity Removal Contribution of Different Zones of DyRF with Filter Bed Materials

This was occurred due to the increase in adsorption of settlable particles in the previous zone (CMA) and in case of UFS zone the gravitational settling was directly affected by the increased up flow filtration rate.

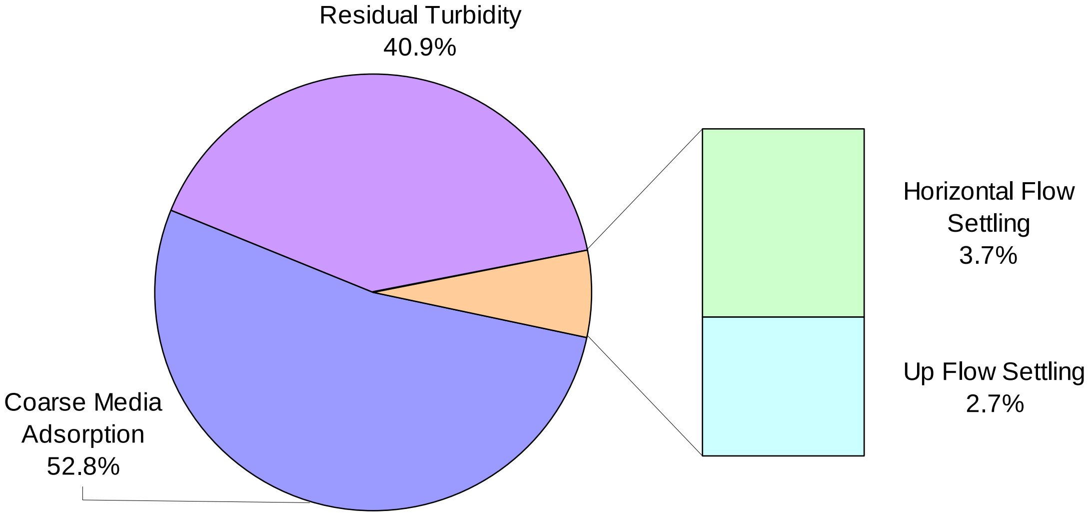


Figure-4.4: Average Turbidity Removal Contribution of Different Zones of DyRF (Final Setup)

Finally the average turbidity removal contribution of the three zones of DyRF is expressed by pie diagram in the figure-4.4 which reveals that CMA zone performed very important role in turbidity removal compared to the others. For CMA zone filtration rate more than 1.6 m/h can be used for DyRF in the final setup bed material condition but for HFS and UFS zones flow rate need to decrease for better contribution of these zones. It can be done by increasing the active area of UFS zone and settling can be enhanced by incorporating tube settler or inclined settler arrangement with DyRF unit.

4.2.2.2 Performance of URF Unit Bypassing DyRF

Some experimental runs were also done by flowing the raw water directly to the up flow roughing filtration unit with raw water having four ranges of turbidity levels and filtration rates presented in figure-4.5. It reveals that the turbidity removal percentage of up flow roughing filtration unit decreased with filtration rate, which is identical to the other results, but increased with increase in raw water turbidity. The situation is further illustrated separately with different raw water turbidity range in figure-4.6 and with different filtration rate of up flow roughing filter in figure-4.7.

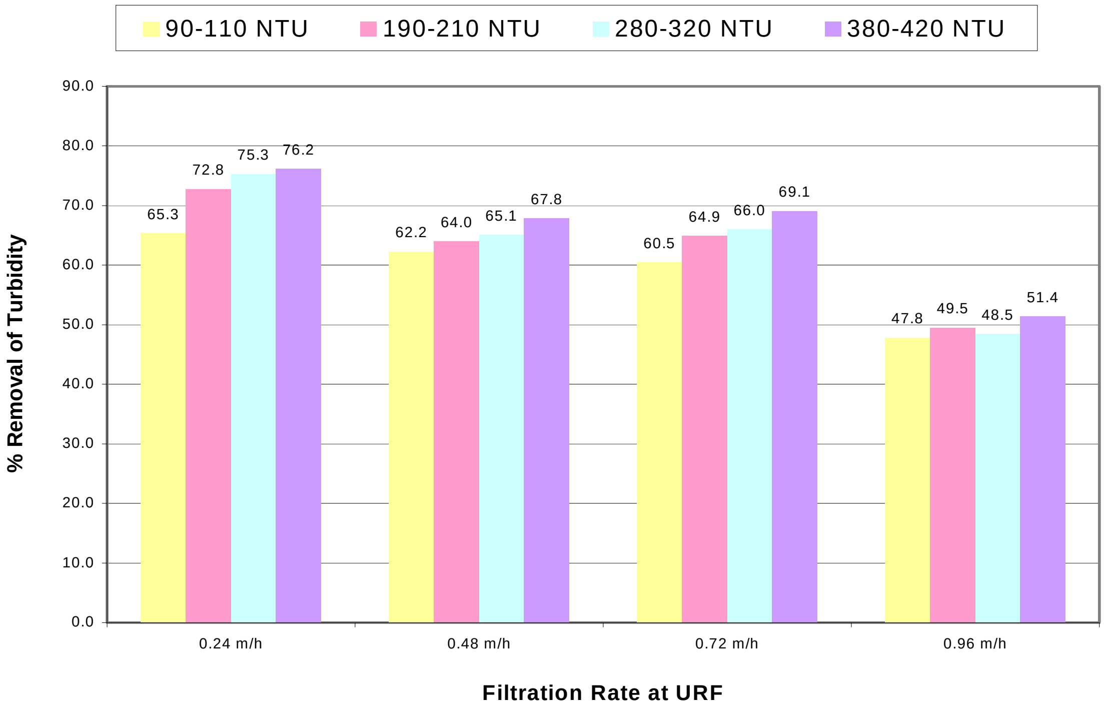


Figure-4.5: Turbidity Removal Efficiency of URF with Bypassing DyRF Condition

Figure-4.6 reveals that at flow rates in the range 0.48 m/h to 0.72m/h the turbidity removal performance differed very slightly, beyond and below of this filtration range significant drop and rise occurred in removal performance respectively, which indicates that a long range of filtration rate can be used for design purpose. Preferably the upper limit should be selected for design as lower flow rate cause less yield which affects the user acceptability.

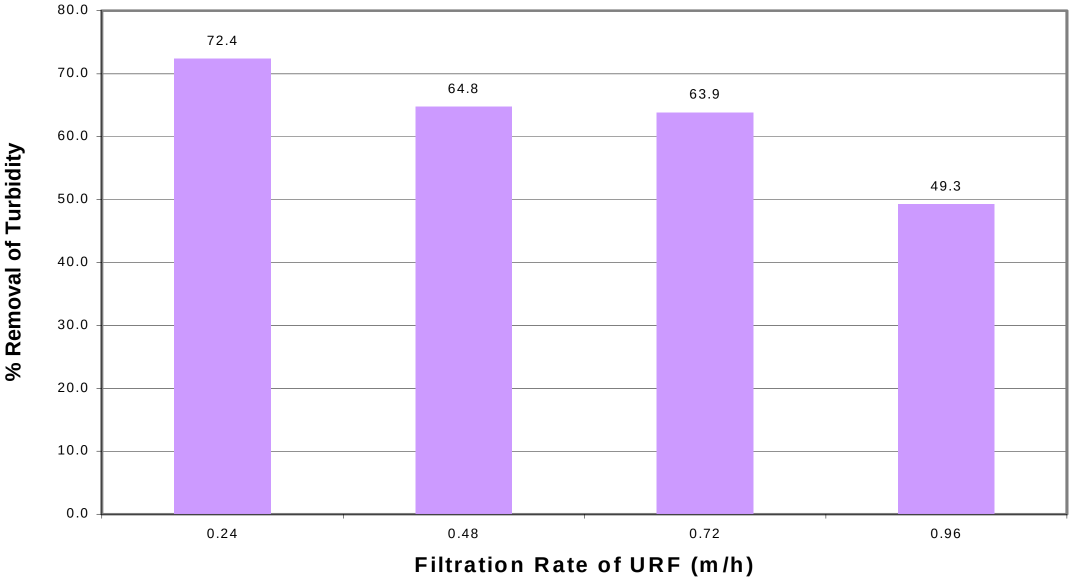


Figure-4.6: Average Removal of Turbidity with Variable Flow Condition of URF

Figure-4.7 shows turbidity removal percent in URF increased with increase in influent turbidity. In the laboratory MSF, turbidity of raw water was raised synthetically by mixing of clay soil which contained some amount of coarser and larger particles for

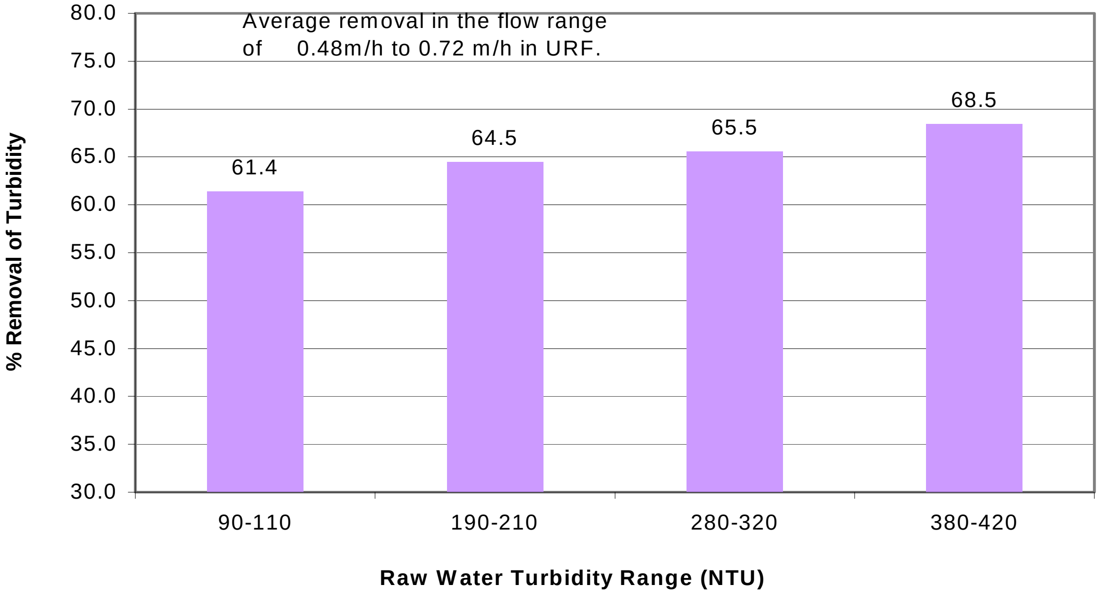


Figure-4.7: Average Removal of Turbidity with Variable Turbidity Range of Raw Input example sand and others. In higher range of raw water turbidity the amount of larger particles were higher and as a consequence, for the settling of these particles, the removal percent became higher. In case of DyRF, the identical situation was occurred in the coarse media adsorption zone, however, the overall removal did not vary due to the compensation made by other zones in removing the excess turbidity.

The filtration rate for URF can be proposed within a range of 0.48 m/h to 0.72 m/h in design for turbidity improvement. For average of 65% turbidity removal, observed in the experiment and showed in figure-4.6, turbidity greater than 60 NTU in raw water warrants install of pre treatment unit like DyRF prior to up flow filtration (URF) for safe and sustainable slow sand filer operation treating influent turbidity below 20 NTU.

4.2.2 Effect of Process Variable on Removal Performance

The physical quality improvement performances of laboratory MSF units were investigated through all the experimental runs observing the effects of the various process variables to develop appropriate design criteria. The maximum raw water turbidity and color concentrations, effect of bed materials, effect of filtration rate and flow condition, mean values and average percent removals under different environmental conditions have been analyzed and presented in the following sections to describe the contribution of respective units and to determine the design criteria.

4.2.2.1 Effect of Filter Bed Materials:

Turbidity removal performance:

The effect of the bed materials on turbidity reduction contribution of MSF units are presented in the Table-4.1 and also shown in Figure-4.8 and 4.9. The results indicate that average turbidity reduction contribution of DyRF and URF in the 2nd, 3rd and 4th experimental runs were identical and slightly better than that of 1st experimental run, i.e. around 58% and 27% respectively. This is possibly due to the use of comparatively smaller sizes coarse media with higher depth of bed material in these (2nd, 3rd and 4th) experimental runs. Bed material characteristics of different experimental runs have been described in detail in Article 3.2.1.

Table-4.1: Contribution of Different MSF Units in total Removal of Turbidity with Experimental Run

Experimental Run # (Filt. rate at SSF)	Average Raw Water Conc. (NTU)	Average Effluent Conc. (NTU) (Percent Removal Contribution)			Average Cumulative % Removal
		DyRF	URF	SSF	
1st Run (0.20 m/h)	90	43.2 (52%)	22.5 (23%)	1.05 (23.8%)	98.8%
2nd Run (0.20 m/h)	85	35.7 (58%)	12.8 (27%)	0.7 (14.2%)	99.2%
3rd Run (0.20 m/h)	77	32.2 (58%)	11.3 (27%)	0.7 (14.1%)	99.1%
4th Run (0.20 m/h)	87	35.2 (59%)	13.0 (26%)	0.6 (14.3%)	99.3%

[Rate of Filtration: SSF = 0.20 m/h, URF = 0.43 m/h and DyRF = 1.6 m/h]

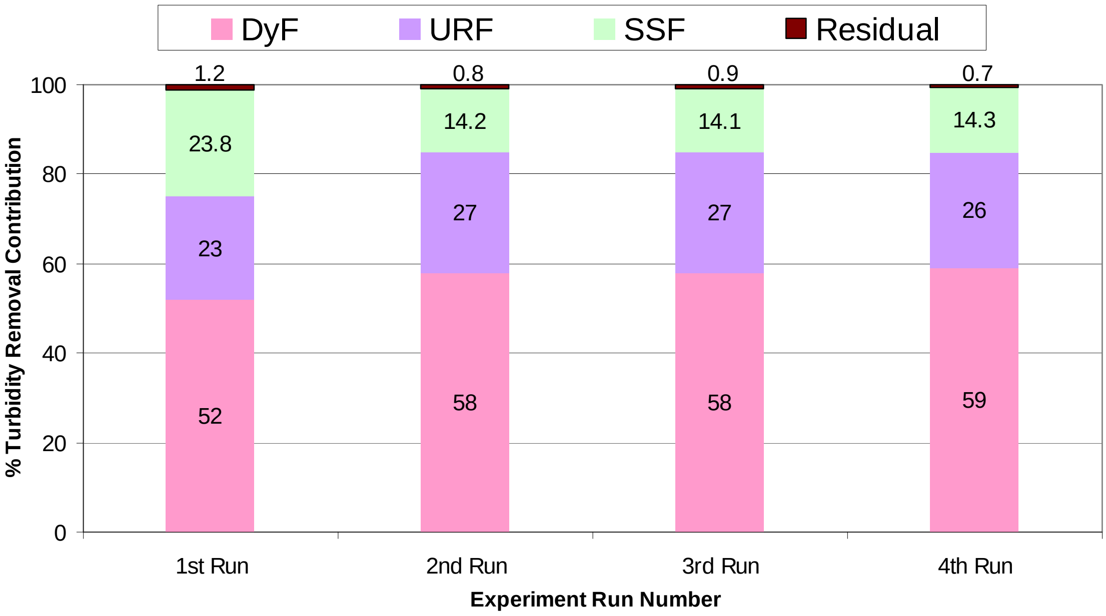


Figure-4.8: Variation of Turbidity Removal Contribution of Laboratory MSF Units with Experimental Run

Figure-4.8 indicates that, substantial turbidity removal was achieved through coarse media pre-filtration processes, however, contribution of slow sand filtration process in total turbidity removal was around 15% particularly during the last three experimental runs. Figure-4.9 shows that overall average SSF effluent turbidity values in all the experimental runs reduced from 85 NTU to 0.75 NTU which is much lower than the Bangladesh Environmental Quality Standard (EQS, 1997) of 10 NTU. This effluent turbidity value matches with other research findings (AWWA, 1996). Although this turbidity value does not satisfy the recommended turbidity value of 0.1 NTU for effective disinfection process, however, it is much less than the turbidity value which is usually acceptable to consumers, i.e. 5 NTU (WHO, 2004).

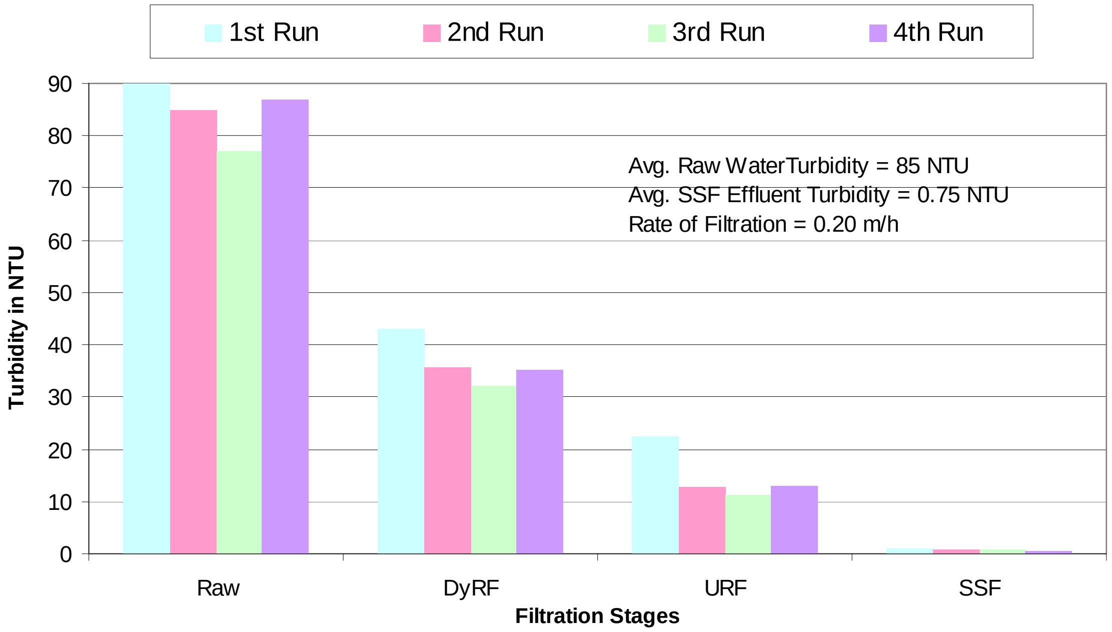


Figure-4.9: Reduction of Turbidity Value in Different MSF Units

Color removal performance:

The effect of the bed materials on color reduction contribution is presented in the Table-4.2 and also shown in Figure-4.10 and 4.11.

Table-4.2: Contribution of Different MSF Units in total Removal of Color with Experimental Run

Experimental Run # (Filt. rate at SSF)	Average Raw Water Conc. (Pt.Co.Unit)	Average Effluent Conc. (Pt.Co.Unit) (Percent Removal Contribution)			Average Cumulative % Removal
		DyRF	URF	SSF	
1st Run (0.20 m/h)	50	45.5 (9%)	35.5 (20%)	13.5 (44%)	73%
2nd Run (0.20 m/h)	41	36.9 (10%)	26.7 (25%)	8.6 (44%)	79%
3rd Run (0.20 m/h)	35	31.5 (10%)	22.4 (26%)	7.0 (44%)	80%
4th Run (0.20 m/h)	37	32.5 (12%)	23.3 (25%)	6.3 (46%)	83%

[Rate of Filtration: DyRF = 1.6 m/h, URF = 0.43 m/h and SSF = 0.20 m/h]

The average contribution to color removal, shown in figure-4.10, under the same experimental condition (2nd, 3rd and 4th experimental runs) through DyRF and URF processes were only 11% and 25% respectively, which is not identical to the turbidity removal contribution of the same units.

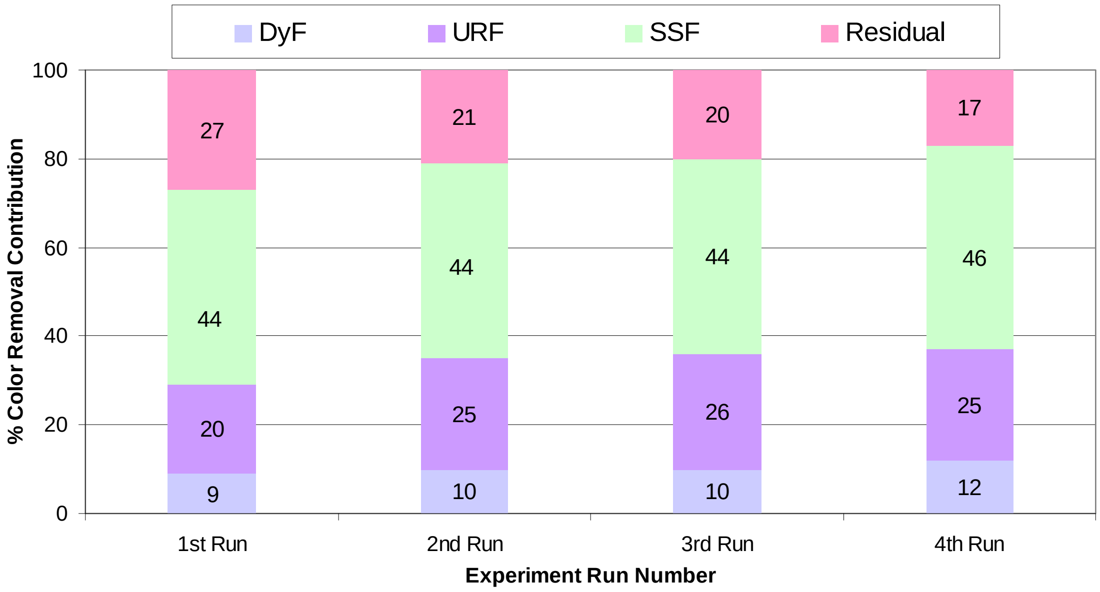


Figure-4.10: Variation of Color Removal Contribution of laboratory MSF Units with Experimental Run

Again, completely reverse situation was observed in case of color removal compare to turbidity removal in the slow sand filtration process through which major portion of color removal was occurred and average removal contribution of color was 45%.

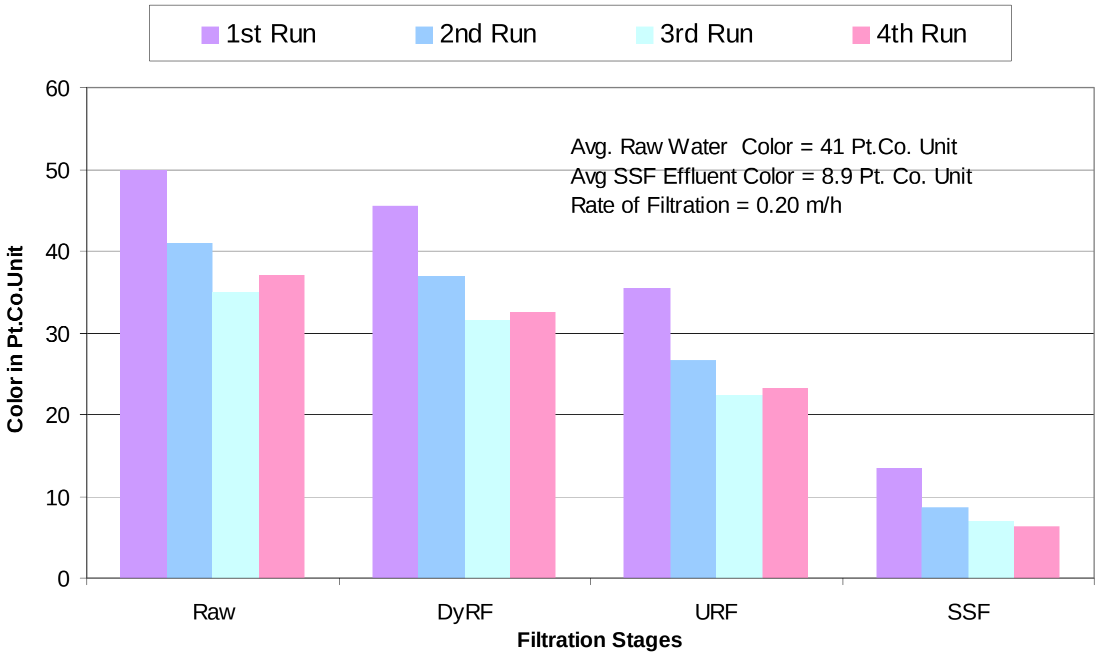


Figure-4.11: Reduction of Color Value in Different MSF Units

This was due to the fact that in the slow sand filtration unit biological activity was prominent which took part in the color removal process, converting color producing organic matter by chemical and biological oxidation, in addition to adsorption in the sand bed. Figure-4.11 shows that overall average SSF effluent color values in all the experimental runs reduced from 41 Pt.Co.Unit to 8.9 Pt.Co.Unit which is lower than the Bangladesh EQS, 97 of 15 Pt.Co.Unit. This value is usually acceptable to consumers and above which most people can detect color (WHO, 2004).

Coarse media pre-filtration steps are effective for the reduction of turbidity, while SSF is effective for the reduction of color value. Coarse media size range and depth of bed in DyRF and URF are more important parameter rather than SSF media size range for the reduction of turbidity. Filter bed materials used during the 4th experimental run may be selected for the design. Only the pre-filtration stages, DyRF including with URF, could be used for treating raw water having a moderate range of turbidity and color value to a standard recommended range excluding the slow sand filtration unit.

4.2.2.2 Effect of Raw Water Turbidity

Variation of turbidity removal contribution of MSF units under different raw water turbidity levels have been presented in the Table-4.3 and shown in Figure-4.12. Dynamic Roughing Filter was capable to handle high level of turbidity and on average 60% removal was achieved, which was almost same for all ranges of raw water turbidity tested.

Table-4.3: Role of Raw Water Turbidity on the Turbidity Removal Performance

Filtration Stages of MSFs	**Raw Water Average Turbidity Range (NTU)**					**Average Turbidity Removal (%)**
	75	**125**	**300**	**400**	**475**	
	Average Effluent Concentration (NTU)					
DyRF	31.6 (59%)	51.6 (59%)	121 (60%)	160 (60%)	180 (62%)	Raw/DyRF= 60%
URF	11.6 (26%)	18.4 (27%)	42 (26%)	55 (26%)	60 (25%)	Raw/URF = 86% DRF/URF = 64%
SSF	0.69 (14.1%)	0.94 (13.3%)	1.0 (13.5%)	1.2 (13.7%)	1.3 (12.7%)	Raw/SSF = 99.5% URF/SSF = 96.5%

[Rate of Filtration: DyRF = 1.6 m/h, URF = 0.43 m/h and SSF = 0.20 m/h]

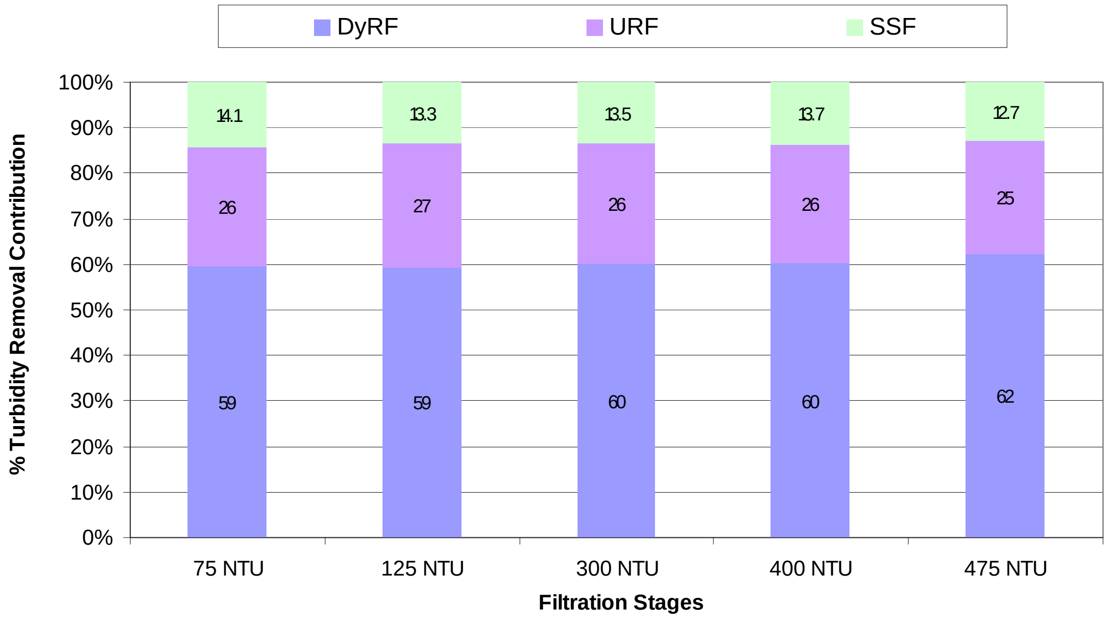


Figure-4.12: Turbidity Removal Contribution of MSF Units under Different Raw Water Turbidity Level

[Rate of Filtration: DyRF = 1.6 m/h, URF = 0.43 m/h and SSF = 0.20 m/h]

Subsequent removal through URF process individually was also around 64%, slightly less than the previous result of 65% in bypassing DyRF condition, and contribution of URF process in total reduction of turbidity through MSF was 26%, resulting an average cumulative removal of 86% after two stage prefiltration processes. Average turbidity removal contribution of SSF process was found around 13.5% though the individual removal efficiency of this process was very high (96.5%). Table-4.3 indicates that turbidity removal contribution of all the multistage filter units were almost same irrespective of raw water turbidity level which was reverse to the situation found in removal performance of URF analyzed individually where removal percentage increased with increase in raw water turbidity. This could be due to the removal of larger and coarser particles, responsible for the increase in removal percentage with raw water turbidity, in the DyRF prior to URF unit as described earlier in article 4.2.2.2.

It is usually recommended that influent turbidity to SSF should not exceed 10 NTU for effective operation of SSF (AWWA, 1996), however, in other study it has been observed that SSF treating raw waters turbidity value up to 30 NTU produced a good quality of water with turbidity well below 1NTU (Joshi et al., 1982). Therefore, a moderate influent turbidity value around 20 NTU may be proposed for SSF and from the Table-4.3, it may be concluded that in case of raw water turbidity level greater than 150 NTU, either pre-settling process in a plain sedimentation tank should be adopted, or water should be passed through an "Infiltration Galleries" for the removal of settleable suspended solids before multistage filtration processes. And it can be concluded from here also that if the raw water level remains within 60 NTU, DyRF step may be omitted.

4.2.2.3 Effect of Rate of Filtration

The performance of MSF units operated at various rates of filtration is summarized in Table-4.4 and presented in Figures-4.13. It was observed that the turbidity removal performance of DyRF reduced with successive higher filtration rate, however, increased in case of URF and SSF and ultimately total cumulative turbidity removal variation was found negligible up to maximum SSF operation rate of 0.20-0.25m/h. This result occurred because of the fact that, different zones of DyRF i.e. down flow course media zone, up flow settling zone are mainly dependent on gravity settling which are highly affected by filtration rate and as a result suspended particles were washed away due to higher velocity of flow from upper units which were subsequently retained on URF and SSF bed which are less vulnerable to flow rate.

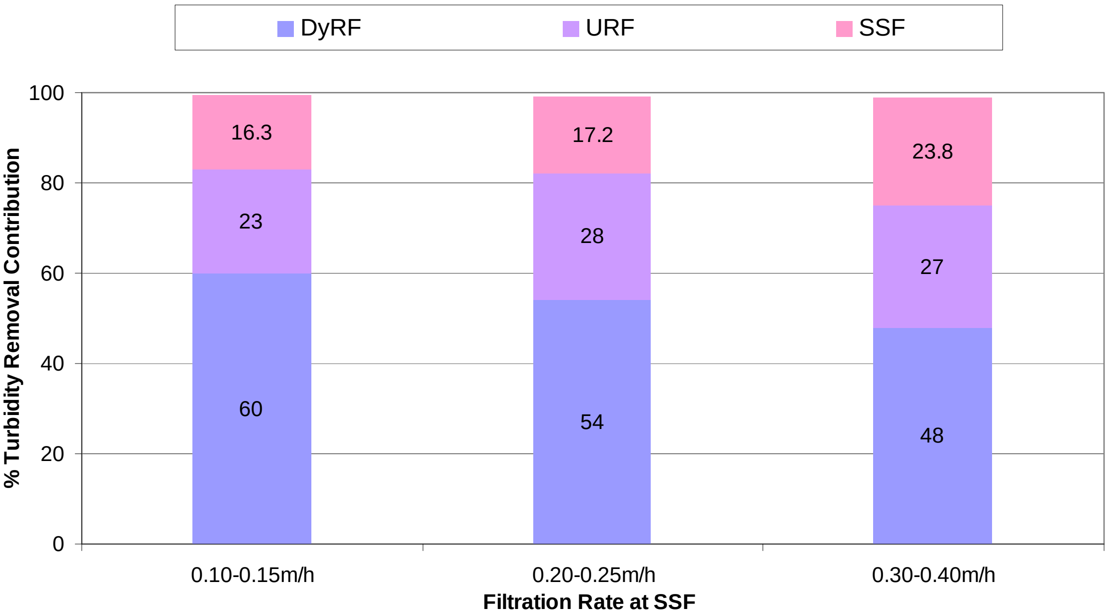


Figure-4.13: Variation of Turbidity Removal Performance with Rate of Filtration through SSF[Uniterrupted Flow]

[Filtration rates of DyRF and URF corresponding to that of SSF have been given in Table-4.4]

When the filtration rate was 0.30-0.40m/h at SSF, a definite deterioration of performance was observed as it happened in other studies (Paramasivam and Sundaresan, 1978).

Moreover, it was observed from the Figure-4.14, that increase of filtration rate beyond 0.20-0.25m/h also exceeds the proposed slow sand filter influent turbidity value of 20 NTU.

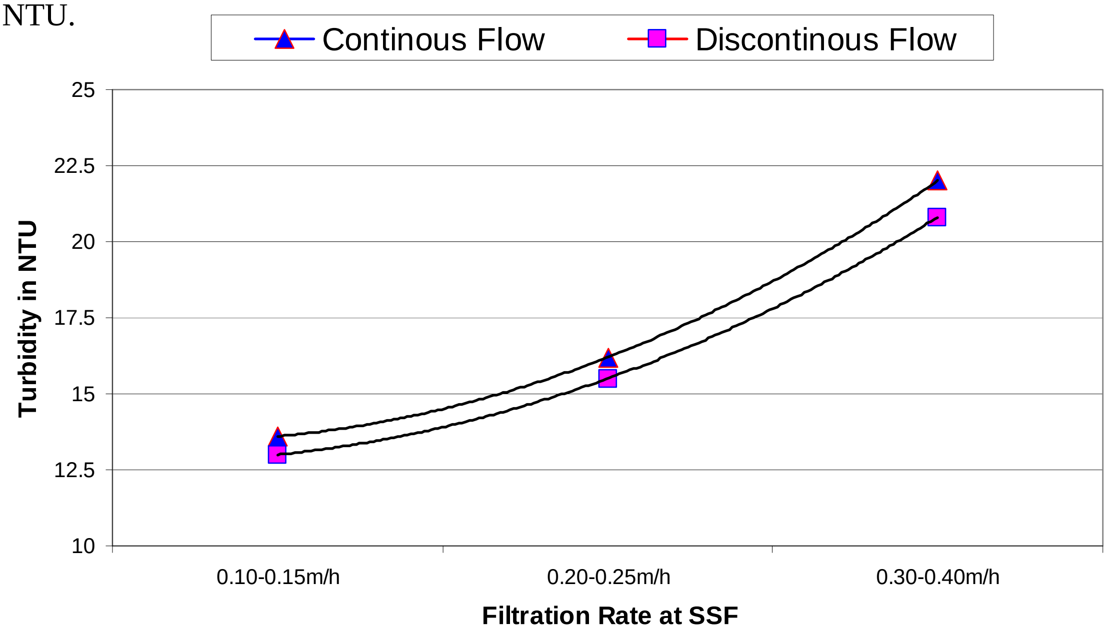


Figure-4.14: Variation of SSF Influent Turbidity with Rate of Filtration

Regarding the effect of rate of filtration on color removal, figure-4.15 shows that removal contribution of DyRF and SSF processes decreased with the increase of filtration rate and this rate was comparatively higher than turbidity removal. This occurred due to the shorter retaining period of water in the sand bed to adsorb and oxidize the color producing organic matter.

Table-4.4: Variation of Turbidity Reduction with Rate of Filtration

	Multistage Filtration Units		
	DyRF		
Rate of Filtration	0.80 - 1.20 m/h	1.60 - 2.00 m/h	2.40 - 3.20 m/h
Cumulative % Removal	60 %	54 %	48 %
	URF		
Rate of Filtration	0.22 - 0.33 m/h	0.43 - 0.54 m/h	0.65 – 0.87 m/h
Cumulative % Removal	83 %	82 %	75 %
	SSF		
Rate of Filtration	0.10 - 0.15 m/h	0.20 - 0.25 m/h	0.30 - 0.40 m/h
Cumulative % Removal	99.3 %	99.2 %	98.8 %

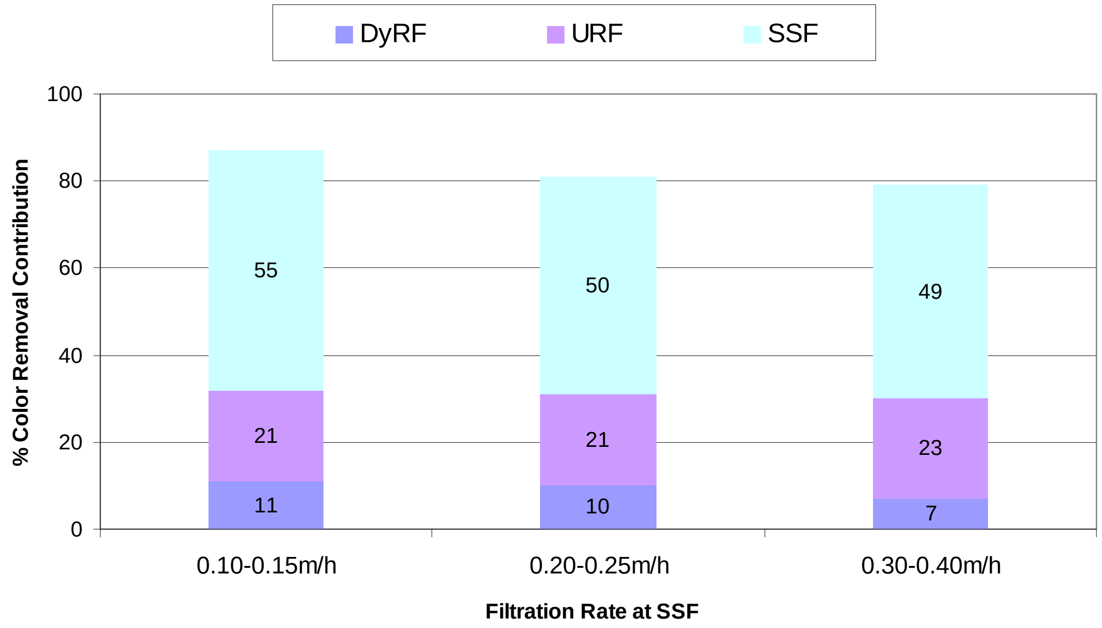


Figure-4.15: Variation of Color Removal performance with Rate of Filtration through SSF[Uniterrupted Flow]

[Filtration rates of DyRF and URF corresponding to that of SSF have been given in Table-4.4]

It is usually recommended that source water color should be limited within 15 to 25 platinum color units for effective operation of SSF (AWWA, 1996). to maintain an influent color value below 25 Pt. Co. Unit, it is recommended that the flow rate should be limited within 0.20-0.25m/h as depicted from Figure-4.16. To maintain slow sand filter influent turbidity value within 20 NTU and Color value within 25

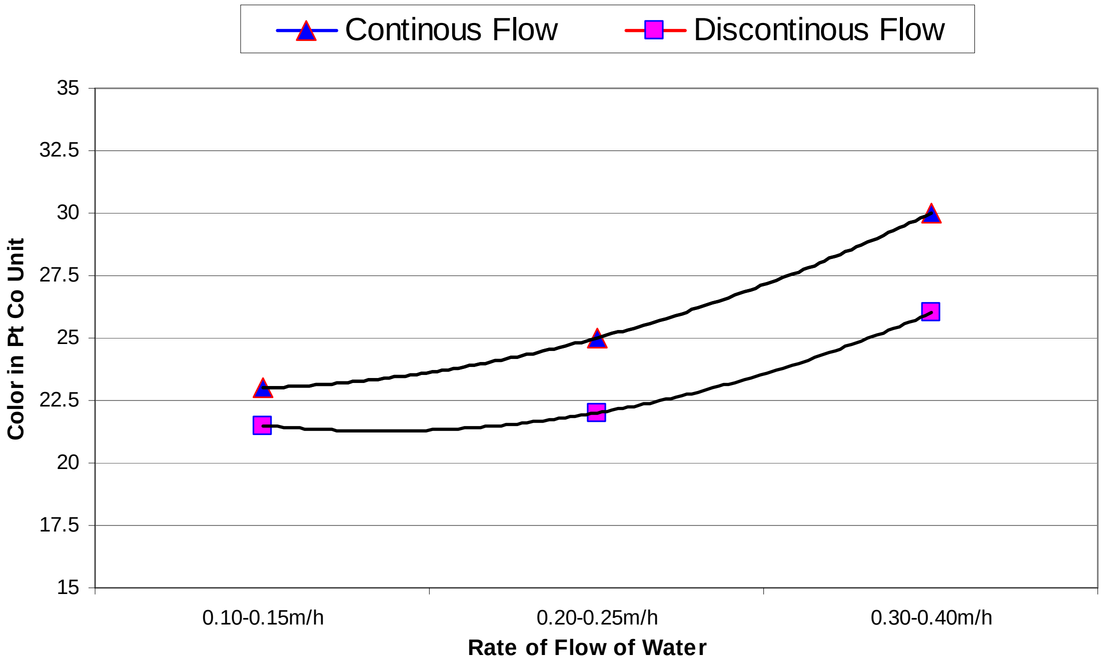


Figure-4.16: Variation of Slow Sand Filter Influent Color Value With Filtration Rate

Pt.Co.Unit, filtration rate below 0.20-0.25m/h at SSF unit may be accepted. To maintain this range of flow rate at SSF, the corresponding flow rates at URF and DyRF are in a range of 0.43-0.54 m/h and 1.6-2.00 m/h respectively.

4.2.2.4 Effect of Intermittent Operation of Flow

The results of Turbidity and Color tests under both interrupted and intermittent flow condition have been compared in Figure-4.17 and Figure-4.18. It was observed that the method of filter operation did not have any effect on turbidity removal

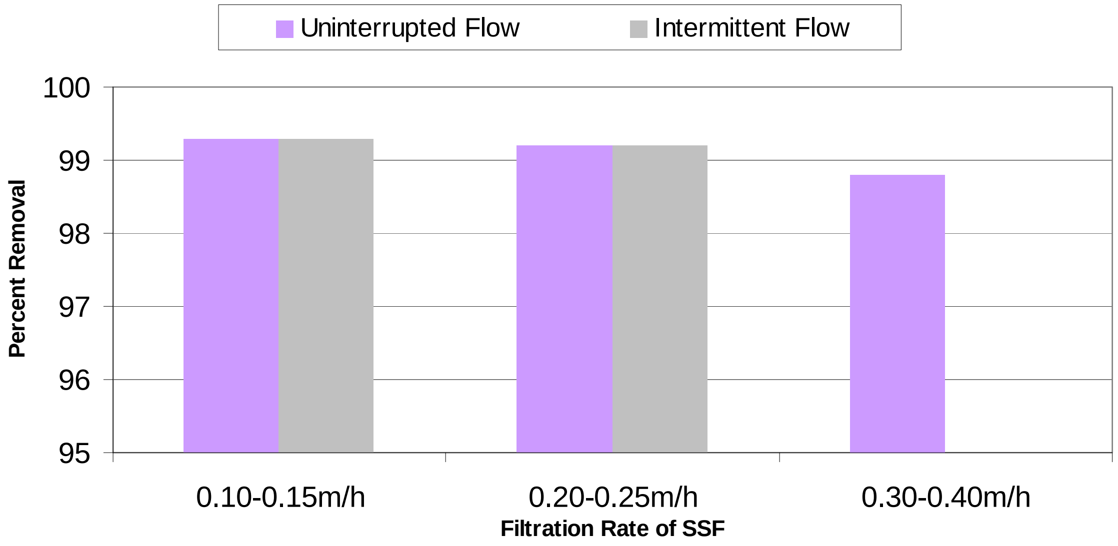


Figure-4.17:Variation of Cumulative Turbidity Removal Performance with Type of Flow Pattern

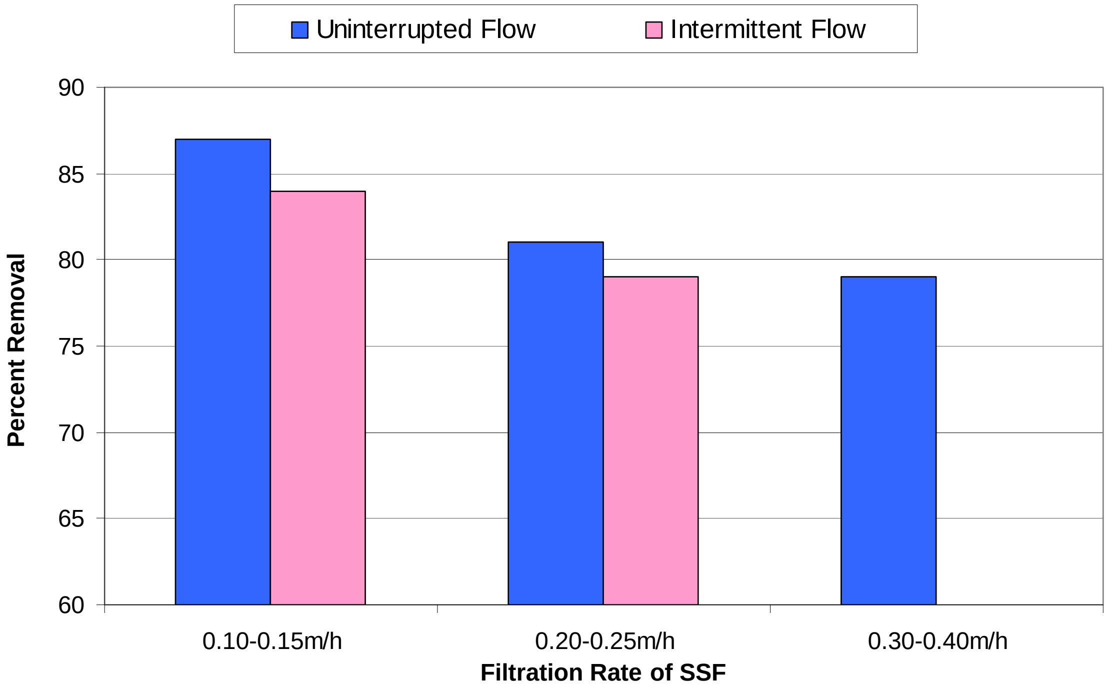


Figure-4.18: Variation of Cumulative Color Removal Performance with Type of Flow Pattern

performance, however, removal performance of color reduced during the intermittent flow condition. Because, during intermittent flow condition further decomposition of organic matter contributed color to the effluent water. Intermittent operation affected the color removal performance not the turbidity removal performance. To obtain a better removal performance uninterrupted flow condition should be maintained.

4.2.2.5 Effect of Shading on Filter Bed

During the 1st experimental run when the filter bed was kept exposed, slightly better turbidity removal performance was observed due to presence of algae on filter bed, however, this increase of removal was not very significant as can be seen from the Figure-4.8. Contrary, growth of algae on the filter sand increased residual color in the effluent water slightly (Figure-4.10). Exposure of filters increased the algal activity on filter bed and affected the filter performance slightly. Filter bed should be kept covered to avoid the unnecessary growth of algae particularly on slow sand filter bed.

4.3 Performance of the Field MSFs

As noted earlier in article 3.3.1, three MSFs were monitored in three districts of the country for treating pond water having no dynamic roughing filtration unit. Water samples were collected once a week from different stages of the MSFs and physical water quality parameters analysis were performed for turbidity and color both in the field and in the laboratory. Table-4.5 shows the average water quality data collected during the 6th, 7th and 8th week of operation before cleaning of the filter bed. Out of the two filter beds, one filter bed was cleaned after 8th week of operation and another filter bed on the following week, i.e. 9th week of operation.

Table-4.5: Physical Water Quality of Field MSFs

MSFs Location	Turbidity (NTU)			Color (Pt.Co.Unit)		
	Pond water	**URF**	**SSF**	**Pond water**	**URF**	**SSF**
Chowgacha, Jessore	40	3.67	1.12	86.7	39.0	21.0
Saharasti, Chandpur	24.3	2.70	1.25	60	33.3	20.3
Muradnagar, Comilla	25.7	2.87	1.31	69.3	35.0	20.5

(Average of last 3 weeks [6th, 7th and 8th] data before Cleaning)

Average water quality data of samples collected during the 9th, 10th and 11th week of operation after cleaning of filter bed is also presented in Table- 4.6.

Table-4.6: Physical Water Quality of Field MSFs

MSFs Location	Turbidity (NTU)			Color (Pt.Co.Unit)		
	Pond water	URF	SSF	Pond water	URF	SSF
Chowgacha, Jessore	33.5	2.75	1.57	67.5	31.5	23.3
Saharasti, Chandpur	22.3	2.3	1.79	48	28.5	22.3
Muradnagar, Comilla	22.3	2.3	1.83	48	28	20.7

(Average of first 3 weeks [9th, 10th and 11th] data after Cleaning)

4.3.1 Turbidity Removal Performance

Water quality analysis results reveal that significant turbidity removal can be achieved through up-flow roughing filtration system, as shown in Figure-4.19. The rate of removal increased with operation time due to gradual formation of slime on the media surfaces. The removal in Jessore was comparatively higher due to higher pond water turbidity. Through the up-flow roughing filtration system, on an average 90% turbidity removal was observed. This might be occurred due to the higher algae content of pond water which enhanced the slime formation of URF.

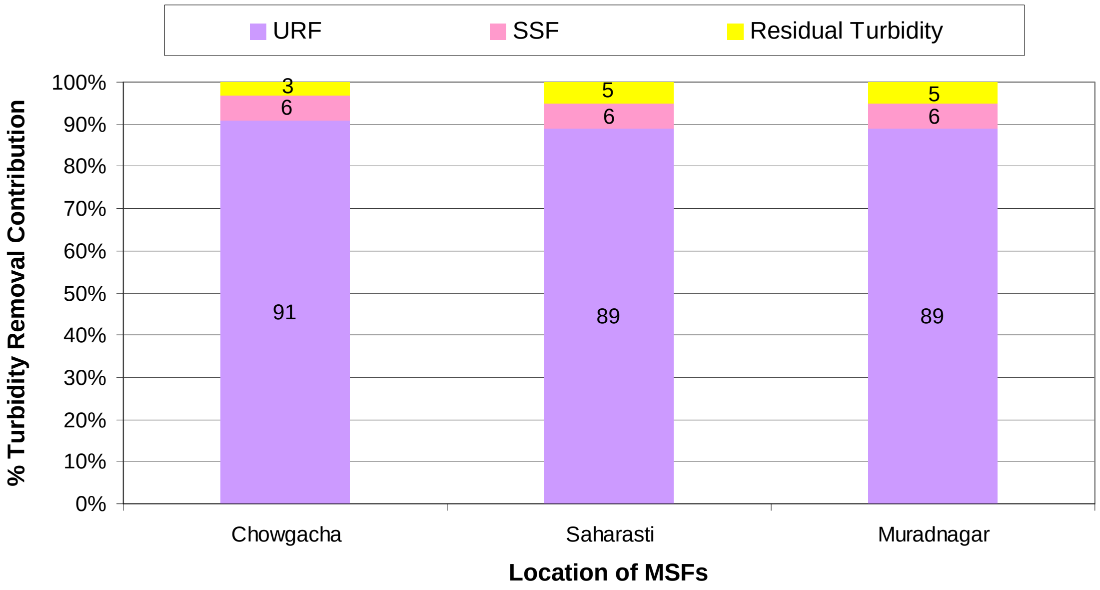


Figure-4.19: Turbidity Removal Performance of Different Field Multi Stage Filtration Units

After cleaning of the roughing filter bed, this removal did not reduce because simple flushing of the bottom deposit was done through opening the washout valve which did not affect the slime on the filter media.

Since a major portion of turbidity removal was achieved through roughing pre-filtration system and turbidity removal contribution of SSF process was only around 6%, the propensity of frequent clogging of sand bed decreased and eventually the length of run between cleanings of sand bed also increased. Average overall removal performance of turbidity was 96 % and the slow sand filter effluent turbidity of 1.23 NTU and 1.73 NTU were observed before and after cleaning the filter bed, which is much lower than the Bangladesh EQS 1997. The slow sand filter effluent turbidity results before and after cleaning of bed was not very significant (3%), because of the fact that only 2-3 cm of the top sand layer was scraped without removing the whole sand bed materials.

4.3.2 Color Removal Performance

Water quality results reveal that color removal performance through roughing filtration system was not as efficient as turbidity removal. Through up flow roughing filtration system, around 50% color removal was achieved. Removal performance through roughing filter depends on pond water color. Higher the pond water color, greater was the removal performance as was observed in Jessore.

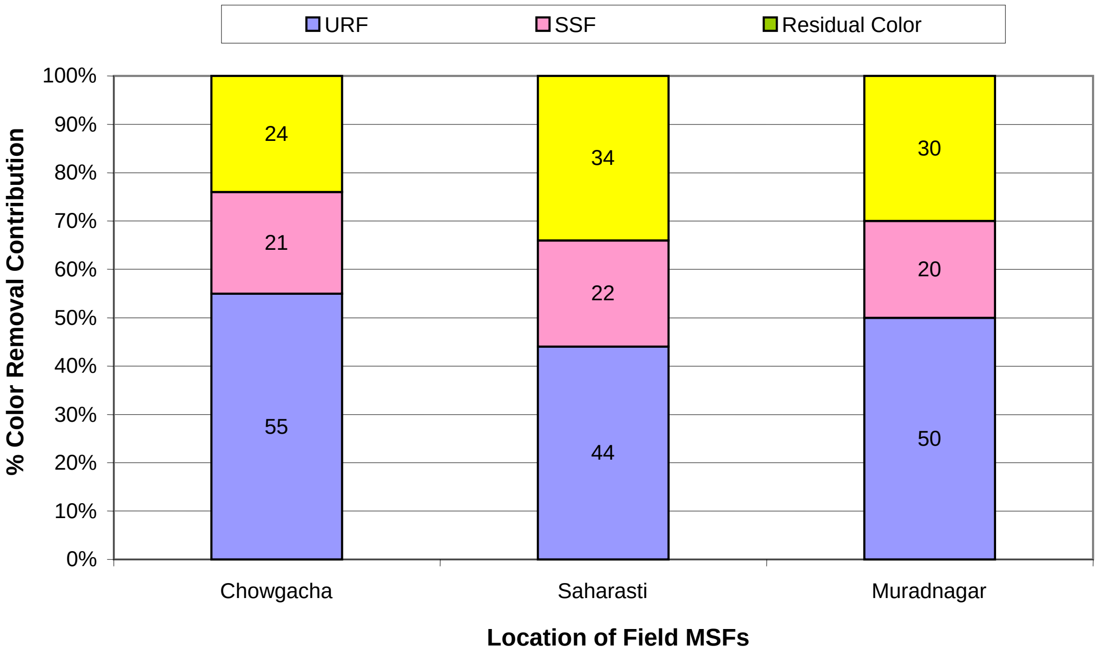


Figure-4.20: Color Removal Performance of Different Field MSFs

Slow sand filtration system removed around 21% of total color in the system and a total removal of 71% was achieved; however, after cleaning of the filter bed, average total removal reduced down to 59%.

Figure-4.20 shows the average contribution of color removal in different multi stage filtration units. Average slow sand filter effluent color concentrations of around 20.6 and 22.1 Pt.Co.Unit were found before and after cleaning the filter bed, respectively, which are higher than the Bangladesh EQS 1997. The decrease of color removal performance after cleaning was about 12% and it was higher than that of turbidity removal due to the washing of biological layer which enhanced the color removal by oxidizing the color forming organic matter. Poor removal performance of color was also due to the intermittent flow operation of field condition which contributed color to the effluent water by further decomposition of organic matter; however, post-Chlorination reduced the residual color concentration in the filtrate water in the clear water storage chamber.

4.4 Comparison in Performance of Field and Model MSF Units

4.4.1 Turbidity and color Removal Contribution of MSF Units

Overall turbidity and color removal contribution of different multi stage filtration processes obtained during all the experimental runs both in the laboratory and field have been summarized in the Figure-4.21 to Figure-4.24 to compare the performance of MSFs in laboratory and field situation.

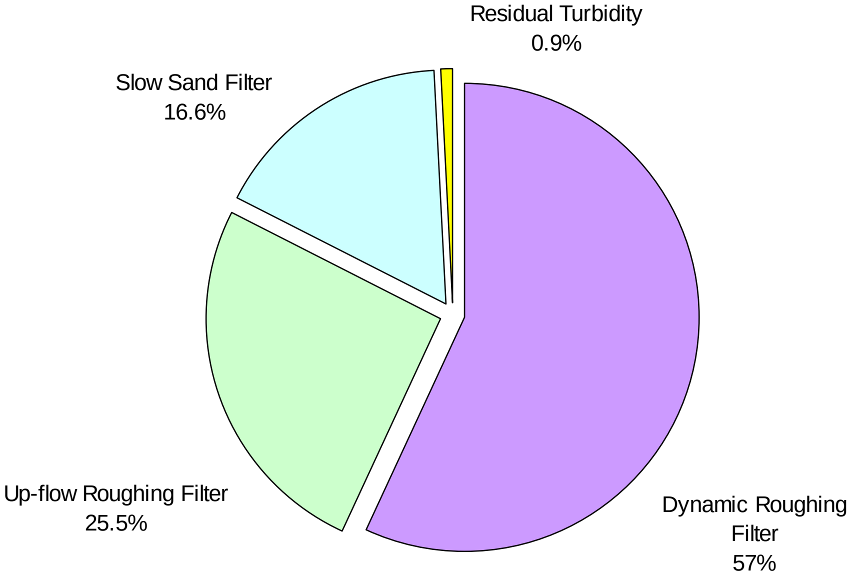


Figure-4.21: Average Overall Contribution inTurbidity Removal of Laboratory MSF Units

Turbidity removal performance

Figure-4.21 shows that, the role of two stage prefiltration processes in reduction of turbidity was significant and on an average around 83% turbidity removal was achieved in the laboratory and in the field MSFs a better turbidity removal performance (around 90%) was observed through single stage URF process (Figure-4.22). The removal percent in the field was better might be due to the reasons that the actual filtration rate in the field was much lower than designed due to the intermittent operation of handpump attached to the MSF and the algae content of pond water in the field was higher, than that of the synthetic water produced in the laboratory by mixing tap water with pond water to maintain specific range of turbidity and microbial load in the raw water (Article 3.4), which aided in removing turbidity in URF. However, removal through SSF process in the field was less than the turbidity removal contribution of laboratory SSF unit (Figure-4.22).

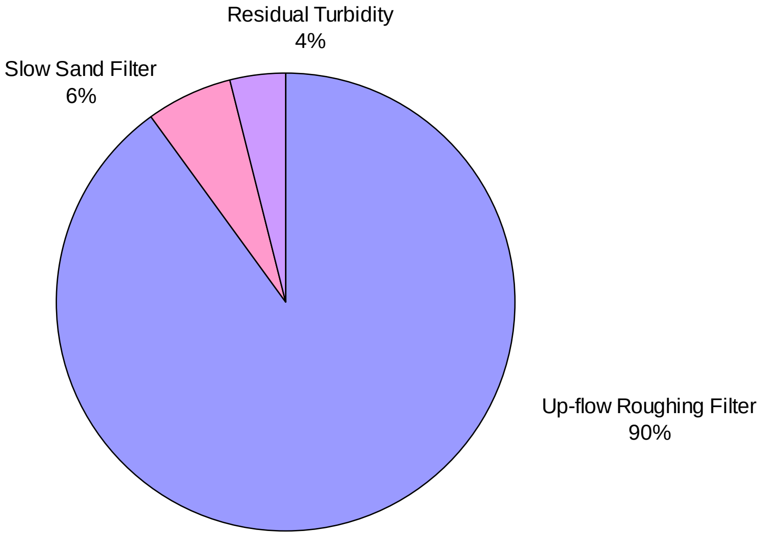


Figure-4.22: Average Overall Contribution of Turbidity Removal in Field MSF Units

Therefore, for moderately polluted surface water sources a residual turbidity value close to Bangladesh Standard (EQS, 97) may be achieved without slow sand filtration.

Color removal performance

Water quality results reveal that color removal contribution of two prefiltration process of laboratory MSF units were not as effective as turbidity removal and around total 34% color removal was achieved as indicates in the figure-4.23. However, in the field around 50% color removal was observed through single stage URF process

(Figure-4.24). In the laboratory, the flow was mainly uninterrupted and on the other hand, overnight intermittent flow condition prevailed in the field even with intermittent handpump operation which slowed down the flow rate providing more time for color adsorption. Again, biological removal in the field was mainly achieved by URF process (around 88% as in article 5.3), this biological activity also took part in color removal by oxidizing color producing organic matter.

Figure-4.23 reveals that contribution of laboratory SSF process in removal of color was around 44% which was much better than the removal contribution of SSF process in the field which was around 21% shown in the figure-4.24.

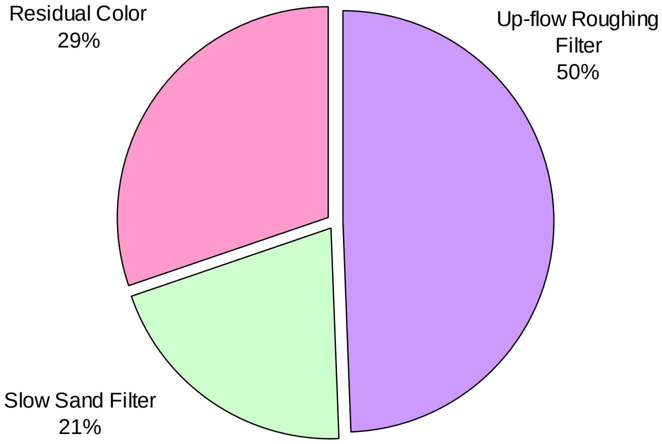


Figure-4.24: Average Overall Color Removal Contribution of Field MSF Units

Poor color removal contribution of field slow sand filtration unit was due to the intermittent flow operation of field condition which contributed color to the effluent water by further decomposition of organic matter. On the other hand laboratory slow sand filtration unit contained an extra layer of finer particles and a prominent biological layer where huge biological and microbial activity took place which might enhance color removal by adsorption and oxidizing dissolved organic color producing substances to inorganic solids.

4.4.2 Head Loss and Yield Capacity of Laboratory and Field MSFs.

Removal performance varies at a different rate at different units of MSFs as a consequence of increase in head loss developed with operation period. Development of head loss decreases yield capacity of MSF plants which adversely affect the user acceptability in the field. In figure-4.25, the variation of turbidity removal of lobaratory MSF units with operation period is illustrated.

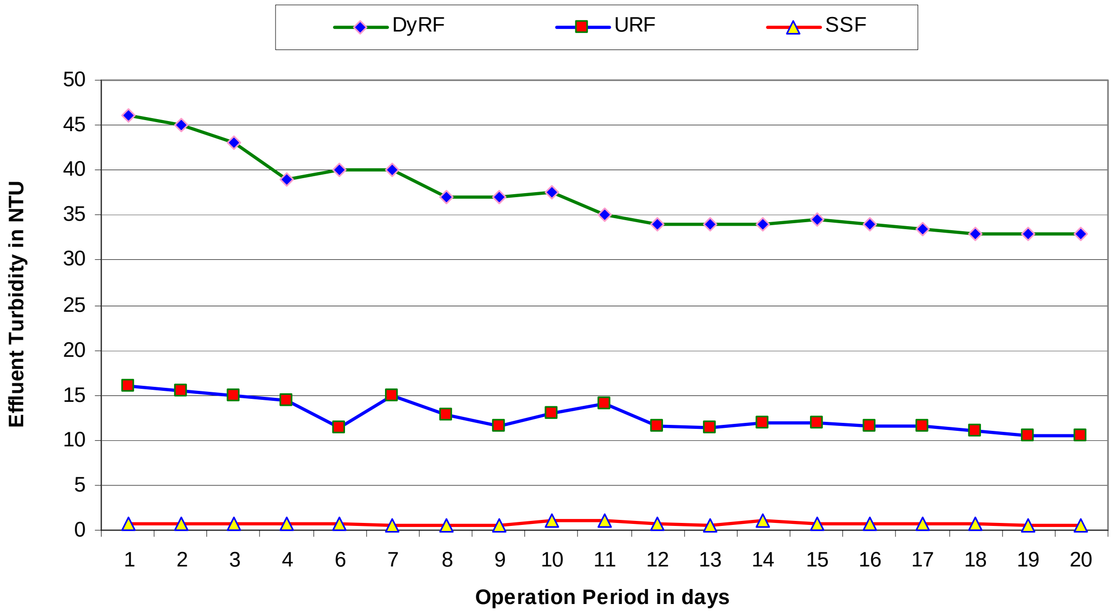


Figure-4.25: Variation of Turbidity Removal with Operation Time in Model MSF

It indicates that initially through DyRF turbidity removal performance was low in comparison to the subsequent periods due to the ripening of the filter bed; however, this reduction was not very significant. Although removal through URF and SSF processes were almost uniform throughout the operation period, there was an increase of head losses with operation period in both the filtration units.

In Figure-4.26 the head loss measured in roughing filter and slow sand filter of the laboratory MSF has been plotted with operation period which reveals that initial head loss across URF bed was around 6.9 cm for a flow rate of 0.43 m/h and increased to a maximum value around 9.7 cm after two weeks period of operation and remain almost constant for the rest 6 weeks operation period.

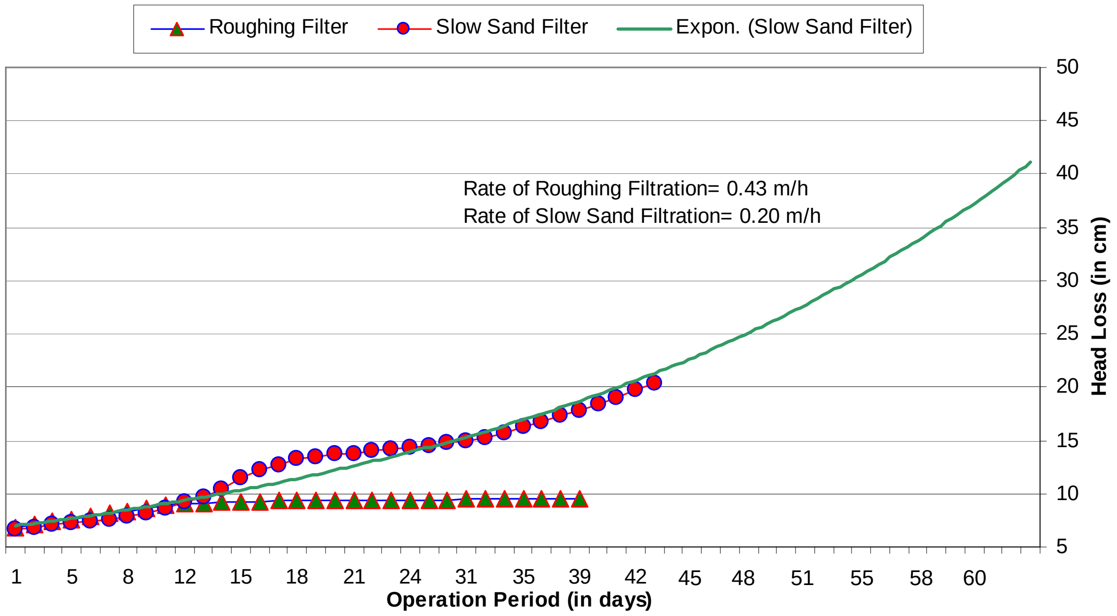


Figure-4.26: Increase of Head Loss on Model MSFs with Operation Period

Situation of SSF bed was quite different, where terminal head loss after 6 weeks of operation reached to a value around 20 cm. Maximum head loss through DyRF during this operation period was found less than 2 cm.

In field condition the yield capacity with operation period of MSF units was measured. The pumping capacity of MSF hand pump was found approximately 1.5 m^3/h and it was observed that the average discharge capacity of a new MSF was around 0.70 m^3/h. However, after 8 weeks of operation this yield reduced down to around 0.35 m^3/h, which was seemed to affect the user acceptability.

The head loss increase curve of SSF unit in Figure-4.26 was extrapolated to determine the maximum expected head loss before cleaning or minimum yield without affecting user acceptability. The extrapolated curve shows that head loss reaches around 40 cm with 60 days or 8 weeks of operation period.

CHAPTER FIVE

MICROBIAL WATER QUALITY IMPROVEMENT IN LABORATORY AND FIELD MSF UNITS

5.1 Introduction

Bacteriological water quality is of major concern for surface water treatment. Drinking water should not contain any pathogenic organisms, which are often difficult to detect analytically. Even clear and pleasant water may carry harmful and disease-causing microorganisms. Slow sand filtration is one of the most efficient processes for the production of hygienically safe drinking water. Roughing Pre-filtration by coarse media not only provides the requisite protection for slow sand filtration in adverse raw water physical conditions but also, in addition, it may contribute valuable improvements in microbiological quality. This chapter describes the removal efficiency of Thermotolerant Coliform (TTC), Fecal Coliform (FC) and Escherichia Coli (E Coli) through different units of model MSF and field MSFs considering the effect of different process variables including the comparison of performance between field and laboratory model.

5.2 Performance of laboratory MSF units

5.2.1 Effect of Process Variable on Removal Performance

Microbiological quality of the end water passing through a treatment system is of utmost concern in terms of efficiency of the system in producing water suitable for domestic consumption. The microbial quality improvement performances of the multistage filtration units were investigated in all the experimental runs observing the effects of the following process variables on the removal of four types of indicator organisms. The maximum, median, mean, minimum values and average percent removals under different environmental conditions have been calculated and presented in the following sections to describe the performance and to determine the design parameters of MSFs.

5.2.1.1 Effect of Filter Bed Materials

The effect of the bed materials on Thermotolerant Coliforms (TTC) removal performance has been presented in the Table-5.1 and also shown in Figure-5.1. The results indicate that average cumulative TTC removal performance through different filtration stages gradually increased during the successive experimental runs, because size, grading and depth of filter media, particularly slow sand filter materials were improved during the successive experimental runs. It was observed that not only the Fineness Modulus (FM) or Effective Size (D10) of filter materials are the important criteria for filter material design, the size range (Passing sieve # and retaining on Sieve #) and gradation (Uniformity co-efficient) are also need to be considered in the selection of filter materials (Art.- 3.2.1).

Table-5.1: Role of Filter Bed Materials on SSF Effluent Water Microbial Quality

Experimental Run #	Influent Average Concentration (TTC in CFU/100ml)	Effluent Concentration (TTC in CFU/100 ml)				Average Percent Removal
		Min	Median	Mean	Max	
1st Run	1700	15	60	58	100	96.6
2nd Run	550	0	4	8	45	98.6
3rd Run	480	0	2	3	8	99.5
4th Run	570	0	1	2	6	99.6

[Filt. Rate: DyRF=1.6m/h, URF=0.43m/h and SSF=0.20m/h; Continuous Flow]

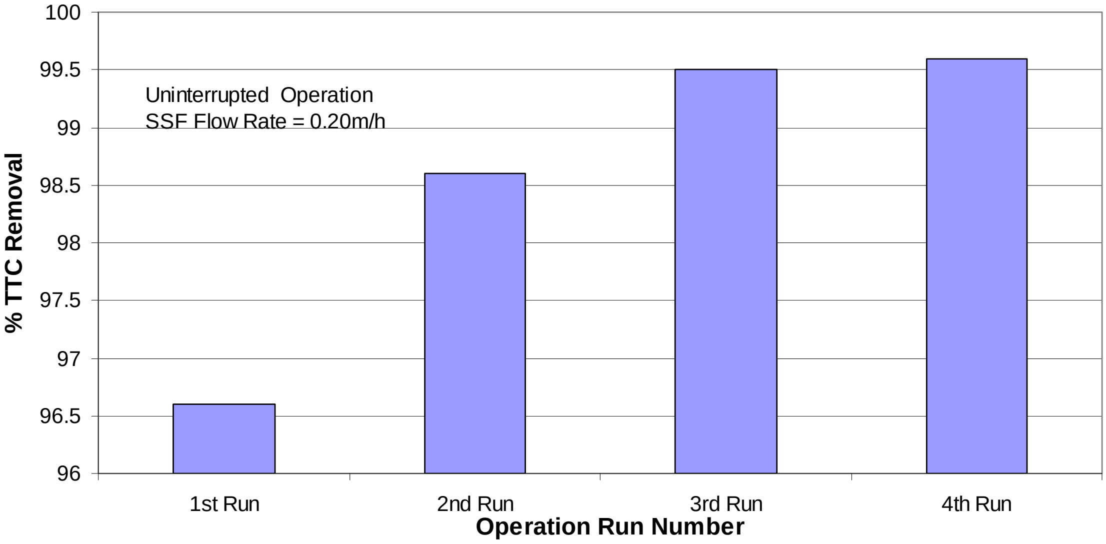


Figure-5.1: Effect of Filter Bed Materials in Different Operation Run on TTC Removal Efficiency of MSF Units

Filter sand with following characteristics which was used during the 4th experimental run may be selected for the design:

FM = 1.8-2.0, D10=0.21-0.22 mm, D60 = 0.45-0.47 mm, U = 2.14 -2.16 and Filter Media Size Range = 0.15 mm to 1.1 mm.

5.2.1.2 Variation of Removal with Operation Period

On average, it was found that SSF performed considerably well in removing TTC. Observation from the Figure-5.2 indicates that at the beginning of each filter run, the removal efficiencies were low in comparison to the subsequent periods and approximately 7 to 9 days were required to improve the removal performances under the laboratory test conditions. This can be attributed to the fact that during this period, the filter was establishing itself in terms of full development and establishment of the filter skin- Schmutzdecke. Rate of filtration, quality of feed water and other factors, obviously, determine this ripening period.

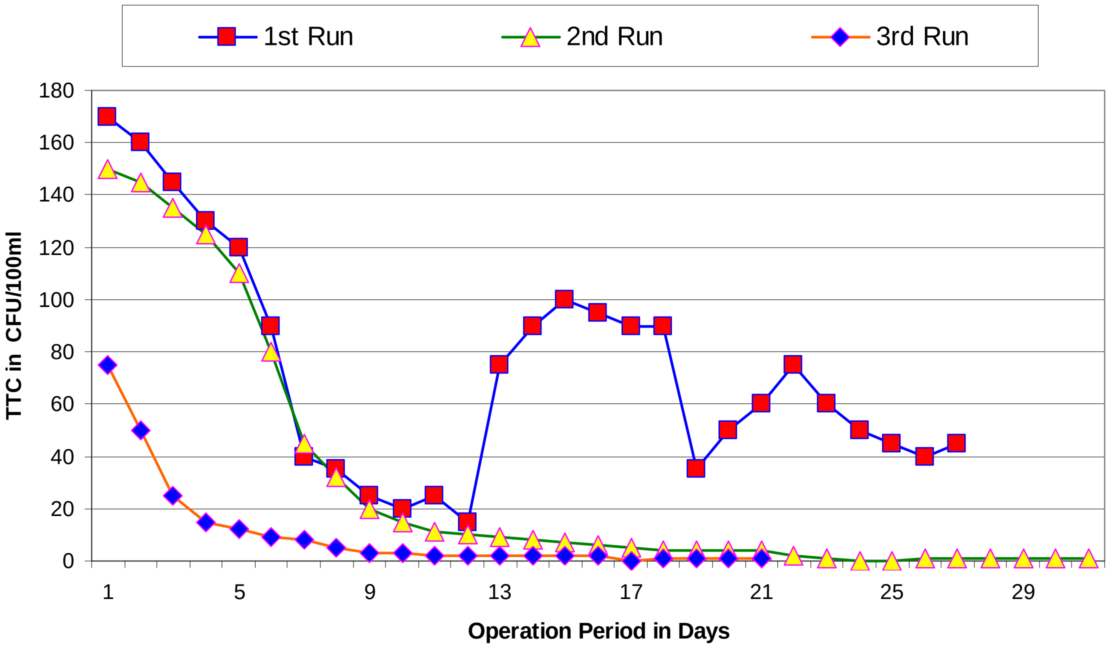


Figure-5.2: Variation of TTC Count with Length of Filter Operation

At least 7 to10 days interval should be allowed for the formation of the “Schmutzdecke” on filter sand before the filter bed is brought in to full operation for domestic use. Cleaning of filter bed worsen the water quality by disrupting this biological layer. Thus twin bed filter chambers may be used in place of single bed and cleaning may be performed alternatively to achieve the above purpose.

5.2.1.3 Effect of Rate of Filtration

The performance of slow sand filter operated at 0.10, 0.15, 0.20-0.25 and 0.30-0.40 m/hr rates of filtration in uninterrupted flow condition is summarized in Table-5.2 and 5.3 and presented in Figures-5.3 and 5.4.

Table-5.2: Role of Filtration Rate on Microbial Quality Improvement of Slow Sand Filter Effluent

[Thermotolerant Coliform (TTC) under Uninterrupted Flow Condition]

Exp. Run # (Rate of SSF Filt.)	Influent Avg. Concentration (CFU/100 ml)	Effluent Concentration (CFU/100 ml)				Avg. Percent Removal
		Min	Median	Mean	Max	
4th Run (0.10 m/h)	410	0	0	< 1	1	99.97
4th Run (0.15 m/h)	650	0	1	1	2	99.8
3rd Run (0.20-0.25 m/h)	480	0	2	3	8	99.5
4th Run (0.20-0.25 m/h)	570	0	1	2	6	99.6
4th Run (0.30 m/h)	500	3	6	5	7	99.0
4th Run (0.40 m/h)	485	4	6	6	7	98.8

Table-5.3: Role of Filtration Rate on Microbial Quality Improvement of Slow Sand Filter Effluent

[Escherichia Coliform (E. Coli) under Uninterrupted Flow Condition]

Experimental Run # (Rate of SSF Filt.)	Influent Avg. Conc. (CFU/100 ml)	Effluent Concentration (CFU/100 ml)				Avg. Percent Removal
		Min	Median	Mean	Max	
4th Run (0.10 m/h)	350	0	0	0	0	100
4th Run (0.15 m/h)	480	0	1	1	2	99.8
4th Run (0.20-0.25 m/h)	250	0	1	1	2	99.6
4th Run (0.30 m/h)	320	2	4	4	5	98.7
4th Run (0.40 m/h)	200	3	5	5	6	97.5

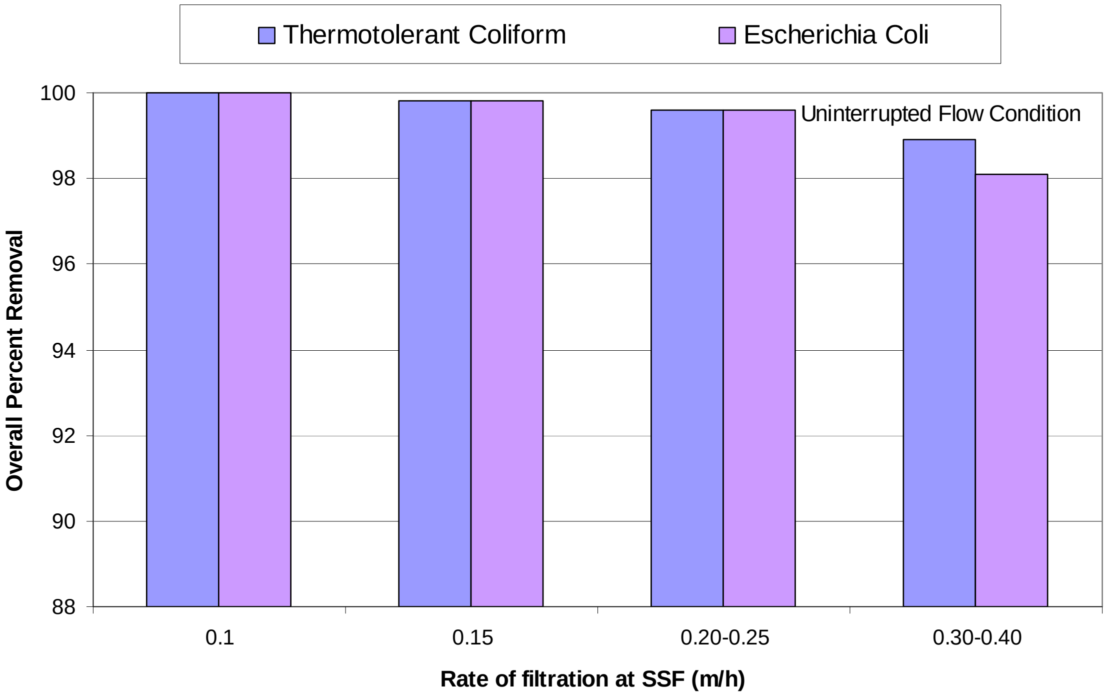


Figure-5.3: Effect of Rate of Filtration on Microbial Removal Efficiency

It was observed that the filter operated at 0.1m/h delivered water free from E.Coli in all the 14 samples tested during one week period of operation after ripening of bed, and only single Thermotolerant Coliform colony was detected in one sample during that period under uninterrupted flow condition. When the filter was operated at a filtration rate of 0.15m/h, the filter produced a filtrate that contained detectable E.Coli

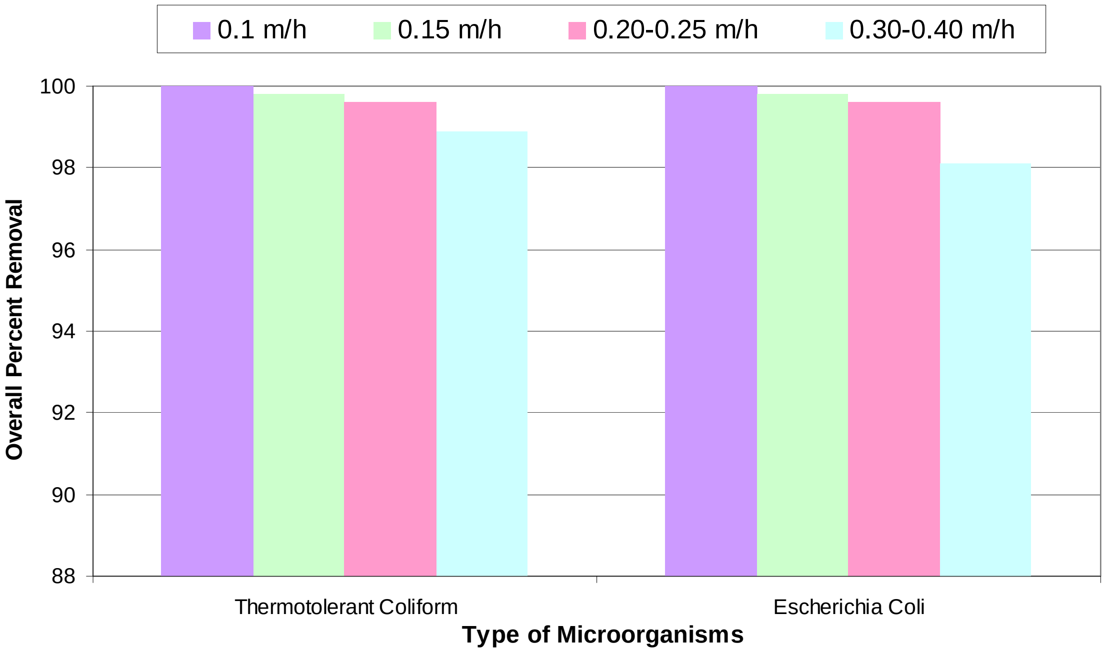


Figure-5.4: Variation of Different Types of Microbial Removal Efficiency under Various Filtration Rate of SSF

and Thermotolerant Coliform. And average densities of both the organisms were only 1 and overall average removal was 99.8 percent for both the cases. During the 4th run when the filter was operated at a filtration rate of 0.20 - 0.25m/h, average densities of E.Coli and Thermotolerant Coliform in the filtrate were 1 and 2 respectively and overall average removal was 99.6 percent for both the cases. It was observed that the microorganism removal performance followed an inverse trend with regard to rate of filtration of water.

Therefore, it may be concluded that for a maximum slow sand filtration rate of ≤ 0.1m/h, an acceptable level of microbial quality of water may be obtained. However, at a filtration rate up to 0.15 m/h TTC and E.Coli may appear occasionally. While this degree of microbial purity may be considered acceptable for small community water supplies, as a safety precaution, terminal disinfection of filtered water may be provided. Beyond 0.20-0.25 m/h filtration rate microbial quality deteriorate significantly. Other investigator also recommended a filtration rate close to 0.2 m/h (Paramasivam and Sundaresan, 1978).

5.2.1.4 Effect of Intermittent Operation

The results of microbiological tests under interrupted flow conditions are presented in Table-5.4 to 5.5 and also shown in Figure-5.5.

Table-5.4: Effect of Intermittent Operation on Slow Sand Filter Effluent Water Microbial Quality with Filtration Rate

[Thermotolerant Coliform (TTC) under Intermittent Flow Condition]

Experimental Run # (Rate of SSF Filtration)	Influent Avg. Concentration (CFU/100 ml)	Effluent Concentration (CFU/100 ml)				Average Percent Removal
		Min	Median	Mean	Max	
4th Run (0.10 m/h)	500	2	3	3	5	99.4
4th Run (0.15 m/h)	700	2	3	4	8	99.4
3rd Run (0.20-0.25 m/h)	610	3	< 5	5	10	99.1
4th Run (0.20-0.25 m/h)	550	4	5	6	10	98.9

Table-5.5: Effect of Intermittent Operation on Slow Sand Filter Effluent Water Microbial Quality with Filtration Rate

[Escherichia Coliform (E.Coli) under Intermittent Flow Condition]

Experimental Run # (Rate of SSF Filtration)	Influent Avg. Concentration (CFU/100 ml)	Effluent Concentration (CFU/100 ml)				Average Percent Removal
		Min	Median	Mean	Max	
4th Run (0.10 m/h)	200	1	1	1	2	99.5
4th Run (0.15 m/h)	375	1	2	3	5	99.2
3rd Run (0.20 m/h)	350	2	4	4	9	98.8
4th Run (0.20-0.25 m/h)	300	2	4	5	9	98.5

It was observed that the slow sand filter operated at 0.1m/h, delivered water that contained E.Coli unlike uninterrupted operation condition. Average concentration of E.Coli and Thermotolerant Coliform densities were 1 and 3 respectively. When the filter was operated at a filtration rate of 0.15m/h the filter produced a filtrate where average concentration of E.Coli and Thermotolerant Coliform densities were 3 and 4 respectively.

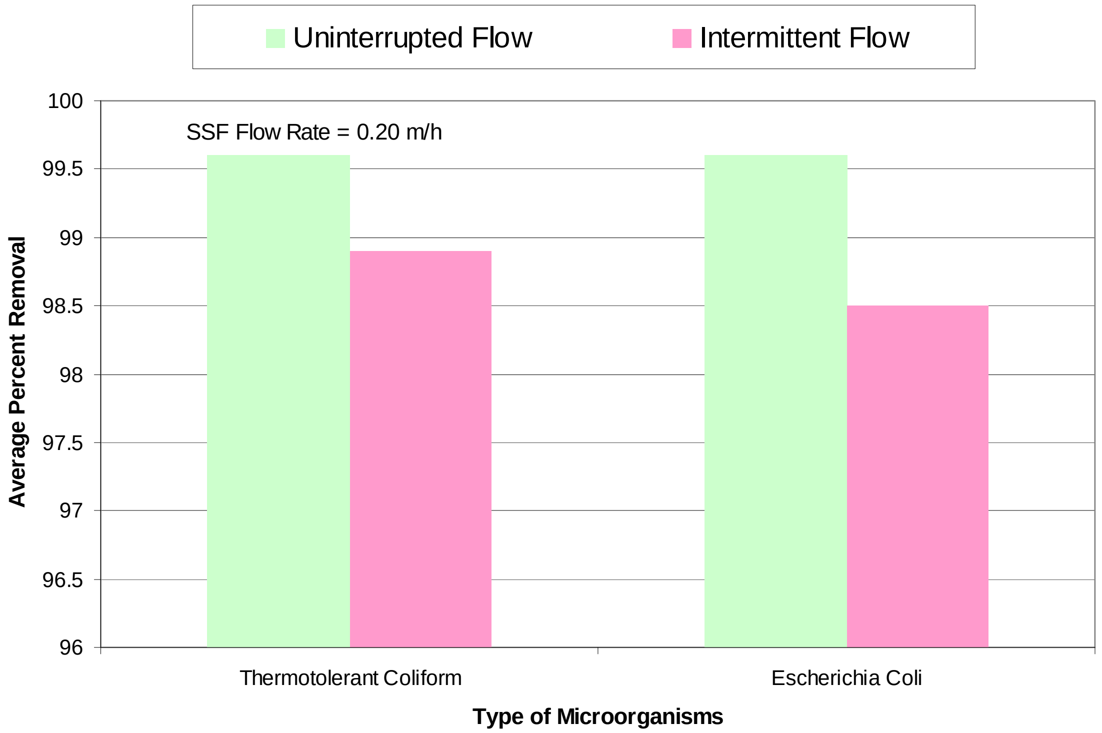


Figure-5.5: Effect of Type of Flow on Microbial Removal Performance

It was clearly observed that when the filter was operated without interruption, a filtrate of consistently satisfactory quality was obtained and, when switched over to intermittent operation, a definite deterioration in microbiological quality noticed. This adverse situation in microbial removal was occurred due to the deterioration of the action of biological layer formed in the sand surface, which mainly remove the microbial load, due to the shortage of Oxygen and Organic matter supply prevailed in the system during interrupted flow condition. However, the impairment did not occur soon after starting the filter or switching over a different flow condition, but after a period of time which appears to vary with rate of filtration.

Filter operated without interruption, a filtrate of consistently satisfactory quality was obtained. However, when switched over to intermittent operation, a definite deterioration in microbiological quality noticed. To obtain a better removal performance uninterrupted flow condition should be maintained.

5.2.1.5 Effect of Shading on Filter Bed

Only in the 1st experimental run, the filter top was kept unshaded. The raw water was very much polluted and as result there was heavy growth of algae on the surface. In some places of the bed thick layers of algal mats developed and after some days gradual sloughing of these mats occurred due to decay of underlying layer.

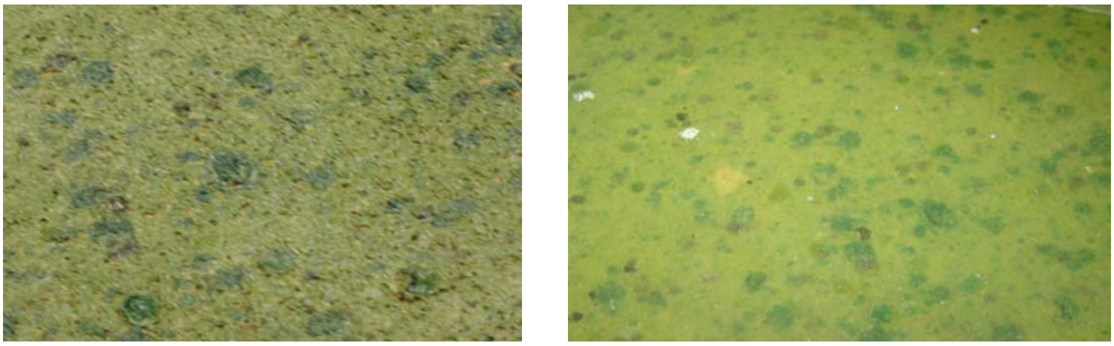


Figure-5.6: Growth of Algae on Filter Sand Bed (left); Sloughing of Algal mass from the Filter Sand Bed (right)

The grey spots in the figure-5.6, indicates the algal growth and sloughed places on sand bed. Sloughing of thick mats left behind week spots without having any Schmutzdecke on sand bed and microbial quality became very unpredictable as shown in the Figure-5.2. The overall microbial removal performance in the 1st run, therefore, was not satisfactory. The influence of shading on filter performance was, therefore, investigated covering the filter top with black polytheline paper during the subsequent three experimental runs. As a consequence the above mentioned situation did not arise and microbial removal performance was comparatively better.

It may be concluded that shading of filters helps reduce the algal activity in the filters but does not affect the filter performance. Filter bed should be kept covered to avoid the unnecessary growth of algae on slow sand filter bed.

5.2.2 Role of Different Filtration Stages

Overall removal performance of different multi stages filtration processes were determined and analyzed during the 3rd and 4th experimental runs for uninterrupted and intermittent flow condition and separate experimental run was done bypassing the DyRF condition to simulate and compare the results with field since the field MSFs have no DyRF unit.

5.2.2.1 Uninterrupted Flow Condition

The average Thermotolerant Coliform removal percentage of different MSF units in 3rd and 4th experimental run with uninterrupted flow condition is presented as pie diagram in Figure-5.7

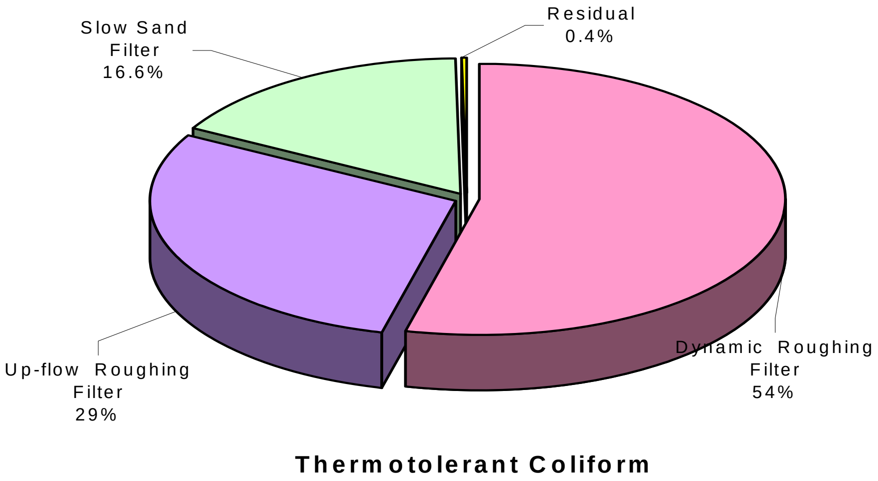


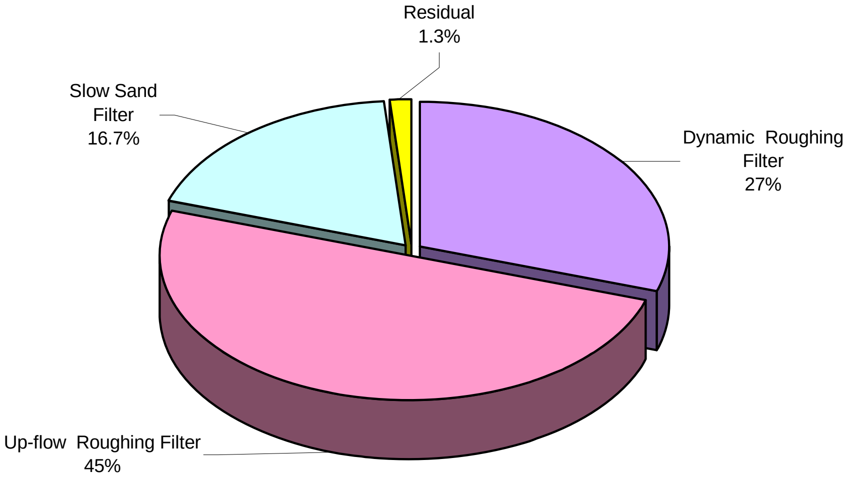
Figure-5.7: Percent Contribution of Different Multi Stage Filtration Processes in Microbial (TTC) Removal.

[Uninterrupted Flow, 3rd and 4th Run]
[Rate of Filtration: DyRF = 1.6 m/h, URF = 0.43 m/h and SSF = 0.20 m/h]

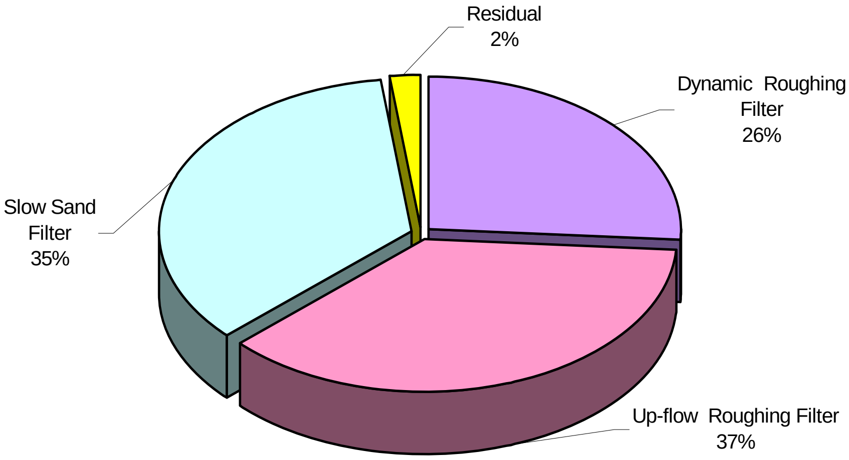
It shows that the role of DyRF process was very significant in the reduction of TTC densities and on average 54% reduction was achieved respectively at a filtration rate of 1.6m/h in uninterrupted flow condition. Total reduction of 83% TTC was achieved through two stages prefitration processes. In DyRF unit top surface layer was covered and remain packed with suspended particles and uninterrupted flow condition kept this layer active by supplying Oxygen and Organic matter constantly.

5.2.2.2 Intermittent Flow Condition

The average Thermotolerant Coliform and Echerichia Coli removal contribution of different MSF units in 3rd and 4th experimental runs with interrupted or intermittent flow condition are presented as pie diagram in Figure-5.8.



Thermotolerant Coliform



Escherichia Coli

Figure-5.8: Percent Contribution of Different Multi Stage Filtration Processes in Microbial Removal

[Intermittent Flow, 3rd and 4th Run]
[Rate of Filtration: DyRF = 1.6 m/h, URF = 0.43 m/h and SSF = 0.20 m/h]

Figure-5.8 shows that the role of DyRF process was not so significant in the reduction of TTC and E.Coli densities as compared to that of interrupted flow condition and on average 27% and 26% reduction was achieved respectively at a filtration rate of 1.6 m/h. URF process was found effective for the reduction of TTC at filtration rate of 0.43 m/h, however, deterioration of performance in slow sand filter process was noticed. Down flow units i.e. DyRF and URF were vulnerable to intermittent flow condition due to the deterioration of active layer on top surface of each unit, suspended particles including microbial content packed top layer in DyRF and biological layer in SSF, due to the intermittent flow, i.e. the discontinuous supply of oxygen and organic matter. Up flow unit was less vulnerable to flow interruption and performed very efficiently in case of the failure of DyRF by removing of excess microbial load left by previous process.

5.2.2.3 Bypassing DyRF Condition

Some experimental runs were also done by flowing the raw water directly to the up flow roughing filtration unit with raw water having wide ranges of microbial load and three filtration rate presented in figure-5.9 and 5.10. This experiment was in the 4th run of the filter media with uninterrupted flow and matured bed condition. Figure-5.9 reveals that the TTC removal percentage of up flow roughing filtration unit decreases with flow which was compensated by the slow sand filtration unit, as a result the net removal remains identical to the previous results with all three units of MSF as a whole in operation.

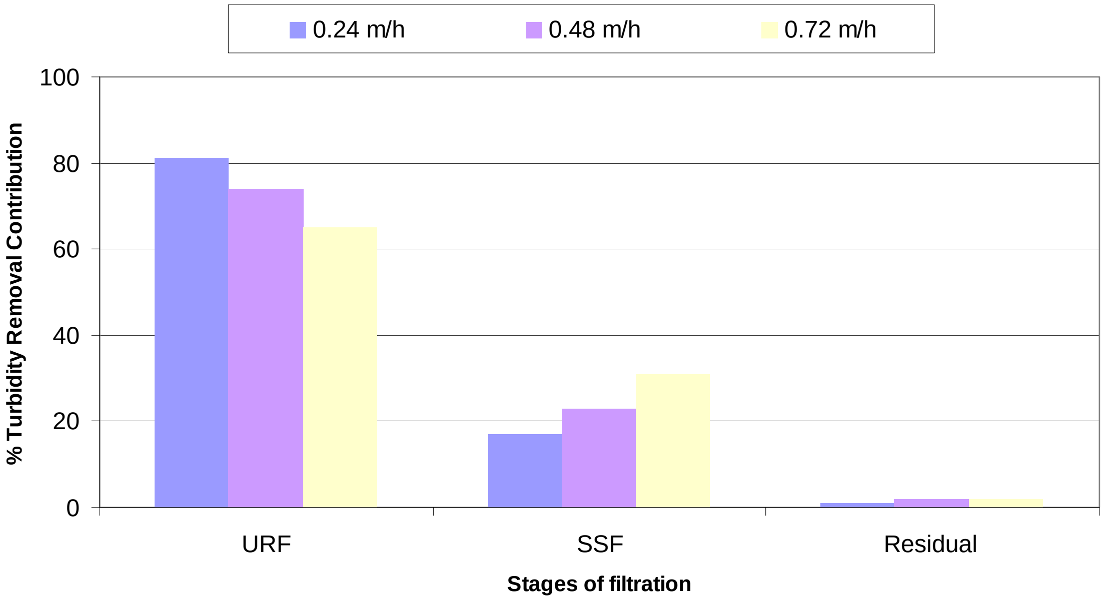


Figure-5.9: Microbial (TTC) Removal Contribution of MSF Units with Filtration Rate at URF (Bypassing DyRF)

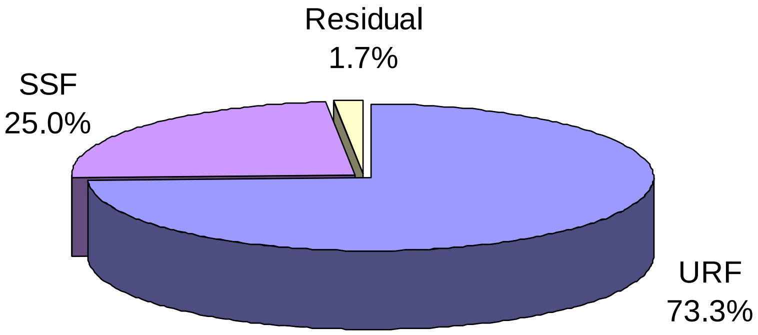


Figure-5.10: Overall Microbial (TTC) Removal Contribution of MSF Units (Bypassing DyRF and 4th Experimental Run)

Figure-5.10 shows that the removal percentage (73.3%) of upflow roughing process was a bit higher in bypassing condition than the individual removal in all units in operation condition which was due to the physical water quality improvement activity specially turbidity removal which was mainly took place in the prefiltration stages and also aided in removing micro organisms by surface adsorption; upflow situation further enhanced these activity.

It was observed that two stages coarse media pre-filtration units reduced both two types of microbial densities over 50% and in case of TTC this removal was maximum 83%. Removal performance was comparatively better under uninterrupted flow condition. Intermittent flow condition adversely affect the down flow units, i.e. DyRF and SSF. However, reverse situation was observed in up flow roughing filtration process. From the bypassing condition it can be concluded that DyRF is not required for treating raw water having moderate microbial load.

5.3 Performance of the field MSFs

Field MSFs, constructed in three districts of the country, were monitored closely and water samples were collected without chlorination for bacteriological analysis. Bacteriological water quality results are summarized and presented in Table-5.6 and 5.7 and Figure-5.11 and 5.12. Table-5.6 shows the average water quality data collected during the 6th, 7th and 8th week of operation before cleaning of the filter bed. Out of the two filter beds, one filter bed was cleaned after 8th week of operation and another filter bed on the following week, i.e. 9th week of operation.

Table-5.6: Microbial Water Quality of field MSFs

MSFs Location	Faecal Coliform (CFU / 100 ml)		
	Pond water	URF	SSF
Chowgacha, Jessore	550	49	2
Saharasti, Chandpur	467	63	3
Muradnagar, Comilla	723	88	4

(Average of last 3 weeks [6th, 7th and 8th] data before Cleaning)

Average water quality data of samples collected during the 9th, 10th and 11th week of operation after cleaning of filter bed is also presented in Table- 5.7.

Table-5.7: Microbial Water Quality of field MSFs

MSFs Location	Faecal Coliform (CFU/100ml)		
	Pond water	URF	SSF
Chowgacha, Jessore	450	43	7
Saharasti, Chandpur	400	43	8
Muradnagar, Comilla	625	140	9

(Average of first 3 weeks [9th, 10th and 11th] data after Cleaning)

Figure-5.11 reveals that on an average around 88.6% Faecal Coliform removal was achieved through roughing filtration system and further removal of total 99% was achieved through slow sand filtration system before cleaning the filter bed.

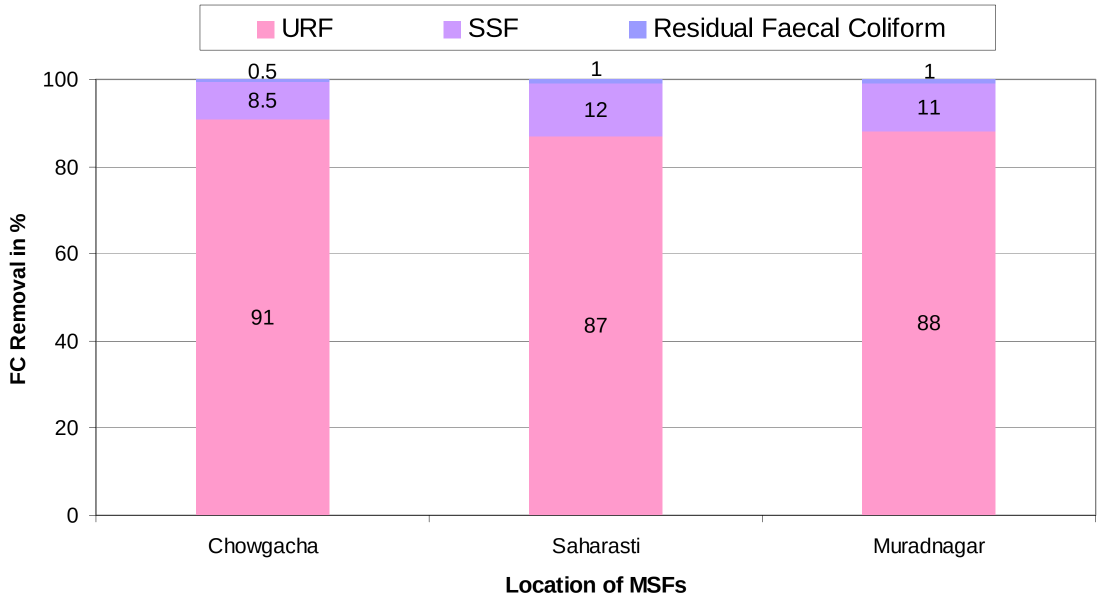


Figure- 5.11 : Faecal Coliform Removal Efficiency through Field MSFs

However, after cleaning of the filter bed, average removal was reduced down to 98%. Thus the slow sand filter effluent microbial results before and after cleaning of bed was not very significant (1%), because of the fact that only 2-3 cm of the top sand layer was scraped with the method of ‘harrowing’ without removing the whole sand bed materials.

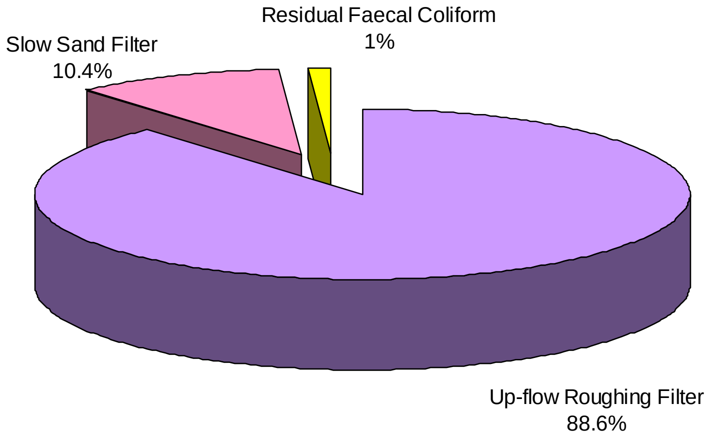


Figure-5.12: Overall Faecal Coliform Removal Performance of Field MSFs

Fig.-5.12 shows the average faecal coliform removal efficiency of field MSFs. Removal efficiency through slow sand filter increased with the time required for maturation of ‘schmutzdecke’ layer on sand surface. Since a major portion of impurities were removed through roughing filtration system, ripening of “Schmutzdecke” naturally took around 6 to 8 weeks period. However, complete removal can not be expected through sand filtration system. Post chlorination completely disinfected the filtrate water.

Complete removal can not be expected through sand filtration system. Post chlorination unit is necessary for complete disinfected of the filtrate water. Cleaning process of the sand bed need to maintain critically which can be ensured by proper training and awareness rising by information dissemination to both the caretaker and the users.

5.4 Comparison in performance of field and model MSF units

Overall microbial removal performance of different stages of MSF were obtained during all the experimental runs both in the laboratory and field have been summarized in the Figure-5.13 to compare the performance of MSFs in laboratory and field situation. It reveals that the microbial removal performance of the prefiltration unit in the field was better than that of model MSF units in the laboratory. This could be happened due to the actual filtration rate in the field is much lower than designed because of removal were comparatively better due to longer time for adsorption during intermittent operation of hand pump attached to the MSF. Again the higher algae content of pond water in the field, might be the certain types of filamentous species, enhanced the filtration process by providing greater surface area for biological activity.

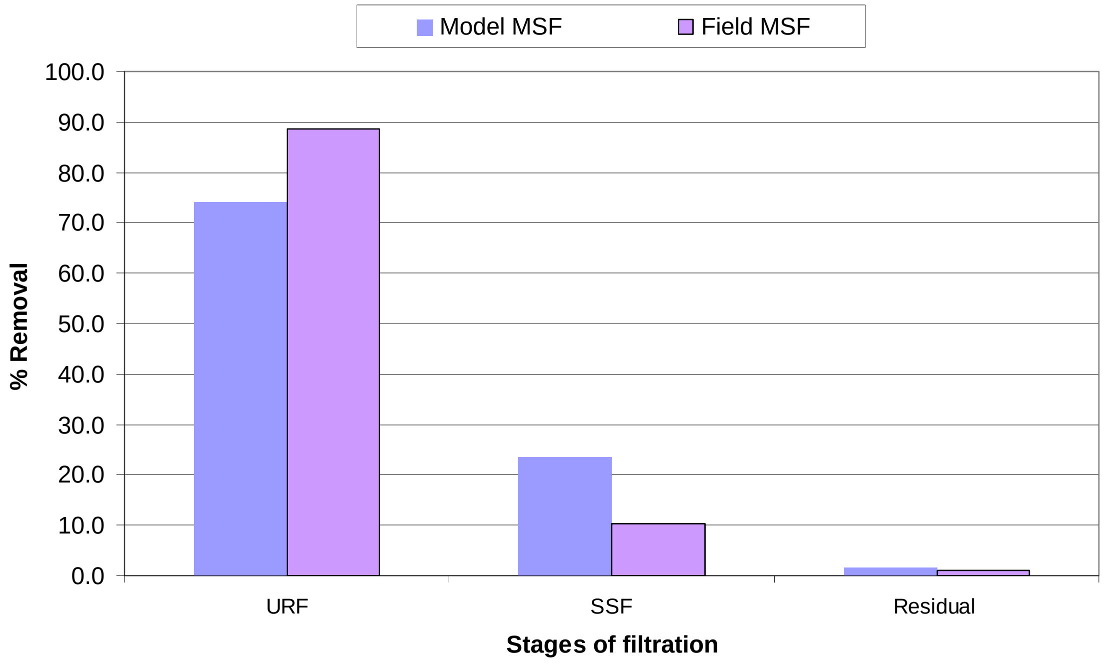


Figure-5.13: Overall Microbial Removal Performance of Different Stages of Field and Laboratory MSF

However, the removal percentage of slow sand filtration unit in the laboratory was better than that of field. This was due to intermittent flow condition of field MSFs and the comparatively finer top layer on sand bed of laboratory MSF slow sand filtration unit, not having in the field MSFs, which is capable of removing a long range of influent microbial load exerted more in sand bed than that of field. As a result, difference in overall removal efficiency of laboratory and field MSFs was not significant.

CHAPTER SIX

CHEMICAL WATER QUALITY IMPROVEMENT IN LABORATORY MSF UNITS

6.1 Introduction

In addition to physical and microbiological activities, changes in chemical constituents also take place through multi stage filtration processes. When raw water enriched with inorganic and organic matters passes over the microbial layers developed on filter media, soluble and colloidal materials are utilized by bacteria and other microorganisms as food. Organic and inorganic pollutants are dissociated in to simple end products and some of them are adsorbed on filter bed, rests are discharged with filter effluent, resulting changes in effluent water quality. Moreover, zooplankton grazing occurs and continuous respiration of entire biomass causes depletion of dissolved oxygen level. This chapter describes the changes of different chemical constituents of filtered water, which take place with the filtration operation period and stages, i.e. Dissolve Oxygen Level, pH, NH3, Organic Content and Electric Conductivity through different units of laboratory MSF.

6.2 Change of Chemical Quality Parameters in Laboratory MSF Units

6.2.1 Dissolved Oxygen (DO)

The Dissolved Oxygen (DO) concentration reduced due to biological activity in filter media; however, there was an opportunity of increase of DO level through surface aeration during flow through different filtration stages. The net effect was a reduction of DO level with filtration stages as shown in Figure-6.1. The dissolved oxygen in the filtrate was found to be low at lower rates of filtration. This can be explained by the fact that at lower rates of filtration the incoming water was retained for a longer period in the filter media and therefore, a greater depletion of oxygen by the biological system. Average overall depletion was around 40 percent and filtrate

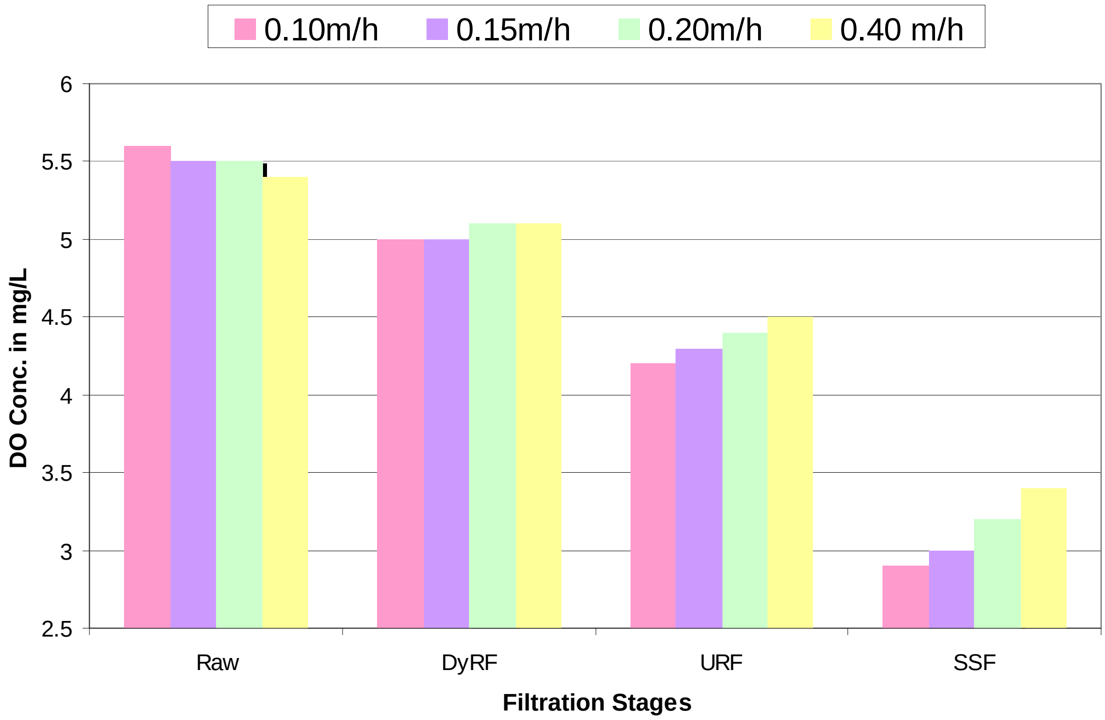


Figure-6.1: Decrease of DO Concentration in Different MSF Units

minimum concentration was about 3.0 mg/L, which is sufficient enough to maintain aerobic condition in the filtration process.

6.2.2 Organic Pollutants

The organic pollution in raw water estimated as oxygen consumed from Potassium Permanganate ($KMnO_4$), varied from about 6.3mg/L to 8.0 mg/L. Due to multistage filtration, the average reduction in this COD Value ($KMnO_4$) was about 60, 58, 55,

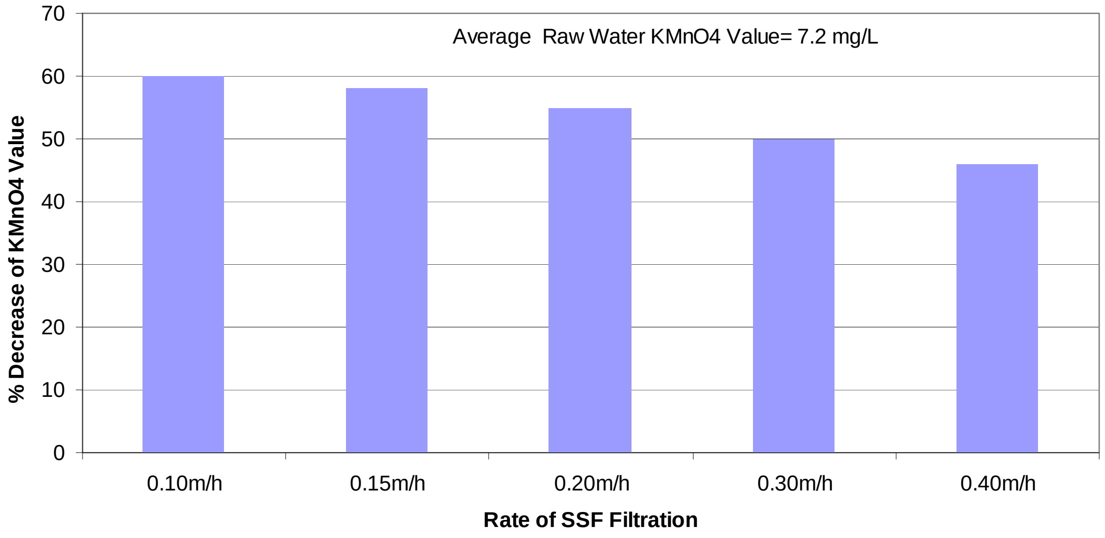


Figure-6.2: Decrease of Organic Matter(KMnO4 Value) with Rate of Filtration

50 and 46 percent respectively at 0.10, 0.15, 0.20, 0.30 and 0.40 m/h rates of filtration at slow sand filter. Figure-6.2 indicates that there was no significant difference in organic removal with regard to rate of filtration.

6.2.3 Ammonia

The percent reduction of ammonia with different filtration stages was analyzed and pictured in Figure-6.3. Average concentration of ammonia in raw water was around 0.5 mg/L and complete removal of ammonia was achieved through multi stage filtration processes as depicted from the graph. Like organic pollutant reduction, this reduction happened due to biological activity in filter media, i.e. biological oxidation of ammonia by nitrifying bacteria (*Nitosomonas* and *Nitrobacter*).

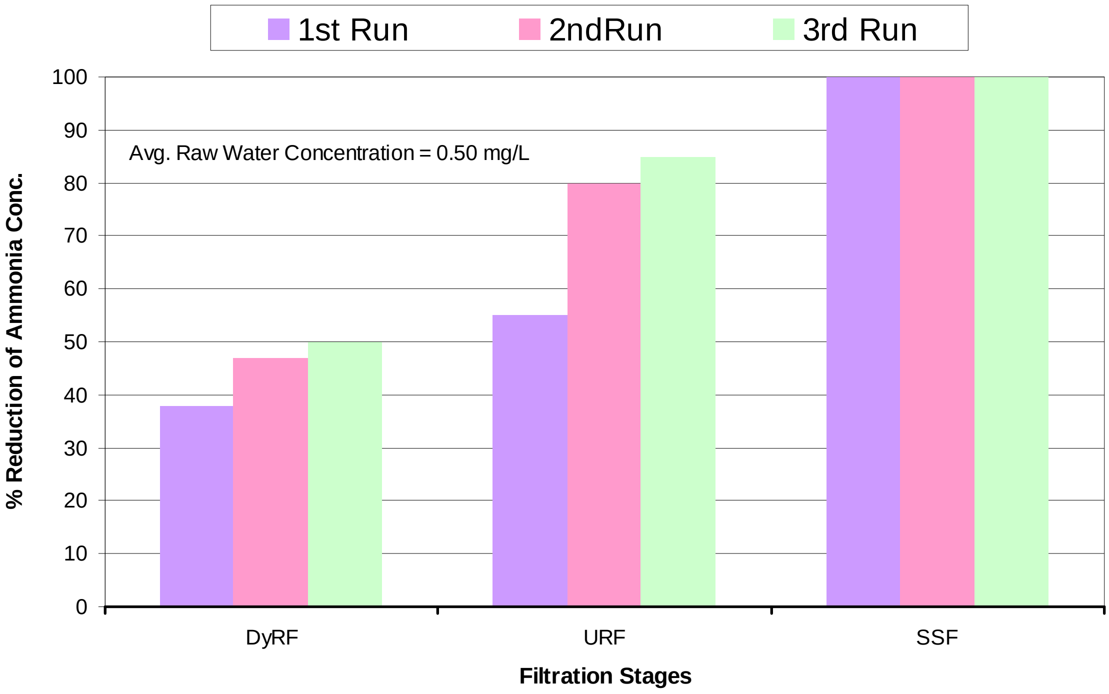


Figure-6.3: Reduction of Ammonia Conc. in Different MSFs

6.2.4 pH Value

Variation of pH with different filtration stages in all bed material or filter run was recorded and analyzed. Figure-6.4 shows the graphical representation where a decrease of pH value is found at the initial stage of the experimental runs may be caused by the biochemical reaction in filter media. But at the later part of the experimental runs, this change was not very significant as can be seen from the figure. Because of the fact that the raw water pH values of the first three experimental runs were slightly higher due to more uptake of carbon-dioxide through algal photosynthesis process during day light period. Decrease of pH resulted due to formation of carbon-dioxide as an end product of biological oxidation process.

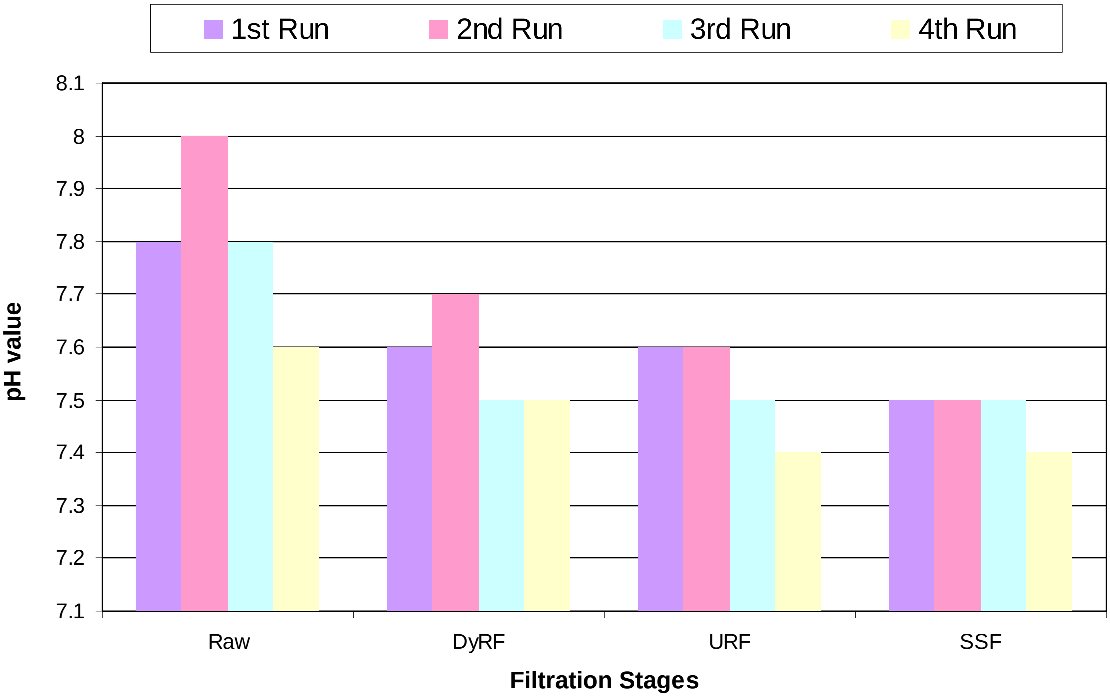


Figure-6.4: Decrease of pH Value in Different MSFs

6.2.5 Electrical Conductivity

Electric conductivity is the result of having dissolved ionized particle in the water. At different filtration stages, the variation of electric conductivity ware measured in the first three experimental runs.

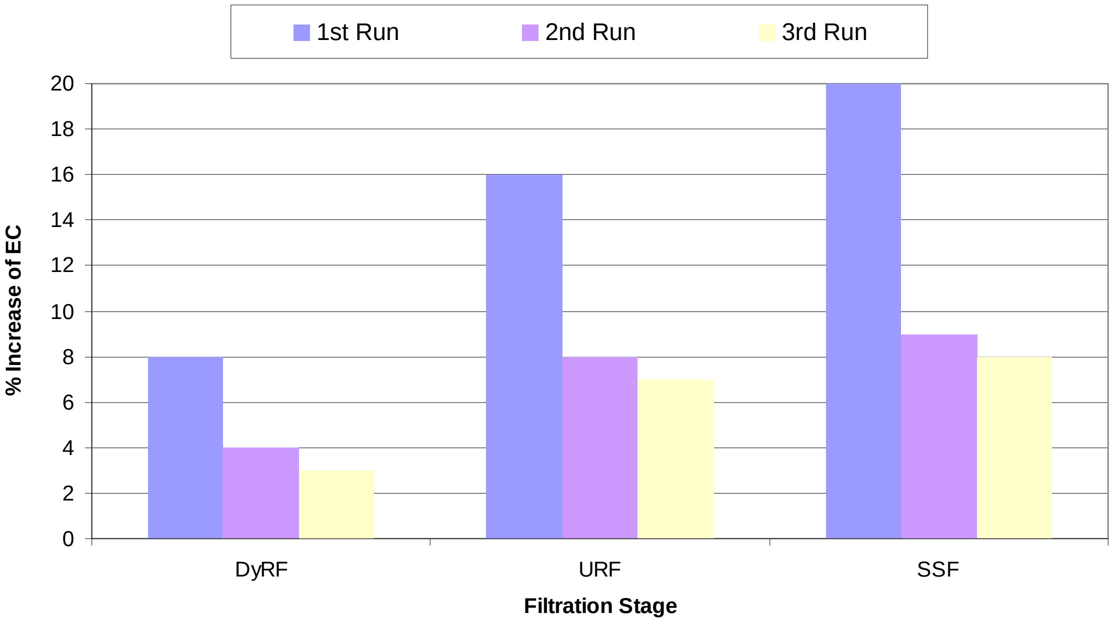


Figure-6.5: Increase of Electric Conductivity in Different MSFs

This is summarized in the figure-6.5 which shows an increase in the electric conductivity, not very significant, with filtration stages. It was due to the biochemical reaction in filter media which causes ionization of organic compounds resulting an increase of total dissolved ions. Some portion of these ions adsorbed on filter media and a fraction escaped with effluent water resulting a net increase of electric conductivity at the later part of the experimental run.

Overall Summery

Reduction of Dissolved oxygen level inversely related to the flow rate of water, and on an Average overall depletion was around 40% and minimum filtrate concentration was above 3.0 mg/L at filtration rate above 0.20m/h at SSF, which is sufficient enough to maintain aerobic condition in the filtration process. And DO level should be greater than 6.0 mg/l. The same effect was also identified in other study (Paramasivam and Sundaresan, 1978). Average reduction of organic matters around 50% was achieved and this removal is approximately independent of rate of flow; thus $KMnO_4$ value should be less than 10 mg/l. Other study on organic content removal through MSF observed the same fact (Joshi et al., 1982). During the filtration process there was slight decrease of pH value and increase of Electric Conductivity; thus pH should be greater than 7.5. Slight reduction of pH value during multistage filtration was also observed by other investigator (Joshi et al., 1982).

CHAPTER SEVEN

SUMMERY OF DESIGN CRITERIA FOR MSF UNITS

7.1 Introduction

The key parameters for a multi stage filtration system design are the type and number of prefiltration stage, media size, filtration rate and raw water particle size and concentration, however, other parameters like method of filter operation, filter bed cleaning frequency and exposure condition of filter bed are also important. The design criteria of different parameters , selected and developed from the analysis of physical, chemical and microbial quality improvement performance of different units of multi stage filter in treating surface water both in the laboratory and field, have been summarized in the following sections.

7.1.1 Raw Water Quality (Particle Size) and Number of Filtration Units

Performance of two stage prefiltration units was found to be very effective for the removal of turbidity and on an average total 83% and 90% turbidity removal was achieved in the laboratory and the field respectively, however, removal of color was found only around 34% and 50% in the laboratory and field respectively. Overall removal of turbidity through the laboratory MSF units were around 99% and average SSF effluent turbidity values in all the experimental runs reduced to 0.75 NTU; again in the field, overall turbidity removal was around 96% and an average slow sand filter effluent turbidity of around 1.45 NTU was observed which were much lower than the Bangladesh Environmental Quality Standard (EQS, 1997) of 10 NTU.

Removal of color was not found as effective as turbidity removal and in total, around 35% and 50% color was removed through two-stage prefiltration processes in the laboratory and field respectively and overall removal of color through the MSF units were around 78% and 69% in the laboratory and field respectively. Average SSF effluent color values in all the laboratory experimental runs reduced from 41 Pt. Co. Unit to 8.9 Pt. Co. Unit which is also lower than the Bangladesh EQS, 97 of 15 Pt.Co.Unit. Thus only the pre-filtration stages, URF including with DyRF, could be used for treating raw water having a moderate range of turbidity and color value close to a standard recommended range excluding the slow sand filtration unit.

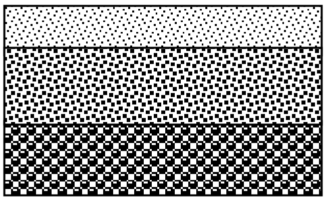
It was also observed that two stages coarse media pre-filtration units reduced all the two types of microbial densities over 60% in laboratory and in case of TTC this removal was maximum 83%. In field about 89% fecal coliform removal efficiency was found by prefiltration unit. The overall average 99.9% TTC removal in the laboratory and 99% fecal coliform removal in the field were achieved. Thus complete removal can not be expected through sand filtration system. Post chlorination unit is necessary for complete disinfected of the filtrate water.

A moderate intermediate influent turbidity value around 20 NTU and color value less than 25 Pt.Co.Unit may be proposed for SSF. To maintain this maximum proposed influent turbidity value, two stage prefiltration processes (DyRF and URF) should be adopted if the raw water turbidity level remains between 60 and 150 NTU. In case of raw water turbidity level greater than 150 NTU pre-settling arrangement should be made, however, if the raw water level remains below 60 NTU, DyRF step may be omitted.

7.1.2 Filter Bed Materials

Coarse media pre-filtration steps are effective only for the reduction of turbidity, while SSF is effective for the reduction of color value and microbial densities. Coarse media size range and depth of bed in DyRF and URF are more important parameter rather than SSF media size range for the reduction of turbidity.

Filter sand size range is important for the reduction of color concentration and microbial densities. Filter bed materials used during the 4th experimental run may be selected for the design which is shown in the Figure-7.1.

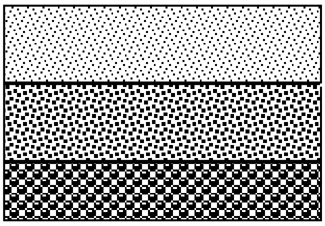


Depth: Top **100 – 150 mm, Size Range : 4.75 – 7.30 mm**

Depth: Meddle **200 – 250 mm, Size Range : 7.3 – 12.5 mm**

Depth: Bottom **200 – 250 mm, Size Range : 12.5 – 25.0 mm**

Down-flow Dynamic Roughing Filter Bed Characteristics

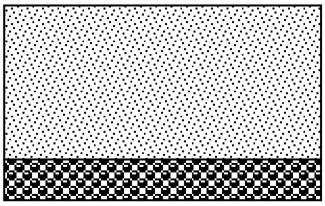


Depth: Top **350 – 400 mm, Size Range : 7.3 – 9.5 mm**

Depth: Middle **350 – 400 mm, Size Range : 9.5 – 12.5 mm**

Depth: Bottom **100 – 150 mm, Size Range : 12.5 – 25.0 mm**

Up-flow Dynamic Roughing Filter Bed Characteristics



Sand Depth**: 600 – 700 mm,**
Size Range: 0.15 to 1.1 mm, FM: 1.8-2.0
U: 2.14 –2.16, D_{10} : 0.20-0.22 mm

Under-drainage **Depth: 150 – 200 mm,**
Size Range : 4.75 - 7.3 mm, 9.5 - 12.5 mm, 18.0 - 25.0 mm

Slow Sand Filter Bed Characteristics

Figure-7.1: Preferred Filter Bed Materials for Multistage Filtration Units

7.1.3 Filtration Rate

To maintain slow sand filter influent turbidity value within 20 NTU and Color value within 25 Pt.Co.Unit, filtration rate below 0.20-0.25 m/h at SSF unit may be accepted. To maintain this flow rate at SSF, the corresponding flow rates at URF and DyRF are in a range of 0.43-0.54 m/h and 1.6-2.00 m/h respectively.

For a maximum slow sand filtration rate of ≤ 0.1m/h, an acceptable level of microbial quality of water may be obtained. However, at a filtration rate up to 0.15 m/h TTC and EC may appear occasionally. Beyond 0.20-0.25 m/h filtration rate, microbial quality deteriorate significantly. It was observed that the microbial removal performance follows an inverse trend with regard to rate of filtration of water. Since microbial quality improvement is the most important objective of surface water treatment a SSF flow rate around 0.10-0.15 m/h may be chosen with the corresponding flow rates at URF and DyRF are in a range of 0.22-0.33 m/h and 0.8-1.2 m/h respectively. .

Reduction of Dissolved oxygen level inversely related to the flow rate of water, and on an average 40% reduction was observed during nominal flow rates maintained in the experimental runs. Average reduction of organic matters around 50% was achieved and this removal is approximately independent of rate of filtration. Thus a moderate range of filtration rate around 0.20-0.25 m/h at SSF may be proposed.

7.1.4 Filter Operation

Method of filter operation did not affect the turbidity removal performance. Color removal performance reduced slightly during intermittent operation. However, microbial removal performance was seriously affected during the intermittent flow condition. Therefore, to obtain a better removal performance uninterrupted flow condition should be maintained.

7.1.5 Exposure Condition

Exposure of filter bed increased the algal activity on filter surface. Growth of algae adversely affected the microbial removal performance; however, effect on physical quality improvement was not very significant. Sloughing of algal mats from the surface of sand bed, not only seriously affected the microbial quality improvement performance but also made the removal situation became very unpredictable. On the other hand, shading of filters helped reduce the algal activity on the filters but did not affect the filter performance. Filter bed should therefore, be kept covered to avoid the unnecessary growth of algae particularly on slow sand filter bed.

These selected design parameters, depending on the physical, microbial and chemical water quality improvement performances of multistage filter units operated both in the laboratory and field, have been summarized in the Table-7.2, 7.3 & 7.4 to determine the design criteria of multistage filter units for surface water treatment in Bangladesh.

7.2 Maintenance and Cleaning of MSF Units

7.2.1 Head Loss and Length of Run

Pumping capacity of field MSF hand pump was observed to be around 1.5 m^3/h. It was also observed that the average discharge capacity of a new field MSF was around 0.70 m^3/h. However, after 8 weeks of operation, this yield reduced down to around 0.35 m^3/h; below this yield capacity of MSF plant in the field the safe operation and user acceptability were adversely affected.

For a Slow sand filtration rate of 0.20 m/h, maximum 40 cm head loss may be permitted before cleaning of bed within 6-8 weeks operation period. For an Up-flow coarse media filtration rate of 0.43 m/h, maximum 10 cm head loss may be permitted before cleaning of bed within 8 weeks operation period. For a Down-flow coarse media filtration rate of 1.6 m/h, maximum 2 cm head loss may be permitted before cleaning of bed within 8 weeks operation period. Therefore, provision of total height of water level about 60 cm (10 cm Initial water depth + 40 cm Head Loss + 10 cm Free Board) should be kept over sand bed.

At least 7 to10 days interval should be allowed for the formation of the "Schmutzdecke" on filter sand before the filter bed is brought in to full operation for domestic use. Cleaning of filter bed worsen the water quality by disrupting this biological layer. Thus twin bed filter chambers may be used in place of single bed and cleaning may be performed alternatively to allow reasonable time for the formation of biological layer.

7.2.2 Chlorination

To ensure constant safe water supply chlorination was done in the clear water chamber prior to service delivery. This was done by installing a pot chlorinator in the top of clear water chamber and connection with the chamber was made by flexible pipe having adjustable valve arrangement. The detailed procedure for chlorination has been given in the maintenance and cleaning manual attached in appendix A.

7.2.3 Cleaning of Different MSF Units

Roughing Filter Units

Following procedures have been practiced in the field MSFs and found very effective for cleaning and maintenance of coarse filter media bed without removing them. Both the dynamic and up-flow roughing filter chamber bottoms were designed to provided with washout valves. Depending on raw water turbidity level once in every 6-8 weeks period, by simply opening the washout valves, the deposited particles are drained out through hydrostatic pressure of water. It may be necessary to make more than one flash to remove major portion of deposited particles, however, removal of all particles are not desired. Complete removal and washing of coarse media (khoa) would be necessary only after 5 to 6 months of operation.

Slow Sand Filter Chambers

One of the two Slow Sand Filter beds may be cleaned alternatively after every 6-8 weeks period using an alternative method of cleaning known as “harrowing” (Shawn, 2005) where the sand top is raked gently for 4–5 minutes by a comb harrow (250 mm width x 150 mm height with 50 mm long teeth connected with steel handle), which penetrates 2-3 cm into the sand bed and detaches particles debris. The debris is then washed away by a continuous flow of water across the top of the sand bed by closing the filtrate outlet pipe and opening the waste water over-flow pipe valve placed just at the top level of the sand bed. Complete removal of filter sand, washing and replacing may be necessary after every 5 to 6 months period of operation.

Table-7.1: Schedule of Cleaning of Multi Stage Filter Units

Chamber /Unit	**Frequency of Cleaning**	**Method of Cleaning**
Dynamic Roughing Filter	Once in every 6-8 weeks without removing Khoa	Simply opening the bottom wash out valves and flushing out 2-3 times.
Up-Flow Roughing Filter	Once in every 6-8 weeks without removing Khoa	Simply opening the bottom wash out valves and flushing out 2-3 times.
Slow Sand Filter Bed	Alternatively one bed after every 6–8 weeks period.	Scraping top 2-3cm sand bed by wooden scraper and opening overflow pipe.

Cleaning process of the sand bed need to maintain critically which can be ensured by proper training and awareness rising by information dissemination to both the caretaker and the users. The detail cleaning schedule and procedure have been described in the maintenance and cleaning manual attached in appendix A.

Table-7.2: Design Criteria for DyRF Unit on the Basis of Water Quality Improvement Performance of Lab & Field MSF Units.

Design Parameters	Water Quality Parameters			Proposed Design Criteria (Considering the All Units)
	Physical Quality	Microbial Quality	Chemical Quality	
Media Sizes and Gradation	Depth:125+225+225=575 mm (# 4-¼ ") / (¼ "-½ ") / (½ "-1")	Depth:125+225+225=575 mm (# 4-¼ ") / (¼ "-½ ") / (½ "-1")	Not Significant	Depth: 500 to 750 mm(3 layers) (# 4-¼ ") / (¼ "-½ ") / (½ "-1")
Filtration Rate	1.60 - 2.00 m/h	0.80 - 1.20 m/h	1.60 - 2.00 m/h	0.80 - 1.20 m/h
Influent Water Quality	Turbidity: >60 NTU and <150NTU, Color : > 40 and < 60 Pt.Co.Unit	TTC: < 500 CFU/100ml	KMnO4 value < 10mg/L, DO > 7.0 mg/L, pH value> 7.5	Raw Water Quality: Turbidity: >60NTU and <150NTU, Color : > 40 and < 50 Pt.Co.Unit TTC: < 500 CFU/100ml, KMnO4 value < 10mg/L DO > 5-6 mg/L
Type of Flow Condition	Intermittent	Uninterrupted	-	Uninterrupted
Safe Operation Period	6- 8 weeks	6- 8 weeks	-	6- 8 weeks
Exposure Condition of Bed	Not Significant	Shaded	-	Shaded

Table-7.3: Design Criteria for URF Unit on the Basis of Water Quality Improvement Performance of Lab & Field MSF Units.

Design Parameters	**Water Quality Parameters**			**Proposed Design Criteria (Considering the All Units)**
	Physical Quality	**Microbial Quality**	**Chemical Quality**	
Media Sizes and Gradation	Depth:375+375+100=850mm (¼ "-⅜ ") / (⅜ "-½ ") / (½ "-1")	Depth:375+375+100=850mm (¼ "-⅜ ") / (⅜ "-½ ") / (½ "-1")	Not Significant	Depth: 800 - 950 mm (3 Layer) (¼ "-⅜ ") / (⅜ "-½ ") / (½ "-1")
Filtration Rate	0.43 - 0.54 m/h	0.22 - 0.33 m/h	0.43 - 0.54 m/h	0.22 - 0.33 m/h
Influent Water Quality	Turbidity: 40 to 60 NTU Color : 30- 35 Pt.Co.Unit	-	KMnO4 value < 10mg/L, DO > 7.0 mg/L, pH value> 7.5	Raw Water Quality: Turbidity: >60 NTU and <150NTU, Color : > 40 and < 50 Pt.Co.Unit TTC: < 500 CFU/100ml, KMnO4 value < 10mg/L DO > 5-6 mg/L
Type of Flow Condition	Intermittent	Uninterrupted	-	Uninterrupted
Safe Operation Period	6- 8 weeks	6- 8 weeks	-	6- 8 weeks
Exposure Condition of Bed	Not Significant	Shaded	-	Shaded

Table-7.4: Design Criteria for SSF Unit on the Basis of Water Quality Improvement Performance of Lab & Field MSF Units.

Design Parameters	**Water Quality Parameters**			**Proposed Design Criteria (Considering the All Units)**
	Physical Quality	**Microbial Quality**	**Chemical Quality**	
Media Sizes and Gradation	D:600 mm, FM=1.8-2.0, D10=0.20-0.22 Range:0.15-1.1 mm, U= 2.10-2.15	D:600 mm, FM=1.8-2.0, D10=0.20-0.22 Range:0.15-1.1 mm, U= 2.10-2.15	Not Significant	D: 600 – 700 mm, FM=1.8-2.0, D10=0.20-0.22 Range:0.15-1.1 mm, U= 2.14-2.16
Filtration Rate	0.20 - 0.25 m/h	0.10 - 0.15 m/h	0.20 - 0.25 m/h	0.10 - 0.15 m/h
Influent Water Quality	Turbidity: < 20NTU Color : < 25 Pt.Co.Unit	-	KMnO4 value < 10mg/L, DO > 7.0 mg/L, pH value> 7.5	Raw Water Quality: Turbidity: >60 NTU and <150NTU, Color : > 40 and < 50 Pt.Co.Unit TTC: < 500 CFU/100ml, KMnO4 value < 10mg/L DO > 5-6 mg/L
Type of Flow Condition	Intermittent	Uninterrupted	-	Uninterrupted
Safe Operation Period	6- 8 weeks	6- 8 weeks	-	6- 8 weeks
Exposure Condition of Bed	Not Significant	Shaded	-	Shaded

CHAPTER EIGHT

CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

1. Two stage prefiltration units were found very effective for the removal of turbidity and slow sand filtration unit for the removal of pathogen and color. The size and depth of filter bed material were found very important for the removal performance of MSF units. Filter bed materials used during the 4th experimental run have been selected for the design already shown in the Figure-7.1.
2. In case of raw water turbidity level greater than 150 NTU pre-settling arrangement should be made and if the raw water level remains within 60 to 150 both DyRF and URF units will be required, however, turbidity value below 60 NTU, DyRF step may be omitted. The pre-filtration stages, URF including with DyRF, could be used solely for treating raw water having a moderate range of turbidity and color value to a standard recommended range excluding the slow sand filtration unit.
3. Removal performance of microorganisms followed an inverse trend with regard to rate of filtration of water; therefore, to obtain the maximum removal performance without disinfection process, slow sand filtration rate should be kept around 0.10 m/h and for DyRF and URF it should be 0.22 m/h and 0.8 m/h respectively.
4. Due to the type of flow condition microbial quality of water affected more than the physical quality of water. To obtain a better microbial removal performance uninterrupted flow condition should be maintained.
5. Microbial activity in filter bed caused a reduction of DO concentration around 40%, however, resulted a decrease in organic content. Around 50% of average reduction of organic matters was achieved and this removal is approximately independent of rate of flow. Complete removal of ammonia was achieved through multi stage filtration processes. During the filtration process there was a slight decrease of pH value due to mainly formation of

CO2 as an end product of biological activity. There was an increase of Electric Conductivity due to dissociation or ionization of complex compounds into simple substances through biological activity.

6. Shading condition of filter bed materials have significant effect on microbial water quality improvement performance and should be kept covered to avoid the unnecessary growth of algae particularly on slow sand filter bed.
7. At least 7 to10 days interval should be allowed for the formation of the “Schmutzdecke” on filter sand before the filter bed is brought in to full operation for domestic use. Filer sand bed should be cleaned after every 6 to 8 week interval, however, twin bed filter chambers should be used in place of singe bed and cleaning may be performed alternatively after 7 to10 days interval.
8. Frequent cleaning of filter bed and scouring action of falling water on sand bed seriously damage the formation of biological layer on the sand bed and ultimately affecting the microbial quality of water.
9. The removal performance of different water quality parameters were higher in that of the field since the actual rate of filtration is much lower than design due to intermittent operation of hand pump attached to MSFs in the field.

8.2 Recommendations

1. It is recommended that to fully verify the laboratory test results, few pilot plants comprising of all three units in the field level for treating river water with high turbidity load should be constructed and monitored for finalization of design criteria and also to estimate the construction cost. Some further extensive researches need to undertake both in the laboratory and field to improve the color removal efficiency, to investigate the shock load absorbing capacity of dynamic roughing filtration unit and to find out the capacity of sand bed in removing other pathogens and virus on a long term basis.
2. In the case of field installation of MSF it is recommended that close involvement of future users need to accommodate as much as possible in the planning phase and need to ensure adequate caretakers training and to provide a post project support, which will contribute to enhancing a sustainable use of

the treatment processes developed. Beside this motivation activities for using safe water must be ensured to the community through awareness raising programs. User group may be formed among the beneficiaries for regular monitoring and maintenance work.

3. Cleaning process of the sand bed need to maintain critically which can be ensured by proper training and awareness rising by information dissemination to both the caretaker and the users.

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APPENDIX-A

MAINTENANCE AND CLEANING MANNUAL FOR FIELD MULTISTAGE FITRATION UNIT

1. Introduction

Operation and maintenance are the key parameters to ensure the sustainable use of any community based water supply scheme; and it is the responsibility of the community. For maintaining the field MSF units, it does not require costly chemicals, mechanical spare parts or highly trained staff. However, the caretaker plays a key role in the operation and maintenance of field MSF. The major task of a caretaker at the field is to control the water use, monitor the quality, clean the filters and carry out general maintenance work. Thus a manual for the caretaker describing simply the maintenance work of different MSF units of the field has been mentioned here including the different steps for chlorinating the clear water chamber for ensuring safe water supply.

2. Cleaning of MSF Units

After a filter has been working for several months, the time will come when the filter control valve is fully open but flow rate is below the design filtration rate. Then the filter needs to be cleaned. The caretaker also plays a key role in this cleaning process. Thus the steps are describing here for the caretaker for cleaning of different MSF units of field.

2.1 Roughing Filter Unit

Following procedures have been practiced in the field MSFs and found very effective for cleaning and maintenance of coarse filter media bed without removing them.

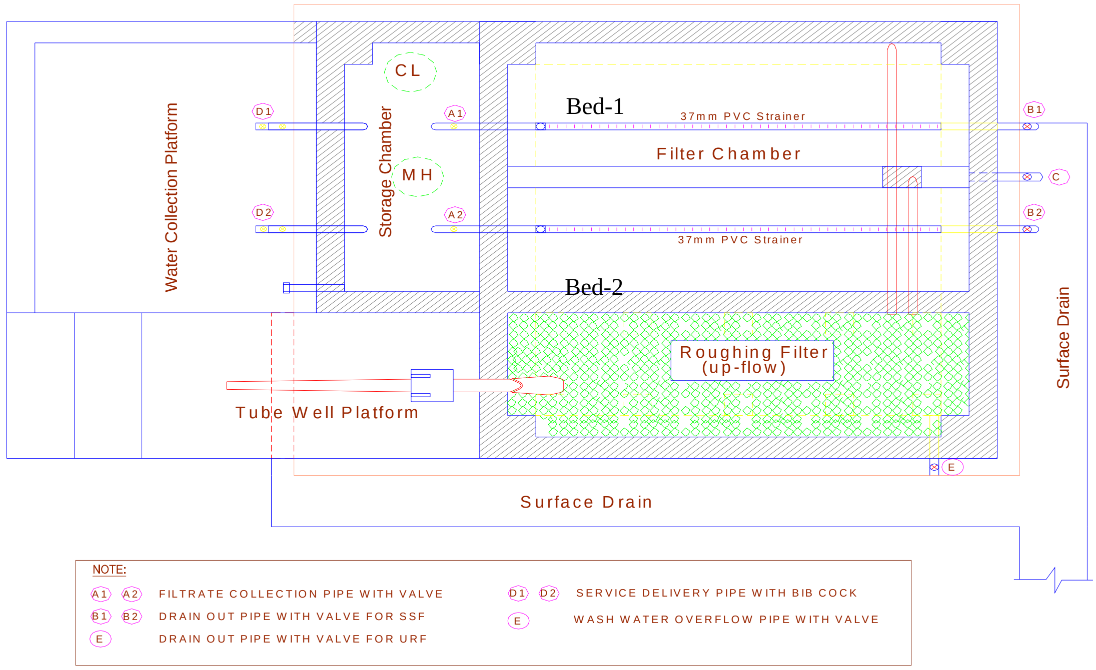

Figure-1: Plan of MSF Plant Showing Different Pipes with Connecting Valves

1. Stop pumping and open the washout valve (E in Figure-1)
2. The deposited particles will be drained out through hydrostatic pressure of water.
3. It may be necessary to make more than one flash to remove major portion of deposited particles, however, removal of all particles are not desired.

2.2 Slow Sand Filter Unit

One of the two Slow Sand Filter beds needs to be cleaned alternatively with duration of one week by just harrowing the top sand bed using a comb harrow (250 mm width x 150 mm height with 50 mm long teeth connected with steel handle)

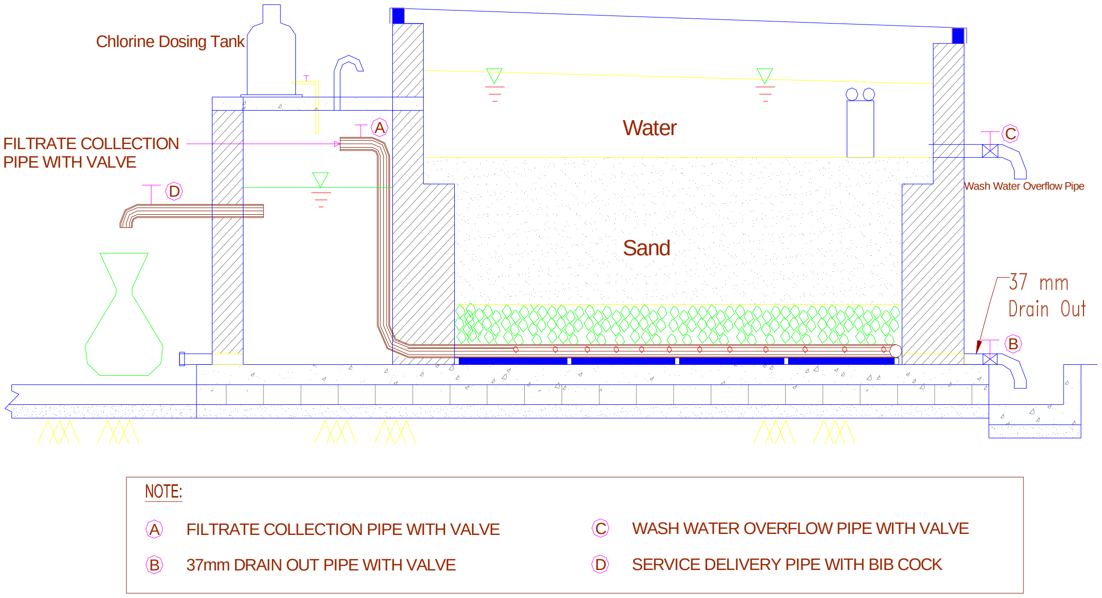

Figure-2: Section of MSF Showing Different Washout Valves

<u>Cleaning of filter bed (1/2)</u>

1. Stop pumping and open the manhole and roof cover.
2. Stop the filtrate outlet pipe valves (A1) & (A2) and washout valves (B1) & (B2) remain close.
3. Rake gently the sand top of bed (1/2) for 4–5 minutes by the comb harrow which penetrates 2-3 cm into the sand bed and detaches particles debris.
4. Open the waste water over-flow pipe valve (C) to wash away the debris by a continuous flow of water across the top of the sand bed.

5. Pump again to repeat the same procedure 2 to 3 times.
6. After cleaning of filter bed, open the filtrate outlet pipe valve (A2/A1) & keep (A1/A2) remain close and keep the bottom wash out valve (B1/B2) slightly open to allow very slow flow of water across the sand bed (1/2) for at least one week period.
7. After one week, open the filtrate outlet pipe valve (A1/A2) and close the bottom wash out valve (B1/B2).

Figure-3: Alternative Cleaning Procedure for Field MSFs

3. Chlorination

To ensure constant safe water supply chlorination was done in the clear water chamber prior to service delivery. This was done by installing a pot chlorinator in the top of clear water chamber and connection with the chamber was made by flexible pipe having adjustable valve arrangement. The working steps for the caretaker for chlorination of clear water chamber are described below:

1. First in a 30-35 litre bucket approximately 20 gm Bleaching Powder (average 15-20% strength) mix with clean water.
2. Keep it at rest for 30 minutes to settle out all suspended particles at the bottom.
3. From the mixing bucket, transfer the chlorine solution to the PVC Chlorine Feeding Tank (30 litre capacity) placed on the Clear Water Storage Chamber.
4. The chlorine feeding tank is connected with clear water chamber by flexible plastic pipe having flow control arrangement through which adjust the flow of chlorine solution.

5. Adjust the chlorine dose by observing residual chlorine concentration or physical observation of taste i.e. a dose which just imparts taste to clear water.
6. Residual chlorine concentration can be measured from time to time with potable ‘Chlorine Testing Kit’ and maintain a residual chlorine concentration of about 0.1 mg/L in the treated water (tap water),

4. Cleaning and Maintenance Schedule

To keep the plant properly functioning, some maintenance work and cleaning should be done regularly according to the following schedules by the caretaker.

Frequency	Cleaning and Maintenance Works
Daily	i) Keep the plant area clean from any pollution. ii) Keep the manhole and the roof cover closed at all times unless cleaning the filter bed. iii) Collect water from the storage chamber only from the tap. iv) Try to pump an equivalent amount of water into the chamber as drawn from the outlet. v) Always keep the taps closed to prevent wastage of water. vi) No one should be allowed disturbing the sand bed
Weekly	i) Keep the surface drain clean and free from stagnant water. ii) Maintain PVC screen pipe in pond at a certain level of water iii) Check and adjust the chlorine dozing for proper functioning of the unit. iv) Add chlorine mixture to the pot chlorinator if required. v) Check the intake screen and floating balls to ensure that they are in right place and position.
Monthly	i) If required intermediate semi flushing(flush only the turbid water below roughing filter media) may be done in case of worse raw water quality. ii) Within 6-8 weeks clean the URF by several flushing iii) Within 6-8 weeks clean the SSF beds alternatively by scrapping of top sand layer. iv) Clean the intake screen by lifting it from the pond.
Yearly	i) Complete removal of top layer filter sand, washing and replacing would be necessary after every 6 to 8 months period of operation. ii) Complete removal and washing of coarse media (khoa) would be necessary after 6 to 8 months of operation.

5. Precautions and Regulations

1. The lid and manhole should be kept closed at all times except when cleaning the MSF
2. Roughing filters should never be kept dry unless the filters are properly cleaned in advance.
3. Pump every time you draw the water.
4. The taps should always be closed to prevent wastage of water.
5. No one should be allowed to disturb the sand bed.
6. Nothing should be dropped into the filter chamber or storage chamber.
7. The MSF lid should be shut gently to avoid damage.
8. Always keep the manhole under lock and key to prevent the people from going into the storage tank.
9. MSF should be used for as many purposes as possible.

APPENDIX-B

RAW DATA OF LABORATORY MULTISTAGE FILTRATION UNITS

Experimental Condition
Continuous Flow (0.1 m^3/h)
Flow rate 0.1 m^3/h & Surface velocity 0.2 m/h for SSF
Unshaded condition

Sample Collection Day	Turbidity				Color				TTC			
	Raw	Dy.F	URF	SSF	Raw	Dy.F	URF	SSF	Raw	Dy.F	URF	SSF
1	90	48	24.5	1					650			35
2	112	52.5	33.0	1.2					700			40
3	130	63	33.0	1.4	87	40	50	18	750			40
4	116	63.2	35.4	1.15					650			35
5	150	72	37.0	1.87					600			25
6	100	50.5	31.8	1.5					400			15
7	100	48.7	25.5	1.4								
8	130	63.5	32.8	1.85								
9	120	54.5	23.8	1.05	64	54	35	12	2500			75
10	155	72	32.5	1.16					3000			90
11	150	71	32.0	1.2	60	50	35	14	3000			100
12	255	99.5	15.9	2.92					2500			90
13	155	75	39.0	1.23	55	48	42	16	500			35
14	145	75	36.0	1.1					2500			50
15	170	79	41.0	1.2	50	38	40	17	1600			40
16	125	59	25.5	0.95								
17	97.5	38.5	20.7	1	22	17	18	18	800			75

Experimental Condition
Continuous Flow (0.1 m^3/h)
Flow rate 0.1 m^3/h & Surface velocity 0.2 m/h for SSF
Unshaded condition

Sample Collection Day	Dissolved Oxigen				Electric conductivity				Ammonia				pH			
	Raw	Dy.F	URF	SSF	Raw	Dy.F	URF	SSF	Raw	Dy.F	URF	SSF	Raw	Dy.F	URF	SSF
18																
19					390	480	520	580								
20	6.5			2.5					0.4	0.2	0.15	0				
21	6.5			2.8	430	470	520	600								
22									0.4			0				
23																
24					370	450	530	610	0.6			0				
25					445	480	536	609					7.3	7.3	7.4	7.3
26	4.7	4.2	3.9	3	400	450	510	600					6.7	6.8	6.7	6.7
27					400	450	520	580	0.5	0.3	0.1	0	7.9	7.8	7.8	7.8
28					580	620	640	650					7.9	7.6	7.6	7.6
29					600	630	690	710					7.8	7.8	7.8	7.7
30	6.5	5.4	4.5	2.4	560	600	590	550								
31	6.7	5.5	4.3	1.5	520	540	550	580					8.2	8	7.8	7.8
32	7.1	5.3	4.2	3	520	530	550	550					8.2	8	7.9	7.6
34					590	570	600	540					8.1	7.8	7.7	7.6
35	6.4	5.1	4	3.4												

Experimental Condition

Continuous Flow (0.1 m^3/h)

Flow rate 0.1 m^3/h & Surface velocity 0.2 m/h for SSF

Shaded condition

Sample Collection Day	Turbidity				Color				TTC			
	Raw	Dy.F	URF	SSF	Raw	Dy.F	URF	SSF	Raw	Dy.F	URF	SSF
36	104	40	13.0	1.1								
37	140	60	25.0	1.7					1000			150
38	110	44	20.0	1.4								
39	130	57	24.0	1.4	47	41	40	14	2000			140
40	135	57	21.0	1.2					1400			50
41	120	51	20.0	1	24	24	20	7	1500			125
42	110	48	19.0	0.9					2200		1800	45
43	125	49	20.0	0.95					600			28
45	115	46	20.0	0.85					1000			16
46	130	62	24.0	0.9					1050			16
47	120	54	20.0	0.8	35	29	21	10	2500	2100	1000	12
48	125	54	19.0	0.8					1200			10
49	140	58	20.0	1					1500			13
50	115	54	16.0	0.9								
51	145	56	17.0	1.1								
52	129	50	14.0	0.76					2200			36
53	122	50	16.0	0.74					2100	1600	720	16
54	127	51	14.0	0.9	38	22	14	6	1400	900	700	4
55	160	61	18.0	1.1					1450			16
56	133	49	15.0	1.15	53	42	28	12	1300	850	500	14
57	130	47	16.0	0.8	36	30	19	7				
58	120	45	16.0	0.7					700			4
59	135	48	17.5	0.65					1800	1500	1000	9
60	125	47	16.0	0.5	41	34	20	9	2000			10
61	115	46	16.0	0.6					2200			25
62	105	45	15.5	0.75	48	40	25	10	2800			21

Experimental Condition

Continuous Flow (0.1 m^3/h)

Flow rate 0.1 m^3/h & Surface velocity 0.2 m/h for SSF

Shaded condition

Sample Collection Day	Dissolved Oxigen				Electric conductivity				Ammonia				pH			
	Raw	Dy.F	URF	SSF	Raw	Dy.F	URF	SSF	Raw	Dy.F	URF	SSF	Raw	Dy.F	URF	SSF
63																
64																
65					460	480	480	490					8.2	7.8	7.7	7.5
66	6	403	3.5	1.5	460	480	520	520					8.1	7.9	7.7	7.6
67					470	490	490	460					8.1	7.9	7.8	7.7
68	6.4	5	4	2.3												
69																
70	6.6	5.8	4.8	2.1	660	670	640	620					8.1	7.8	7.7	7.6
71																
72																
73									0.5	0.35	0.2	0				
74	6.6	5.4	4.4	1.7												
75													8.2	7.8	7.7	7.6
76	6.8	5.8	4.6	2									8	7.8	7.7	7.6
77																
78																
79																
80					450	475	594	675								
81																
82	4.7	3.4	1.8	1	654	675	694	670					7.8	7.4	7.3	7.3
83					635	657	697	753	0.3	0.2	0.1	0	7.9	7.5	7.3	7.3
84					654	657	697	753								
85	5.1	3	1.2	0.7	6.3	637	685	671								
86	5.2	3	2.4	0.7	539	581	645	735	0.3	0.15	0	0	7.9	7.5	7.3	7.4
87																

Experimental Condition
Discontinuous Flow (0.1 m^3/h)
Flow rate 0.1 m^3/h & Surface velocity 0.2 m/h for SSF
Shaded condition

Sample Collection Day	Turbidity				Color				TTC			
	Raw	Dy.F	URF	SSF	Raw	Dy.F	URF	SSF	Raw	Dy.F	URF	SSF
88	90	39	14.5	0.8	38	33	21	8	1050			45
89	122	51	11.5	0.8					1400			8
90	95	40	15.0	0.5	37	34	22	8	1200	950	350	8
91	80	37	12.5	0.5					1000			2
92	75	34	11.5	0.6	36	33	27	9	1000			15
93	85	37.5	13.0	1					2500	2100	1400	14/28
94	95	39	14.0	1.1	47	36	35	13	2000			70
95	65	32	11.5	0.8					1300			60
96	75	34	11.4	0.6	36	30	28	8	1000			45
97	85	34	12.0	1					1000			75
98	70	32	11.0	0.9					1000			50
99	70	29	9.0	0.8	41	38	36	19	1600			20
100	65	27	8.5	0.7					1200			18
101	60	26	8.0	0.7	30	29	27	13	480	400	160	2
102	65	26	8.5	0.87					2000			7
103	70	30	10.5	0.7					1400			11
104	80	32	10.5	0.6	24	22	21	9	1500			0
105	70	28	8.5	0.4					650			0
106	90	31	10.0	0.6	28	23	21	8	2000	93	350	18