

**PILOT SCALE STUDY ON PRESSURE
FILTRATION SYSTEM
FOR EVALUATION OF FILTRALITE
FILTER MEDIA**

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By

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CERTIFICATE

This is to certify that the thesis report entitled "Pilot Scale Study on Pressure Filter for the Evaluation of Filtralite Filter Media" submitted by Nidhi Tyagi in the partial fulfillment in the award of the degree of **Master of Technology in Environmental Science and Technology**, Thapar University, Patiala, is a record of student's own work carried out by her under my supervision and guidance. The report has not been submitted for the award of any other degree or certificate to this or any other institution.



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ABSTRACT

Filtration is one of the principal unit operation used for the supplemental removal of suspended solids (including particulate BOD) and even for the removal of pathogens from water and wastewater. Conventionally, sand and occasionally anthracite have been used as a filter media. But these days many other synthetic filter media available in the market for use in place of the conventionally used sand. Suppliers claim many more things in addition to the removal suspended solids. Removal of pathogens, BOD, odours and smells, heavy metals are among these claims even in the rapid gravity filtration modes. However wide spread use of these synthetic media will depend on demonstrating the filtration process and proving the claims.

Filtralite one such synthetic medium claimed to have the capabilities beyond that of sand and/or anthracite. Supplier of this medium in India has shown interest in evaluating this medium and developed specifications and design parameters for the rapid gravity filters and the pressure filter alternatives. Consequent this pilot scale evaluation of the filtration process using filtralite as medium on synthetic water/wastewater has been planned. Modular pilot scale filtration systems with all the provisions for necessary experimentation and monitoring have been designed and articulated. The articulated systems were supposed to be used for the evaluation of 8 different types of filtralite media vis-à-vis the conventional media, sand and anthracite. In the present study two pilot scale filtration systems was designed and articulated. Test runs were carried out for making the filtration, the filter backwashing, and the filtration process monitoring and analysis standardized. To begin with all the types of filtralite media, conventional sand and anthracite media were characterized. The filtration system was assembled using one of the filtralite media, MC 0.8-1.6, and three filter runs were carried out, the filtration process was monitored and the monitored data was analysed. The results obtained are presented in this report.

Filtration was carried out at a required rate of 20m/hr. Raw water modified through dosing bentonite clay for the desired turbidity was filtered. Results showed that the

backwashing needs to be done after 12 hours of run as the turbidity and overall pressure increases at that time.

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CHAPTER-1

INTRODUCTION

1.1. Background

Filtration is a polishing process which involves passing the water and also waste water through a layer (or bed) of porous granular material that results in the removal of suspended solids by trapping them in the pore spaces of the filter media. Two types of filtration system (slow sand filters and rapid sand filters) are most commonly used. Pressure filters are also rapid sand filters with only difference of occupying very less space and are compact. Conventionally sand and occasionally anthracite coal have been used as filter media. But these days many other synthetic media are commercially available which are becoming popular because of their better removal efficiency as compared to conventionally used media such as plastic, crushed glass etc. These are also being used in combination with sand in dual media filters. One such media available is filtralite and suppliers of this media often claim BOD, heavy metals, etc. contaminants removal along with the suspended solids. Filtralite has been extensively used for biological as well as physical treatment of water and waste water in different parts of the world. In the study planned for the M.tech dissertation this commercially available media is evaluated at the pilot scale filtration study.

1.2. Objectives

Objectives of the present study are stated as follows:

1. Design and articulation of pilot scale pressure filtration system
2. Standardizing filtration and backwashing, filter analysis and filter monitoring techniques.
3. Experimental running of pilot scale filtration system.

1.3 Contents of the report

Present thesis work on pilot scale filtration study on pressure filters using filtralite as filter media includes following five chapters.

Chapter - 1 is “**Introduction**”. It highlights the brief information regarding the pilot scale study and explicitly states the objective of the study. Provides overview of the contents of the report and highlights the importance of the work and limitations of the study.

Chapter -2 is “**Literature Review**”. This chapter provides the literature on filtration process and its types. It also provides information regarding the different types of filter media used in rapid filter and how these media performed in different conditions. It also provides information regarding filter profiling, filter analysis and design of filter.

Chapter -3 is “**Materials and Methods**”. This chapter gives information regarding the work elements of the present study and the approach followed for carrying out the work on identified work elements.

Chapter –4 is “**Results and Discussion**”. Results of the present study are covered in this chapter and discussed herein under two sections: characterization of the filter media including gravel and pilot scale experimentation.

Chapter -5 is “**Summary and Conclusions**”. This chapter summarizes the outcomes of the present study and draws conclusions. It goes further to bring forth the limitations of the study and indicates what else can be done in the future studies.

CHAPTER-2

REVIEW OF LITERATURE

2.1. Introduction

Filtration is a fundamental unit operation that separates suspended particles matter from water. Although industrial application of filtration varies significantly, all filtration equipment operate by passing the solution or suspension through a porous medium, upon which solid particles are retained either on the surface of the medium or within the pore spaces of the medium. Conventional filtration processes are normally preceded by coagulation, flocculation, and sedimentation. Direct filtration processes are preceded by coagulation and flocculation only; the floc is removed directly by the filters.

According to the Surface Water Treatment Rule under the 1986 Safe Drinking Water Act (SDWA) Amendments requires that many surface water supply systems and groundwater under the influence of surface water filter their water supplies. Sand filters were proved to be beneficial for the prevention of water borne diseases in 1892 (**Baker, 1949**). Slow sand filter was the first modern technique used for the treatment of surface water. It can eliminate up to 99.9% of the water born bacteria. It has been also used to prevent gastro intestinal diseases for the last 150 years (**Hicks, 2002**). Slow sand filtration has several limitations; the most important of all is required large area, as well as a great amount of filter material. In 1885 the first mechanical filters were installed in the USA, and in 1899 automatic pressure filters were first patented in England. Since then a number of modifications and improvements have been introduced and have attained varying degrees of popularity, particularly in highly industrialized countries.

2.2 Types of filtration process

There are basically two types of filtration process, surface filtration and depth filtration. In **surface filtration** the suspended particles adhered only on the surface of the filtering media. Removal of solids is effected by the previously deposited solids or cake, as cake builds up resistance to flow also increases. Filter aids, such as, diatomaceous earth and porous silica particles, are often added as a layer on the medium for additional support (called precoat) to reduce compression of the cake and impart high permeability. Frequent Backwashing is required in such type of filtration process. In contrast to this in

depth filtration the suspended particles enter into the porous medium. In this case the medium provides the surface area for attachment and cake growth forms around the grains. (Example: sand filters).

Basically there are two types of depth filters, slow sand filters and Rapid sand filters.

Slow sand filters: They consist of the fine sand, supported by gravel. It has been found that biological action occurs in slow sand filter beds. Because of the low hydraulic loading and smaller sand size found in slow sand filters. Most of the solid particles are removed within the top 0.5 - 2 cm of sand. With time biological film called the **schmutzdecke** (dirty layer) also known as a zone of biological activity within the sand bed develops.

Rate of filtration in case of slow sand filters is small, that is .015 to 0.15GPM/ft². The particles are capture near the surface of the bed and are usually cleaned by scrapping away the top layer of the sand that contains the particles. Effective size of slow sand filters lies between 0.15mm to 0.35mm. Unless treating high turbidity water, these filters may run for weeks or even months without cleaning. Loss of head in case of slow sand filters is approximately 10 cm initially, and .8 to 1.2 m is the final limit when cleaning is required. Slow sand filters are most efficient in removal of pathogens from water.

Rapid sand filters: They consist of larger sand grains supported by gravel and capture particles through out the bed. They are cleaned by backwashing mechanism. Rate of filtration in case of rapid sand filters is 2-3 GPM/ft². At low rates of filtration, particles are primarily removed in the upper layers of the filter, causing clogging even though pore spaces in the lower layers are relatively unobstructed. At higher filtration rates, however, large particles penetrate deeper into the filter bed before they are removed such that the head loss per mass of particles removed is lower (**Darby et al., 1991; Kau et al., 1995**).

Furthermore, most studies have demonstrated that increasing the filtration rate has only a minimal impact on removal efficiency of suspended solids (**Tebbutt, 1971; Dawda et al., 1978; Darby et al., 1991; Kau et al., 1995**).

In case of rapid sand filters the sand used has an effective size of 0.35 to 0.55 and uniformity coefficient is 1.2 to 1.8. Rapid sand filters are quite flexible for meeting reasonable variation in demand as compared to slow sand filters. The initial head loss in case of rapid sand filter is 0.3m and 2.5 to 3.5m is the final limit when cleaning is required. Backwashing is done to clean the filter.

Depth filters are also classified on the basis of type of operation (down flow or upflow).

Down flow filters are mainly conventional down flow filters or deep bed down flow

filters in which the flow of water is from the top of the filter. Conventional down flow filters can be mono, dual, or multimedia filter. Dual and multi-medium and deep bed mono medium depth filters were developed to allow the suspended solids in the liquid to be filtered to penetrate farther into the filter bed. In shallow mono-medium down flow filters most of the removal occurs in the upper few millimetre layer of the bed (**Tchobanoglous and Eliassen, 1970**). Other type of down flow filters are deep bed filters that are similar to conventional down flow filters with the exception that the depth of the filter bed and the size of the filter medium (usually anthracite) are greater than the corresponding valued in conventional down flow filters. In general, deep bed filters are not fluidized completely during backwashing. To achieve cleaning, air scour and surface water wash is used in the backwashing operation.

In **Deep Bed Upflow filters** the water or waste water to be treated is introduced into the bottom of the filter and is distributed evenly into the sand bed through the open bottom. Upflow units contain single filter medium—usually graded sand. Gravel is retained by grids in a fixed position at the bottom of the unit. The function of the gravel is to ensure proper water distribution during the service cycle. Another grid above the graded sand prevents fluidization of the media. Air injection during cleaning assists in the removal of solids and the reclassification of the filter media. During operation, the larger, coarse solids are removed at the bottom of the bed, while smaller solids particles are allowed to penetrate further into the media. Typical service flow rates are 5-10 gpm/ft²

2.3. Transport Mechanism: The principle processes by which particles are brought into contact with the filter medium consist of screening, sedimentation, inertial and centrifugal forces, diffusion, mass attraction and electrostatic and electro kinetic attraction.

Screening: This is the process for the interception and retention of particles too large to pass through the interstices between the grains of sand. It takes place almost entirely at the surface of the filter, and is independent of the filtration rate shown in figure 2.1.

Interception occurs when particle motion along a streamline is close enough ($<0.5 d_p$, the diameter of the particle) to the collector for contact to occur. Although interception has been considered a distinct transport mechanism, some researchers have incorporated it as a boundary condition for attachment resulting from diffusion and sedimentation (**Amirtharajah, 1988**).

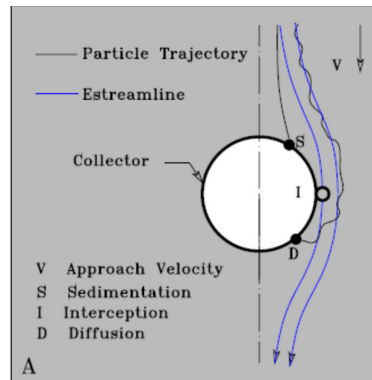


Fig 2.1 Mechanism of interception

Sedimentation: the settling action within the pores, whereby particulate suspended matter is precipitated onto the sand grains. The total upward facing surface area of all the grains is theoretically available for settling. This mechanism can only be significant for $d_p > 1\mu\text{m}$ (Yao *et al*, 1971), and plays an important role in filtration because of the large surface area on the grains available for deposition

Inertial and Centrifugal forces: the particles having specific gravity higher than the surrounding water, leave the flow lines due to the inertial and centrifugal forces acting upon them(Fig 2.2).

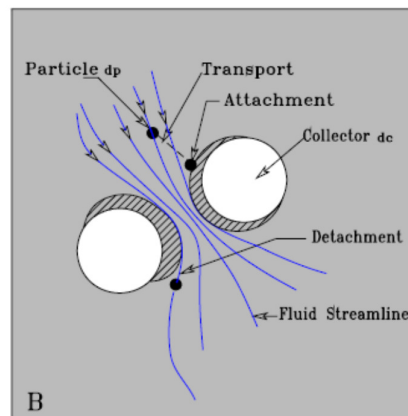


Fig 2.2 Transport mechanism due to centrifugal and inertial forces

Diffusion: It brings suspended particles into contact with the surface of the sand. This mechanism can only be significant for $DP < 1\mu\text{m}$ (Yao *et al*, 1971).

Mass attraction: Also known as Vander Walls force of attraction. This force acts universally and contributes to both the transport and the attachment mechanisms.

2.4 Emergence and Application of Rapid sand filters

The 'American rapid' filter of the 1880's was the first major step in the engineering optimization of the filtration process. Twenty-fold increase in flow rates resulted in proportionately reduced filter area requirements. However, rapidly accumulated solids required more frequent, mechanical filter cleaning. Although not superior to slow sand filtration in effluent water quality, rapid sand filtration was quickly embraced world-wide as a more economic, less labor-intensive and more readily automated process. Rapid sand filtration, generally preceded by coagulation and sedimentation, has become the predominant final physical barrier to the passage of microbial pathogens into public drinking water systems.

The effectiveness of rapid filters was initially evaluated for the removal of suspended solids (or turbidity), colour (apparent), organic matter (volatile solids), and plate count bacteria (**Fuller, 1898**). With the advent of drinking water regulations, the evaluation of filtration performance rapidly narrowed to compliance monitoring for the reduction of turbidity, which served as a primary microbiological surrogate for physical removal processes. The combined effectiveness of filtration and disinfection is monitored through total *coliform bacteria*. Few utilities routinely monitor for heterotrophic plate count (HPC) bacteria. Only in the past decade have limited direct observations been made to demonstrate physical removal of specific pathogens, such as *Giardia* and *Cryptosporidium* (**Rose, 1988**).

Comprehensive assessments of the actual removal of total bacterial cells, particle-associated bacteria, algal micro colonies, and nematodes were conducted at a water treatment plant treating Missouri River water (**Brazos and O'Connor, 1986, 1987, 1988, 1990**). Direct microscopic observations of the effectiveness of comprehensive, two stage pre treatment and rapid sand filtration revealed unexpectedly large seasonal differences in the physical removal of specific particles. During periods of low water temperature, micro organism removals were found to decline significantly, whereas consistent reductions in turbidity (silt, clay) made treatment appear effective year-round. As a result, winter periods of poor microorganism removals consistently passed unnoticed.

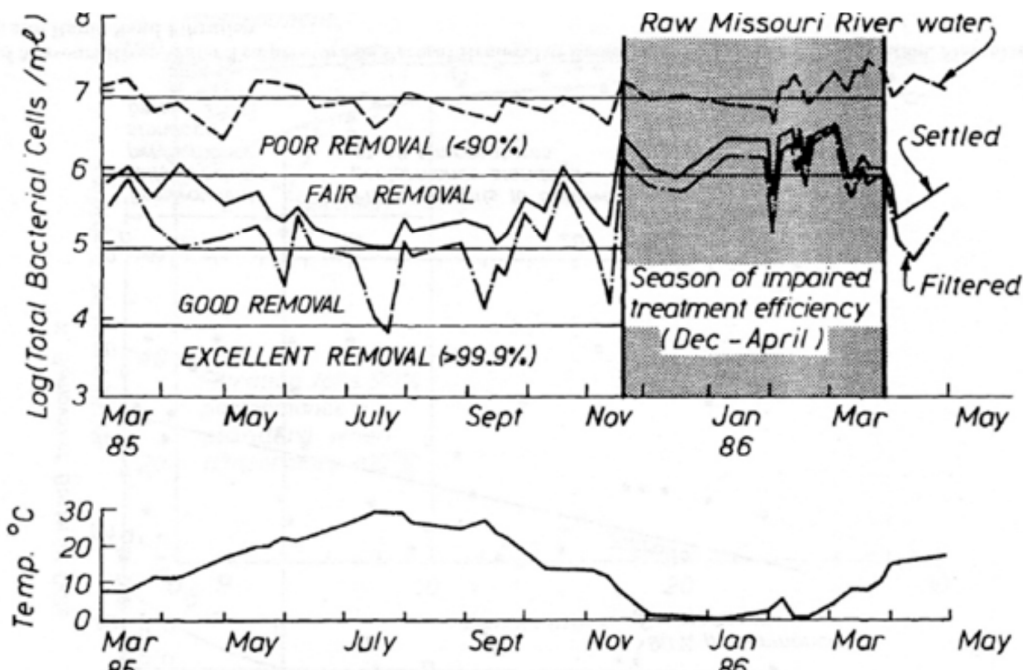


Fig.2.3 Bacterial cell removals by pre-treatment(coagulation, flocculation, sedimentation)and filtration decline significantly when Missouri River water temperature falls below 7 °C (December to April).

Virus removal

The contribution of rapid filtration process to improve virus inactivation and removal in the overall tertiary treatment process has been amply demonstrated (**Rose et al., 1996; Sheikh et al., 1998; Rose et al., 2001**). Virus removal by filtration ranged from less than 1 log to 1.6 log in these studies. It is generally agreed that primary contribution of the filtration step to virus inactivation is due to the removal of suspended particles and aggregated viral clumps wherein viruses can otherwise be shielded against disinfectants applied downstream.

Heavy metals removal

Rapid sand filtration has been used as a cost-effective tertiary treatment process for sewage and wastewaters. However, little information is available on the performance of the process for heavy metals removal. In the study carried out by **Donald B. Aulenbach; Yeung-Yu Chan**, the effect of a rapid infiltration on the removal of total organic carbon (TOC) phosphorus, Cd, Cu, Pb, and Zn from a mixed industrial and domestic wastewater was evaluated. To facilitate observation of the system behaviour under varied conditions, the influent samples were also subjected to extreme pH values. Further studies were conducted to determine the effects of calcium carbonate addition for heavy metals precipitation prior to application onto the sand column. The results

revealed that sand filtration was remarkably successful in removing phosphorus from wastewater under all conditions. The data further confirmed that in a sand filtration process, the mechanism of phosphorus removal was mainly due to chemical precipitation. Under neutral pH conditions, TOC, Cd, and Cu, were removed in the order of 20%, and Pb, and Zn were about 35-40% removed. Addition of a chemical precipitant such as calcium carbonate increased the pollutant removal to about 50%. At pH values below 2.4 and above 11.0, the TOC and all the metals showed an increase in concentration in passing through the sand column.

2.5 Types of Rapid Filters

There are a number of different types of RSFs depending upon bed depth (example, shallow, conventional and deep bed) and the type of filtering medium used (mono-media, dual- media, and multi medium). Typically sand is used as the filtering material in single medium filters. Dual- media filters usually consist of a layer of anthracite over a layer of sand. Design data for dual media and multimedia filter are given in table 2.1 below.

Table 2.1 Typical design data for dual media and multi media depth filters

Characteristics	Unit	Range	Typical
Dual media Anthracite (density 1.6)			
Depth	mm	360-900	720
Effective size	mm	0.8-2.0	1.3
Uniformity coefficient	unit less	1.3- 1.6	<1.5
Dual media sand (density 1.6)			
Depth	mm	180-360	360
Effective size	mm	0.4-0.8	0.65
Uniformity coefficient	unit less	1.2- 1.6	<1.5
Rate of filtration	L/m ² .min	80-400	200
multi media Anthracite (density 1.6)			
Depth	mm	240-600	480
Effective size	mm	1.3-2.0	1.3

Uniformity coefficient	unit less	1.3- 1.6	<1.5
Anthracite (second layer)			
Depth	mm	120-480	240
Effective size	mm	1.0-1.6	1.1
Uniformity coefficient	unit less	1.5-1.8	<1.5
Dual media Anthracite (density 1.6)			
Depth	mm	360-900	720
Effective size	mm	0.8-2.0	1.3
Uniformity coefficient	unit less	1.3- 1.6	<1.5
Sand (density 2.65)			
Depth	mm	240-480	720
Effective size	mm	0.4-0.8	1.3
Uniformity	Unit less	1.3-1.8	<1.5
Coefficient	Unit less	1.3-1.8	<1.5

Source: Tchobanoglous(1988)

(Dr. Awatif Soaded Al-Saqqar, Batool Mohammed Al-Bayaty, 2008) The dual media filter was tested in one of the study carried out by Department of civil engineering, Amanet Baghdad College of Engineering, Water Sector, University of Baghdad, Baghdad. Porcelanite, which is one of the local materials, was selected to be the filter medium with sand in the experimental work. The pilot scale filtration system consisted of three plastic column filters, running parallel. The first contained 70cm sand, the second and third were dual filters of different arrangements. The results had shown that the dual filters perform better than sand filters. About 22 to 36% less volume of water was required to wash the dual filters due to the low uniformity coefficient (UN) of porcelanite and its large effective size. The results also showed that the dual filters were better in turbidity and bacterial removal as compared to single media sand filters.

Further classification can be made based on the driving force as gravity or pressure filters.

Gravity filters are open vessels that depend upon system gravity head for operation. Apart from filter media, the essential components of gravity filter includes: filter shell (either concrete or steel), an underdrain system (which ensures uniform collection of filtered water and uniform distribution of backwash water), Wash water troughs (large enough to collect backwash water without flooding), Control devices that maximize filter operation efficiency.

Pressure filters are similar to gravity filters in that they include filter media, supporting bed, underdrain system, and control device; however, the filter shell has no wash water troughs. Pressure filters are typically used with hot process softeners to permit high-temperature operation and to prevent heat loss. The use of pressure filters eliminates the need for re-pumping of filtered water.

Pressure filters, designed vertically or horizontally, have cylindrical steel shells and dished heads. Vertical pressure filters range in diameter from 1 to 10 ft with capacities as great as 300 gpm at filtration rates of 3gpm/ft². Horizontal pressure filters, usually 8 ft in diameter, are 10-25 ft long with capacities from 200 to 600 gpm. These filters are separated into compartments to allow individual backwashing.

Rapid pressure sand bed filter design considerations

Smaller sand grains provide more surface area and therefore a higher decontamination of the inlet water, but it also requires more pumping energy to drive the fluid through the bed. Most rapid pressure sand bed filters use grains in the range 0.6 to 1.2 mm. Larger sand grains can be used to overcome this problem, but if significant amounts of large solids are in the feed they need to be removed upstream of the sand bed filter by a process such as settling. The depth of the sand bed is recommended to be around 0.6-1.8 m (2-6 ft) regardless of the application. Guidance on the design of rapid sand bed filters suggests that they should be operated with a maximum flow rate of 9 m³/m²/hr **Ives, K.J. (1990)**. Using the required throughput and the maximum flow rate, the required area of the bed can be calculated.

One of the important design considerations is that the fluid is properly distributed across the bed and that there are no preferred fluid paths where the sand may be washed away. Rapid pressure sand bed filters are typically operated with a feed pressure of 2 to 5 bar (28 to 70 psi). The pressure drop across a clean sand bed is usually very low. It builds as particulate solids are captured on the bed. Particulate solids are not captured uniformly

with depth; more are captured higher up with bed with the concentration gradient decaying exponentially.

The shape of the filter particle size-efficiency curve is a U-shape with high rates of particle capture for the smallest and largest particles with a dip in between for mid-sized particles. The build-up of particulate solids causes an increase in the pressure loss across the bed for a given flow rate. For a pressurised rapid sand bed filter this occurs when the pressure drop is around 0.5 bars. The back wash fluid is pumped backwards through the bed until it is fluidised and has expanded by up to about 30% (the sand grains start to mix and as they rub together they drive off the particulate solids). The fluid flow required to fluidise the bed is typically 3 to 10 m³/m²/hr but not run for long (a few minutes) **Coulson, J.M. (1991)** and his co-workers. Small amounts of sand can be lost in the back washing process and the bed may need to be topped up periodically.

Dual or multimedia filters are designed for 6-8 gpm/ft². At ambient temperature, the recommended filter backwash rate is 6-8 gpm/ft² for anthracite and 13-15 gpm/ft² for sand. Anthracite filters associated with hot process softeners require a backwash rate of 12-15 gpm/ft² because the water is less dense at elevated operating temperatures. Cold water should not be used to backwash a hot process filter. This would cause expansion and contraction of the system metallurgy, which would lead to metal fatigue. Also, the oxygen-laden cold water would accelerate corrosion.

On the basis of principle filtration methods used with reference to the rate of flow through rapid filters may be classified as:

- Constant- rate of filtration with fixed head
- Constant- rate of filtration with variable head
- Variable -declining -rate filtration

Constant rate filtration with fixed head: In constant rate filtration with fixed head the flow through the filter is maintained at a constant rate. They are either influent controlled or effluent controlled. Pumps or weirs are used for influent control whereas effluent modulating valve that can be operated manually or mechanically is used effluent control.

Constant rate filtration with variable head: In constant rate variable filtration head, the flow through the filter is maintained at a constant rate, Pumps or weirs are used for influent control. When the head of effluent turbidity reaches a preset value, the filter is backwashed.

Declining -rate filtration with fixed or variable head: In declining rate filtration, the rate of flow through the filter is allowed to decline as the rate of head loss builds up

with time. Declining rate filtration systems are either influent controlled or effluent controlled.

2.6 Components of Rapid gravity or Pressure filters

The major parts of gravity or pressure filters are

- Filter box/filter shell
- Filter media
- Gravel support
- Under drain system, and
- Wash water tanks

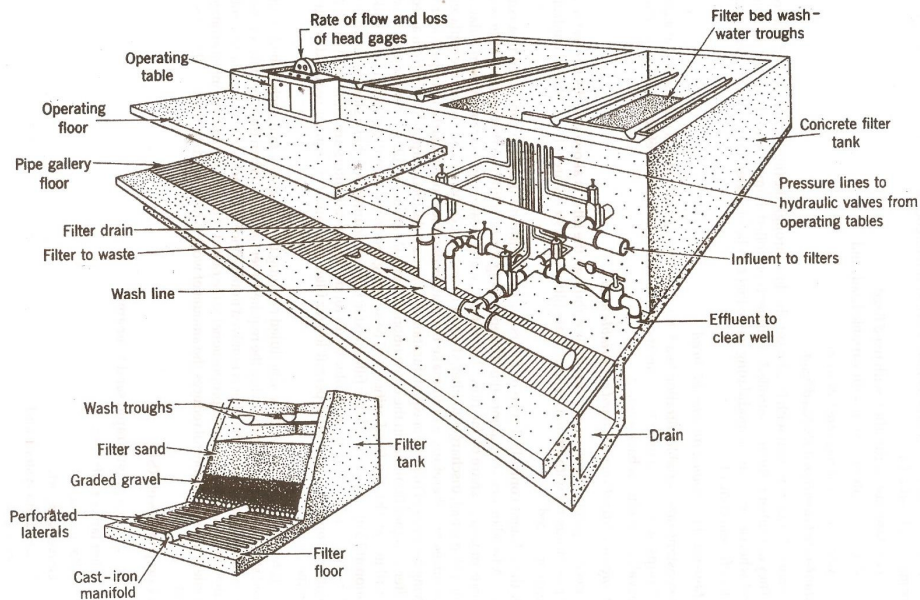


Fig 2.4: showing different components of rapid gravity filter

2.6.1. Filter box: The filter is contained within in a filter box, usually made of concrete. It can be made up of steel or PVC or other such material in case of pressure filters. The filter box can be modular or non modular both. Filter box contains filter media, gravel, below the gravel, there is a under drain system which collects the filtered water and evenly distributes the backwash water.

In addition to the components mentioned above, most rapid filters (may be pressure or gravity) contain a flow controller or filter control system which regulates flow rates of

water through the filter. Other parts, such as valves, pressure gauges, and a backwash pump are used while cleaning the filter.

2.6.2 Filter media: Filter media is the important component of all filter types which actually removes the particle from the water being treated. The best and most economical way to increase the capacity of the existing water treatment plants is to increase its rate of operation rather than to build additional units (**Tuepker & Buescher, 1968**). This may be achieved by improving the performance of the filters, such as changing the filter medium. The media characteristics are among the most important design criteria. The primary media characteristics affecting filtration performance are the effective grain size and uniformity coefficient (**Crites and Tchobanoglous, 1998**). These characteristics tend to affect the retention time of liquid passing through the media and the potential for clogging. The effective size (ES) is defined by the size of screen opening where 90 percent of a sample of granular media is retained on the screen and 10 percent passes through the screen, and is referred to as d_{10} . The larger the grain size, the faster the wastewater moves through the sand and the more wastewater that can be filtered. However, if the grain size is too large, treatment efficiency will be reduced. The ideal filter medium should have such a size and material that will provide a satisfactory effluent, retain the maximum quantity of solids and is cleaned with a minimum volume of washing water (**Steel & McGhee, 1984**). It should be light in weight, enough to allow sufficient depth for long filter runs and graded to allow effective backwash cleaning (**Qasim et al., 2000**). Most commonly used filter media in case of rapid filters are sand and anthracite. Sand and other media filters remove constituents from water primarily through a physical process of filtering out particulates from the water. The type of media used and its grain size distribution determine how small of a particle is strained out. Coarser sands have larger pore spaces that have high flow-through rates but pass larger suspended particles. A very fine sand, or other fine media filter, has small pore spaces which allow slow flow- rates and filter out smaller amount of total suspended solids (*TSS*) particles. Some media, such as peat-sand mix, may also provide ionic adhesion or exchange for some dissolved constituents which further enhance effluent quality. The most important feature of granular media is not the grain particles, but rather the pore space in the media. The treatment of water or wastewater occurs in the pores where suspended solids are trapped, micro organisms grow, and air and water flow (**Emerick, 1997**). **Ball (1997)** illustrated how the particle size of a filter media is related to the size of the void or pore space between the particles by calculating the surface area and void volume for packed spheres of various sizes.

The percentage of void volume generally remains the same even as the diameter of the spheres changes. However, the surface area of packed spheres increases and the size of the pores per unit volume area significantly decrease with smaller diameter spheres. A

granular media filter can benefit from increases in the surface area per unit of volume, but can suffer when pore size becomes too small for unsaturated flow to occur (**Ball, 1997**). A uniformity coefficient of 4 or less is recommended for all filter media (**National Small Flows Clearinghouse, 1997; Crites and Tchobanoglous, 1998; EPA, 2002**). This recommendation is intended to avoid clogging at higher loading rates (**Darby et al., 1996**). Sands from most natural sources are widely graded containing a variety of grain sizes, which results in a high Uniformity coefficient values. If the grain sizes vary greatly, the smaller ones will fill the spaces between the larger particles, making it easier for the filter to clog (National Small Flows Clearinghouse, 1997).

Laboratory and field tests have shown (**Neufeld, 1996; EPA, 1983; Veenhuis, 1989; City of Austin, 1990**) that a filter media consisting of concrete sand provides a good balance between flow-through rates and filtering efficiency.

In case of rapid sand filters the sand used is coarser. Size, angularity and hardness are the important filter sand characteristics to ensure proper filtering.

Physical specification (According to AWWA standard B100-01)

Effective size .20mm- 2.5 mm

Uniformity coefficient 1.3- 1.7

Specific gravity 2.67

Garnet is also used as a filter media in filters. It is a chemically inert and non metallic mineral which is commonly found in the natural environment. Garnet is well known for its hardness and durability. It has a high specific gravity as well as its chemical and abrasive resistance makes it an ideal filter media.

Physical specifications:

Effective size = .20mm-2mm

Uniformity coefficient= < 1.6

Specific gravity = > 4.0

Density = 120 to 140 lbs/ cu.ft.

Green sand plus is also one of the filtering media used now days. It is a purple- grey filter media used for removing soluble iron, manganese, hydrogen sulphide, arsenic, and other heavy metals from well water supply.

Physical specifications

Apparent density= 85lb./cu.ft.

Effective size 0.30m to 0.35mm

Uniformity coefficient= < 1.60

Specific gravity = approx. 2.4

There are many other synthetic media available in which are now being used at a large scale in filters. **Bellingham, Water Integrated Aqua Systems (2008)** exclusively used Perma bead filtration media as a superior plastic alternative to sand filters. These are specifically designed with unique shape and the surface properties which allow for the effective and efficient removal of solid debris. Their ellipsoidal shape creates large spaces between Perma beads to trap large quantities of debris and easily refluidized during the backwash. High surface area of 4,520sq.ft.per.cu.ft provides sufficient surface area of supplemental biological filtration in fish system. Being hard and slippery in nature the material prevent bacteria from etching into the surface as well as allow for even the stickiest waste to be scrubbed off upon backwash and can be easily disinfected with chlorine or muriatic acid.

Different materials are used in dual filters. **Eunpu (1970)** showed that limonite is more efficient than garnet as a filter medium. Mixed media of coal and sand were tested by **Westerhoff (1971)**. This filter produced water of very low turbidity compared with sand filters. **Rawi (1987), Mohammed (1989)** and **Yohe & Getting (1993)** used anthracite. They achieved significant turbidity removal, long filter runs, less head losses with less washing water requirements in the tested filters. **Al-Anbari (1997) and Ansary (1998)** showed that filters of single media (porcelanite and kaolinite) gave better results in turbidity removal and net water product (*NWP*) value (m^3/run) than in sand filters. This was because of their higher porosity and angular grain surface textures. Also **Ansary (1998)** indicated that porcelanite filters had more length in filter runs and less head losses during filtration by nearly 40% than sand filters. **Najar (2000)** used granular ninivite rock as the dual medium in the filters, where **Auraji (2003)** used burnt kaolinite and anthracite. They also reached the same conclusions (lower head losses, longer filtration runs, and better water quality).

Washing the filters is achieved by water backflow the velocity of which must be adjusted to the grain size of the filter medium and temperature of the water (**Degremont, 1991**).

Table2.2: Backwash rates for sand with different effective size for the temperature range.

Effective size (mm)	0.35	0.55	0.75	0.95
Backwash rate (m/hr)	25-35	40-50	55-70	70-90

One of the study carried out by *Hossein Banejad, 2008* to evaluate particle removal efficiency (Y) by changing particle concentration and media grain size in a rapid sand filter in which Five concentrations (100, 200, 300, 400, and 500 ppm) of Kaolin particles and three mean media sizes (0.51, 1, and 1.41 mm) were used. The filter depth and the filtration velocity were 25 cm and 0.086 cm/sec, respectively. Silica sand was used as the filter medium in all the experiments. The results showed that for the filter medium with an average grain size of 0.51 mm, removal efficiency increased with increasing influent particle concentration during the initial hours of filtration. Generally, suspended solids removal efficiency was higher at low particle concentrations. No significant differences were observed in removal efficiency for the three media sizes and particle concentrations of up to 300 mg/L, but for concentrations above 300 mg/L, removal efficiency decreased, especially for filter media with an average grain size of 1.41 mm. Removal efficiency decreased in filter media with average grain sizes of 1 and 1.41 mm at high particle concentrations from the very initial hours of filtration. The highest removal efficiency was observed in the filter medium with an average grain size of 0.51 mm. Differences in removal efficiencies between the filter media with average grain sizes of 0.51 and 1 mm were much greater than those between filter media with average grain sizes of 1 and 1.41 mm. In other words, the critical grain size for the filter medium was 1 mm.

2.6.3. Graded gravel:

The filter gravel at the bottom of the filter bed is not apart of the filter media and it is merely providing a support for media above the under drain and allowing an even distribution of flow of water across the filter bed during filtering and backwashing. The gravel also prevents the filter media from being lost during the operation. The filter gravel is usually graded of sides from 2.5 to 50mm (largest size being at the bottom) in four to five layers to total thickness of 45 to 50 cm, depending on the type of under drain system used. In case the under drainage system with porous bottom false floor no gravel base is required.

(David Shepherd, 2009) The gravel support layers prevent the fine filter medium from entering the under drain and blocking it and help distribute the backwash water and air in the filter. Normally several layers of gravel are used. In the simplest form the largest size gravel (about 20 mm) is at the bottom. Above this are layers of finer gravel down to 2 mm at the top. Each layer is about 50 mm thick, and total gravel depth may be up to 300 mm. Where air scour is used in backwashing it is customary to use an “hourglass” configuration. This configuration is effective in restricting penetration of

media into the under drain and in preventing gravel mounding due to hydraulic shock during backwashing.

Recently, media retention plates have been developed which are able to perform the functions of the gravel layers in a much smaller depth. Media retention plates are porous moulded plates made from high-density polyethylene and fitted to the under drain block using self-tapping screws. The edges of the plate are sealed with an approved polyurethane sealant, and the exposed edges are also sealed to prevent side leakage. The plate is about 30 mm thick and is used to replace gravel layers up to 300 mm thick. As a result either the filter can be shallower or a greater depth of media can be used. The head loss across a media retention plate is the same as or less than for the gravel it replaces.

Three are different types of retention plate available. The single porosity plate has a single porosity layer of 500 or 700 microns. A bi-plate consisting of two layers of 300 microns (top layer) and 500 microns and a tri plate with a layer of 300 microns sandwiched between two outer layers of 500 micron material is available from one manufacturer. The larger pore size is used to protect the finer material from blockage. The larger pore size is excellent for most filtration applications and is especially suited to applications with fine garnet and activated carbon.

2.6.4. Under drainage system:

While the proper filter media is important to the performance of rapid gravity filters, evidence suggests that filtration and backwashing performance is highly dependent upon the design of the filter under drain and the support for the filter medium. The underdrain systems support the filter media bed, collect the filtered water, and distribute the backwash water uniformly. There are a large variety of underdrain systems many of which are proprietary. Most underdrain systems are overlain by gravel grades in five or six layers:

- 40 to 60 mm diameter as the bottom layer
- 2.5 to 5 mm diameter as the upper layer
- layers 60 to 200 mm thick, to a total depth of 400 to 600 mm

The recent development of a dual parallel lateral under drain has been proven to provide an even distribution of backwash water and air. In the dual parallel lateral underdrain, sintered plastic plates are used to replace gravel support layers in the filters. Composite plates of different porosities also are utilised. The underdrain system can be one of the following types connected to main drain.

- Pipe laterals

- False floor
- Porous plates of strainer nozzles

The most common type of under drain is a central manifold with laterals either perforated at the bottom or having umbrella type strainers on top.

Header and Lateral type

(David Shepherd, 2009) The simplest type of under drain is the header and lateral type. In this type of under drain the backwash water enters the filter bottom through a pipe or pressurised flume called a header. Pipes called laterals are connected at right angles to the header and are buried in the filter gravels. The laterals distribute the backwash water through a series of orifices.

The biggest drawback of the header and lateral under drain is the difficulty in obtaining even distribution of the backwash water. The high velocity of the backwash water in the header causes the header's static pressure to be highest at the end. Because of this, the laterals at the end of the header receive most of the flow. This can be overcome by redistributing the head loss from the header to the orifices in the laterals. For this to be effective, the head loss across the orifices must be in the order of 2 to 3 m – a rate that increases pumping costs. Another problem with this type of under drain is that there are no orifices in the header. With no backwash flow, this area is not properly cleaned.

Plenum floor type

Plenum floor or nozzle type underdrains consist of a false floor penetrated by nozzles or strainers. Nozzle systems have large orifices and require the use of gravels to keep the media out of the nozzle. The velocity of the incoming water is such that the flow is greatest at the inlet and near to the sides unless the plenum is very large. In addition, the spacing of the nozzles is often quite wide (up to 200mm) comprising 40 to 60 per m³ of filter floor space and dead spots may occur during backwashing. During a backwash, a considerable upward pressure is exerted on the underside of the plenum. This is exacerbated if the strainers become blocked with suspended solids or bits of sand and gravel which may be in the backwash water. Repeated backwash cycles can cause rupture of the floor due to repeated flexing. Cleaning the strainers can only be done by removing the filter medium. Maintenance is complicated by the fact that personnel access to the plenum area is a health and safety risk. Finally, the plenum floor underdrain's nozzles often become damaged during system installation.

2.6.5. Backwashing

Proper backwashing for cleaning the filter is a very important step in the operation of a filter. If the filter is not backwashed periodically, it will eventually develop additional operational problems. “Water only” backwash was the first method of backwashing in rapid sand filters, and has been practiced for the early 20th century (Thomas D. Davis). Research in the 1950’s recommended 50% bed expansion to reduce mudball accumulation. Limitations of water only” wash include: mudball accumulation; filter channelling; debris accumulation; and high production of backwash wastes.

Surface wash: Surface washers were developed in the mid – 20th century in an attempt to enhance “Water only” for the backwash. To eliminate surface encrustations on filters, surface sweeps were employed. Surface sweeps cannot reach the location where the mudball often accumulate. This system requires a supplemental pressurized water supply (50psi) with appurtenant pumps, valves and piping. To overcome these problems air scour was developed in 1970’s to clean the entire filter media and break up surface encrustations. This method was a slight improvement over the surface sweeps in that it broke up surface encrustations in corners. The limitations of air wash only were many: air wash makes the operation more complicated; air wash alone increases the overall backwash time; air wash is observed to be violently agitating the filter surface, giving operators a false sense of security.

Simultaneous air/ water backwash: In the 1990’s research was conducted by **Amirtharajah, et al**, at Georgia Tech under an AWWA Research Foundation grant. His study proved that backwashing filters with simultaneous air/ water at sub- fluidized rates provides best cleaning of the filter media. Typical backwash rates include 3 to 5 GPM/sq ft. of water with air at 2 to 3 SCFM/sq.ft. applied simultaneously.

2.7. Filtralite filter media

One of the commercially used filter media in high rate pressure as well as rapid gravity filters that is manufactured by the **Norwegian Company Maxit Group** is filtralite. This filter media is used in several water plants in Norway. Filtralite is an expanded aluminium silicate product with high porosity (fig.2.5). Filtralite filter media is made by burning of clay at about 1200° C, followed by crushing and sieving. The material has a porous structure and when crushed, a large surface area is exposed. Dry particle densities in the range 500-1,600 kg/m³. The aggregates do not release harmful substances, and the acid solubility is minimal. Despite its low density and high porosity, Filtralite has high abrasion and impact resistance. Filtralite has the ideal properties to work as a good filter media in both single- and dual media filters for filtration of

coagulated water. In dual media filters Filtralite has proved to be as good as, or better than, comparable media. By replacing the most traditional top layer filter material, anthracite, with Filtralite, time between backwashes can be increased by about 25%. This means fewer stops for backwash and reduced use of backwash water, resulting in more stable water quality and lower operational costs. Filtralite bio filter media is backwashed periodically to avoid a too thick biofilm to be formed on the media surface. The media is very strong material and resist easily more than 1000 hrs of backwashing without any significant deterioration or abrasion.



Fig2.5: Showing porous dense shell of filtralite media.

In biological filters bacteria attach to the filter media and a biofilm arises on the surfaces of the filter grains. A large available surface area for biofilm growth is one of the most essential properties of filter media used in biofilm processes. The crushed Filtralite grains have a large surface area, resulting in Filtralite being an ideal media for use in biological treatment processes. Tests have shown that Filtralite is as good as or better than alternative carrier materials for biological treatment of drinking water. Ammonia, iron, manganese and other biodegradable substances can be effectively removed in biological treatment using Filtralite as a carrier media.

Filtralite has excellent properties for use in pre-treatment filters in desalination plants, both in filters for filtration of coagulated water and in biological processes. Use of Filtralite will provide low SDI values, reduced danger for bio-fouling of the RO membranes and long filter runs between backwashes.

Table2.3: Different size of filtralite media and their physical properties

Properties	HC2.5-5mm	HR3-6mm	MC1.5-2.5mm	HC1.5-2.5mm	HC0.8-1.6mm	NC1.5-2.5mm
Particle density	1550kg/m ³	1450kg/m ³	1300kg/m ³	1600kg/m ³	1650kg/m ³	720kg/m ³
Bulk density	800kg/m ³	825kg/m ³	550kg/m ³	750kg/m ³	700kg/m ³	235kg/m ³
Appearance	Crushed particles, porous surface structure	Crushed particles, porous surface structure	Crushed particles, porous surface structure	Crushed particles, porous surface structure	Crushed particles, porous surface structure	Crushed particles, porous surface structure
Floating particles	<2%	<2%	<2%	<2%	<2%	<2%
Particle porosity	43%	46%	52%	41%	40%	73%
Voids	48%	43%	58%	53%	62%	67%
Acid solubility	<5%	<4%	<5%	<5%	<5%	<5%
SiO ₂	62%	62%	62%	62%	62%	62%
Al ₂ O ₃	18%	18%	18%	18%	18%	18%
FeO ₃	7%	7%	7%	7%	7%	7%
K ₂ O	4%	4%	4%	4%	4%	4%
MgO	3%	3%	3%	3%	3%	3%
CaO	3%	3%	3%	3%	3%	3%
Na ₂ O	2%	2%	2%	2%	2%	2%
C _{tot}	0.02	0.02	0.02	0.02	0.02	0.02

Performance evaluation of filtralite filter media

In a study carried out at **Lulea Kommun** where a water plant is located in the west part of lulea between Storheden and Lulealv (Lule River). The water treatment plant had a rapid filter unit. In the study the two media (filtralite and sand/anthracite) are compared in terms of turbidity, colour, and heavy metals such as aluminium, iron, and manganese. It has been found that filtralite is more effective in terms of reduction in turbidity and colour, whereas heavy metal removal is better in case of sand and anthracite. Filtralite particles are better spread in the filter media. With sand/anthracite, particles are more likely to be stuck in the anthracite. With filtralite, the pressure is more spread, so the time between the two backwashes was more as compared to sand/ anthracite.

Another study carried out at the **Department of Chemical Engineering, Aristotle University of Thessaloniki, Greece by Mitrouli and his co-workers (2009)** to test new granular materials for dual-media bed filtration of seawater and to assess the quality of the filtrate with regard to criteria for feeding reverse osmosis desalination installations, two different filter columns, one with the new materials (expanded clay), i.e. Filtralite NC 1.5-2.5 mm on top of Filtralite HC 0.8-1.6 mm (called Filtralite MonoMulti filter), and another with anthracite coal 1.2-2.5 mm on top of a sand layer 0.8-1.25 mm (called sand/anthracite filter), were tested in parallel operation under various conditions in the summer of 2007. Both filters exhibited similar performance, removing particulates from feed water and producing filtrates of acceptable quality for feeding RO systems (SDI₁₅, 15-min Silt Density Index, values lower than 5). Regarding the hydrostatic head development, it was observed that the Filtralite MonoMulti column had slower head build up than the sand/anthracite column for the same duration of filtration, especially at the higher filtration velocities (10 and 15 m/h). For the lower filtration velocity tested (5 m/h) both filters demonstrated almost the same rate of head build up. Regarding the duration of filtration cycles, Filtralite MonoMulti exhibited either the same (in the cases of filtration velocities 5 and 10 m/h) or longer duration (at the highest filtration velocity tested of 15 m/h) compared to the conventional sand/anthracite filter. Regarding the hydrostatic head development, it was observed that the Filtralite MonoMulti column had slower head build up than the sand/anthracite column for the same duration of filtration, especially at the higher filtration velocities (10 and 15 m/h). For the lower filtration velocity tested (5 m/h) both filters demonstrated almost the same rate of head build up. Regarding the duration of filtration cycles, Filtralite MonoMulti exhibited either the same (in the cases of filtration velocities 5 and 10 m/h) or longer duration (at the highest filtration velocity tested of 15 m/h) compared to the conventional sand/anthracite filter.

One of the treatment plants built in Nore and Uvdal municipal in Norway. The wastewater treatment plant was built in 2003. The plant is designed as a traditional chemical and biological treatment plant. In 2003 a filter bed with Filtralite was installed as a polishing step before the effluent is discharged into a small creek.

The filter bed with Filtralite gives low and stable discharge levels. After 3 years of operation the treatment results showed 99 % phosphorus removal, which gives a discharge phosphorus concentration of 0.06 mg/l.

Filter media used in this plant:

1000 m³ Filtralite P 0-4 mm

100 m³ Filtralite NR 4-10 mm

100 m³ Filtralite NR 10-20 mm

Fredrikstad Waterworks in south eastern Norway has an annual water production of 15 million cubic metres and supplies the municipalities Fredrikstad and Hvaler. During autumn 2003 they have renovated their dual-media filters. After around 8 years of operation, the volume of filter media in the existing sand/anthracite-filters was significantly reduced resulting in poor filtering effect. When renovating the filters the waterworks was interested in testing alternative filter media and replaced the anthracite layer in one of the filters with Filtralite media for evaluation. In March 2002 Filtralite media was installed on top of the existing sand in one out of totally 8 filters. This filter was run for nearly a year in parallel to the other filters. The results were so promising that they decided to use filtralite in all filters.

One of the biological plant installed at **Dalian, China** have a two stage treatment process. The first step includes BOD, COD, and SS removal in 12 bio filters. In these filters filtralite has been used as a carrier for bio film development. The second biofilter stage is nitrification in 12 Biofor filters with the same surface area as in the first step. The filter media used in these filters is crushed Filtralite. Raw water contains BOD 210 mg/l, COD 40 mg/l and TSS 350mg/l. The treatment results were found to be excellent having BOD of treated water less than 3mg/l and COD was found to be less than 30 and TSS 8 mg/l. The removal rates were found to be more than 90% for all the three parameters.

Table2.4: Applications of filtralite media

Year	Location	Purpose	Type of process
2008	Hampton, UK	Roughing filter	Filtralite Mono-Multi
2008	Shadeed, Oman	Pretreatment for desalination plant	Filtralite Mono-Multi
2008	Larvik, Norway	Turbidity, colour etc	Dual media filtration
2008	Coppermills, UK	Roughing filter	Single media filtration
2008	Oxy, Oman	Pretreatment for desalination plant	Filtralite Mono-Multi
2008	Swinford, UK	Turbidity, colour etc	Single media filtration
2007	Oslo, Norway	Turbidity, colour etc	Dual media filtration
2007	Ashford Common, UK	Roughing filter	Filtralite Mono-Multi
2007	Nedre Romerike, Norway	Turbidity, colour etc.	Dual media filtration
2007	Larvik, Norway	Turbidity, colour etc.	Dual media filtration
2006/7	Oppegård, Norway	Turbidity, colour etc.	Dual media filtration
2005	Agadir, Morocco	Pretreatment for desalination plant	Dual media filtration
2005	Moss, Norway	Turbidity, colour etc.	Dual media filtration
2004	Rostock,	Turbidity, colour, Fe- and	Dual media filtration

	Germany	Mn-removal	
2003	Larvik, Norway	NOM-removal	Dual media filtration
2003	<i>Fredrikstad,</i> <i>Norway</i>	Turbidity, colour etc.	Dual media filtration
2003	<i>Borregaard,</i> <i>Norway</i>	Turbidity, colour etc	Dual media filtration
2002	<i>Fredrikstad,</i> <i>Norway</i>	Turbidity, colour etc.	Dual media filtration
2001	<i>Perm,</i> <i>Russia</i>	Turbidity, colour etc.	Dual media filtration

2.8. Filter Hydraulics

2.8.1. Clear water headloss

Over the years several equations have been developed to describe the flow of clean water through a porous medium (**Carman, 1937, Fair and Hatch, 1933; Hazen, 1905; kozeny, 1927; Rose 1945**). Most of the equations for the flow of clean water through the porous medium are derived from a consideration of Darcy - Weisbach equation.

Here are the following equations to compute the clean water headloss through the granular porous medium:

1. Carman-Kozeny equation(1937)

$$h = \frac{f}{\phi} \frac{1-\alpha}{\alpha^3} \frac{L}{d} \frac{v_s^2}{g}$$

$$h = \frac{1}{\phi} \frac{1-\alpha}{\alpha^3} \frac{L v_s^2}{g} \sum f \frac{\rho}{d_x}$$

$$f = 150 \frac{1-\alpha}{N_r} + 1.75$$

$$N_r = \frac{\phi d v_s \rho}{\mu}$$

H= head loss, m,

f is the friction factor,

L is the depth of the filter bed,

v_s is the settling velocity in m/s

g is acceleration due to gravity,

d is grain size in, m,

α is porosity of medium,

μ is viscosity, N.s / m²,

ρ density in kg/m³,

\square kinematic viscosity in m²/s

\square is particle shape factor, Nr is Reynolds number.

2. Fair and Hatch (1933)

$$\frac{1}{k} = \frac{150 \mu (1 - \alpha)^2}{g d^2 \alpha^3}$$

k is filtration constant value lies between 5 to 6

g is acceleration due to gravity

d is grain size in, m

α is porosity of medium,

L is the depth of the filter bed

v_s is the settling velocity in m/s

3. Rose (1945)

$$\frac{1}{k} = \frac{1061 \mu}{\phi \alpha^2 d^2 v_s}$$

$$\frac{1}{k} = \frac{243}{N \sqrt{NR}}$$

where, d is grain size in, m.

L is the depth of the filter bed in m.

\square is particle shape factor.

Nr is Reynolds number.

α is porosity of medium.

Cd is drag coefficient

v_s is the settling velocity in m/s

1. Hazen (1905)

$$h = \frac{160L}{C^2 D_{10}^2 V_h^2}$$

h is head loss in m

T is temperature, °C

D_{10} is effective size of medium

L is depth of filter bed, m

V_h is approach velocity, m/s

2.8.2 Backwash hydraulics

To expand a filter bed comprised of a uniform filter medium hydraulically, the head loss must be equal to the buoyant mass of the granular medium in the fluid. This relationship is expressed as



Where h = headloss in m

L_e = depth of the expanded bed

α_e = expanded bed porosity

ρ_s = density of medium

ρ_w = density of water

From the experimental studies carried out by **Fair and Richardson 1954** it has been found that the expanded bed porosity can be approximated using following relationship, assuming the Reynolds number is approximately 1.

$$\alpha e = (v_s/v)^2$$

Where, v_s is the settling velocity of the particle in m/s.

However, because the volume of the filtering media per unit area is same, also $(1 - \alpha)$ is equal to $(1 - \alpha e)$ so that

$$\begin{aligned} L_e/L &= (1 - \alpha) / (1 - \alpha e) \\ &= 1 - \alpha / 1 - (v/v_s)^{0.22} \end{aligned}$$

Where the filter medium is stratified, the smaller particles in the upper layer expand first. To expand the entire bed, the backwash velocity must be sufficient to lift the largest particles. The above equation is modified assuming that particles retained between the sieve sizes are substantially uniform (Fair and Hatch, 1933).

$$L_e/L = (1 - \alpha) \sum \rho / (1 - \alpha_e)$$

ρ = fraction of filter medium retained between sieve sizes

2.9. Filter analysis

The time space removal for particulate matter within the filter is based on a consideration of the equation of continuity, together with an auxiliary rate equation.

The equation of continuity is developed by considering a suspended solids mass balance for a section of filter of cross sectional area A of thickness Δz , measured in the direction of the flow.

Mass balance equation can be written as:

$$\begin{aligned} \text{Rate of accumulation of} & & = & & \text{inflow - outflow} \\ \text{Solids within the volume element} & & & & \end{aligned}$$

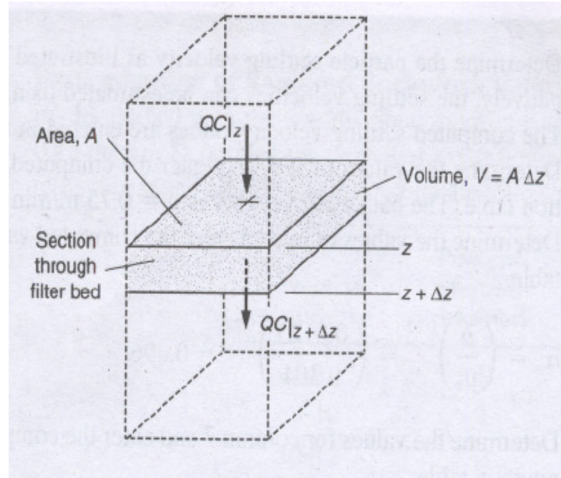


Fig2.6. Sketch for filter analysis

Symbolically it is represented as:



$\partial q/\partial t$ = change in quantity of solids deposited within the filter, $g/m^3 \cdot min$

$\alpha(t)$ = average porosity as a function of time

$\partial C/\partial t$ = change in average concentration of solid in pore space with time, $g/m^3 \cdot min$

ΔV = differential volume, m

V = volumetric flow rate, L/min

C = concentration of suspended solids, g/m^3

$\Delta C/\Delta z$ = change in concentration of suspended solids in fluid stream with distance, $g/m^3 \cdot m$

The above equation is simplified as



- The first term represents the difference between mass of suspended solids entering and leaving the section.

- The second term represents the time rate of change of mass of suspended solids accumulated within the interstices of the filter medium.
- The third term represents the time rate of change of suspended solids concentration in the pore space within the filter volume.

If the straining is the principal removal mechanism in filtration process, the shape of the normalized curves will be curvilinear (**Tchobanoglous and Eliassen, 1970**). From the size distribution of influent particles and the shape of normalized curves, it can be concluded that the rate of change of concentration with distance must be proportional to some removal coefficient that is changing with the degree of treatment or removal achieved during filtration. The probability of removing particles from water decreases from top layer to bottom fig (). The phenomenon can be expressed mathematically using following equation:

$$\frac{dC}{dz} = \frac{1}{(1+r_0)^n} C^a$$

Where, C = concentration, mg/l

z = distance from top of the filter bed, cm

r₀ = initial removal rate

a, n, = constants

In the above equation the term within the brackets is a retardation factor. The above equation was verified only with the filtration rates up to 400L/m².min.

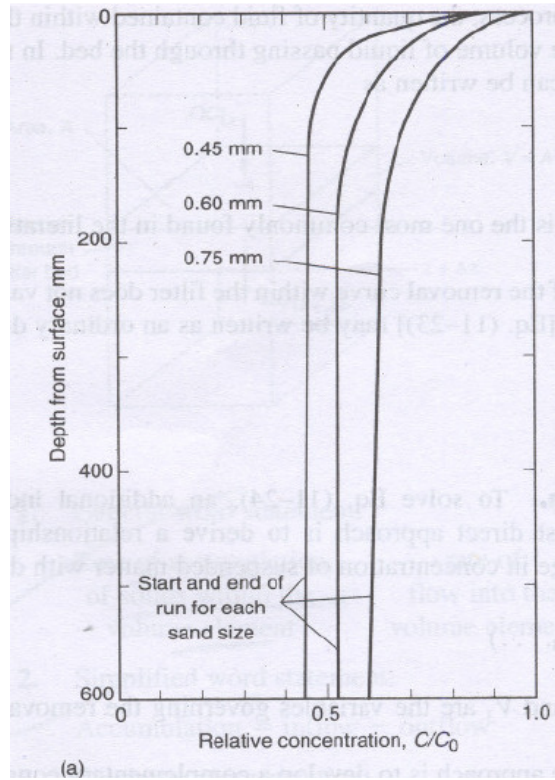


Fig2.7: Normalized suspended solids removal curve as a function of depth and time

On the basis of experimental results derived from the pilot scale filtration studies five major factors appeared to affect the time- space removal of residual suspended matter with in a granular media filters for a given temperature. The factors are listed below

- Size of the filter medium
- Rate of filtration
- Influent particle size and size distribution
- Floc strength
- Amount of material removed in the filter medium

A generalized rate equation in which all five factors are considered is given below

$$\frac{dC}{dt} = -k C^{1.5} \left(\frac{d}{d_p} \right)^2$$

q = quantity of suspended solids deposited in the filter

q_u = ultimate quantity of solids that can be deposited in the filter

m = a constant related to floc strength

As the upper layers begins to clog, the term in brackets in above equation approaches zero, and the rate change in concentration with distance is equal to zero.

CHAPTER-3

METHODOLOGY

3.1 Introduction

This chapter presents the methodology followed in the pilot scale filtration study on rapid pressure filters using filtralite (a synthetic filter material) as a filter media. For achieving the objective that is evaluation of filtralite filter media, work was planned on the following work elements:

- Characterization of the filter media
- Pilot scale filtration system set up
- Pilot scale Experimentation on the filtralite

3.2 Characterization of filter media

Under this element of work all the media procured were subjected to sieve analysis in order to find out the effective size, uniformity coefficient and d_{90} values (used in calculating backwash velocities). For the sieve analysis following procedure was followed:

Known amount (200gm) of filter media is sieved through a series of screens of desired pore size (pore size decreasing from top to bottom) by placing over a vibratory shaker for 30 min. After 30 min of shaking, amount of media retained on each of the sieve was quantified. The sieve analysis was repeated five times and average retentions were taken. After this a graph was plotted between percent of media passed through the sieve and the sieve size. Using these graphs d_{10} , d_{60} , d_{90} , values were obtained. Further uniformity coefficient was taken as d_{60}/d_{10} .

Seven Filtralite media (filtralite HC 2-2.5mm, filtralite HR 3-6mm, filtralite MC 0.8-1.6mm, filtralite MC 1.5-2.5mm, NC 1.5-2.5mm), two sand media and one anthracite media were analyzed.

The series of screens used for each of the media are indicated in table-3.1.

Table 3.1: Series of screens used or the sieve analysis of different media

	Filtralite HC 2.5- 5mm	Filtralite HR3- 6mm	Filtralie MC 0.8- 1.6mm	Filtralite MC 1.5- 2.5mm	Filtralite NC 1.5- 2.5mm	Filtralite HC 1.5- 2.5mm	Sand	Anthracite
S	9.0mm	9.0mm	2.36mm	2.36mm	2.36mm	2.36mm	2.36mm	2.36mm
C	4.75mm	4.75mm	1.2mm	1.2mm	1.2mm	1.2mm	1.2mm	1mm
R	2.36mm	2.36mm	1mm	1mm	1mm	1mm	1mm	0.85mm
E	1.2mm	1.2mm	.85mm	.85mm	.85mm	.85mm	0.85mm	0.6mm
E	1mm	1mm	.600mm	.600mm	.600mm	.600mm	0.6mm	0.43mm
N	-	-	.300mm	.300mm	.300mm	.300mm	.43mm	0.30mm
S	-	-	.212mm	.212mm	.212mm	-	-	-

To find out the percentage of carbonate present in the media, known amount (10g) of the media was taken in a beaker and treated with concentrated HCl for overnight. Next day the media was washed with water, dried off and loss of mass was measured. This loss should be less than 5%.

To find out the void spaces (porosity) for a media a known volume of media (200ml) was taken and poured in a graduated cylinder having 200 ml of water and final overall volume of medium plus water was noted. Further media was left in the water for 24 hours and change in the volume of medium and overall volume was noted.

Porosity of the filter medium was obtained by using the following equations:

- For the medium which are not absorbing water and are not swelling following equation is used.

$$\text{Pore space} = \frac{\text{water volume} - (\text{overall volume} - \text{medium volume})}{\text{Medium volume}}$$

- Porosity of swollen material

$$\text{Pore space} = [\text{water volume} - (\text{overall volume} - \text{swollen medium volume})] - \text{mass of medium} \times \text{absorption} / \text{volume of swollen medium}$$

3.3. Pilot scale filtration system set up

The pilot scale study required following facilities:

- A pressure filtration system (single media filtration system)
- A pump with necessary flow control and measurements for loading water for filtration
- Raw water tank for preparing, storing, and dosing water of desired turbidity.
- Filtered water collection tank.
- Water tank for supply of water for backwashing.
- Pump with necessary piping and controls for pumping backwash water through the filter.
- Pressure and differential pressure monitoring system.

3.3.1. Pilot scale pressure filtration system

Pilot scale pressure filtration system is made up of following five modules. Line diagram of pilot scale pressure filtration system is given figure 3.2.

- An underdrain module
- A gravel support module
- A filter medium module
- Water reservoir module

- An inlet module

The modules were constructed from 210mm internal diameter PVC pipes. Each module has end flanges to facilitate assembly of the run into the filtration system. The underdrain module and the inlet module are blind from one side. Blind ends of both these modules have piping coming out.

An underdrain module: It includes a slotted plate. Each slots of 30mm length and 5mm wide. Spacing between the slots is 5 mm. consists of a perforated plate. Each perforation has a length of 30mm and width of 5mm. please see figure 3.1 for details. A pressure tap is provided on the module to facilitate pressure measurements.

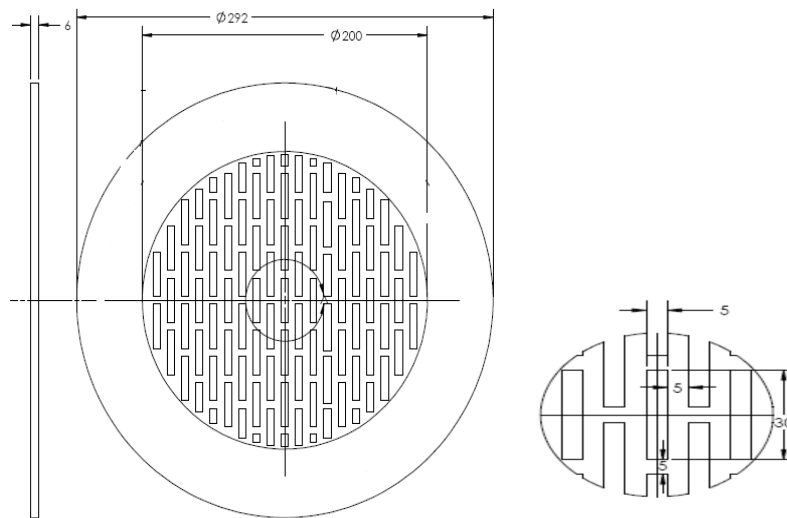


Fig3.1: Showing dimensions of perforated plate in underdrain module

A gravel support module: The total depth of this module is 350mm. This module is filled with multiple layers of graded pea gravels. This module has a pressure tap at the top end for facilitating pressure measurements.

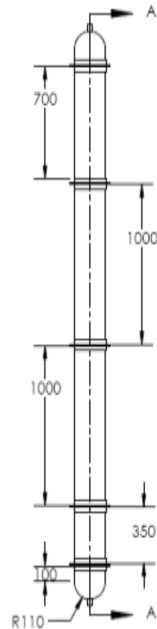


Fig3.2: Diagram showing different modules of pressure filter system (underdrain module (100mm), gravel support module (350mm), filter bed (1000mm), water reservoir (1000mm), inlet module (750mm)).

A filter medium module: The total depth of filter media is kept one meter. But it may vary upto 1m. Two pressure taps are provided in this module (one tap at 50 mm from top and the other in the middle) for facilitating pressure measurements.

Water reservoir module: This module is just above the filter medium module. Total depth of the module is 1000 mm (1m). This module has a pressure tap and a sampling port for facilitating pressure measurements and influent sample collection.

Inlet module: Total depth of the inlet module was kept 700mm.

3.3.2. Assembly of pressure filtration system

Inlet/ raw water tank: Total capacity of raw water tank is 10000 L. The raw water was kept in this tank and was mixed continuously with the help of submersible pump placed inside the tank.

Inlet water loading system: From the raw water tank water is pumped to the filter at a desired rate. For pumping water a centrifugal pump was provided. A valve is provided at the inlet end. There is a provision of recirculation of water back to the tank. For the purpose a control valve is provided at the inlet end. A water meter and a regulatory valve are provided at the outlet end to regulate the flow.

Filtered water handling system: For collecting the filtered water a storage tank of 1000 L capacity is provided.

Backwash water tank: Total capacity of backwash water tank is 2000 L. From here the water is pumped from the bottom of the filter to clean the filter.

Back wash water loading system: For loading backwash water a centrifugal pump is provided. The water is pumped from the bottom of the filter at the desired rate. Regulatory valves are provided at the inlet and outlet sections to maintain the required backwash flow.

Backwash water handling system: The backwash water was collected at outlet end during backwashing for monitoring purpose and rest was allowed to drain off.

Piping and fixtures: GI pipes of 1 inch diameter were used for water circulation from different tanks to filter.

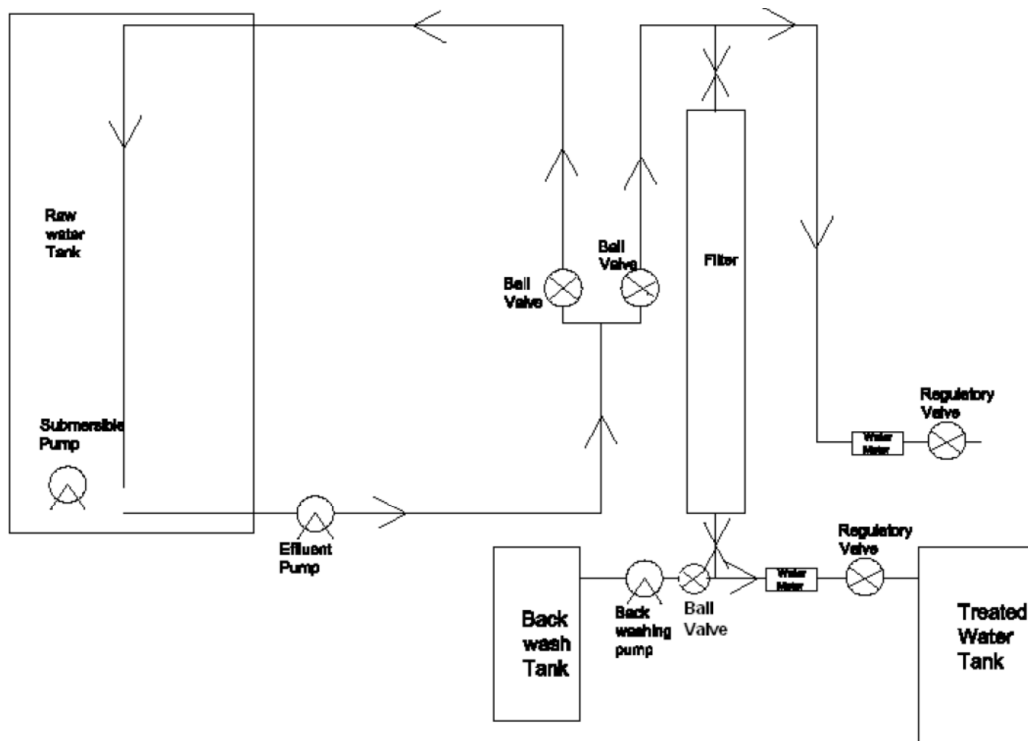


Fig3.3: Assembly of pressure filtration system

3.4. Pilot scale experimentation:

To carry out experimentation firstly raw water was prepared.

Preparation of raw water: A suspension was prepared by mixing bentonite clay with water in a bucket. It was then added to the raw water tank and was allowed to be mixed for at least two hrs before starting the run. After two hrs of mixing filtration was started.

Filtration/ run: While keeping the tank contents completely mixed run was started at desired rate. To maintain the flow rate, the flow metres were adjusted at the outlet end. After adjusting the flow rate by regulating the outlet valve the water was allowed to filter. Inlet and outlet samples were collected at regular intervals for filter monitoring. Also differential pressure at different points and overall pressure build up was also noted at regular intervals. As the turbidity in outlet start increasing and there is increase in pressure more then the preset value the filter run was stopped and the filter was backwashed.

Backwashing of filter: As the pressure builds up inside the filter and there was increase in the turbidity at the outlet end the filter was backwashed. Backwashing was done at the desired rate. The backwash rate was decided by using some of the design equations provided in the review of literature. Valves required for backwashing were opened and all other valves were closed. During backwashing samples were collected after every 5 min and the total time required for backwashing was recorded. Backwashing was done till the water coming out at the outlet end appeared to be clear. The collected samples were analysed for determining the turbidity and TSS values.

Start of run: After the completion of backwashing filtration was again started. Before starting the next run raw water was prepared again. Initially some amount of water is wasted as it was found to be slightly turbid. As clear water started coming out the water was stored in the storage tank. Samples were collected at regular intervals at inlet and outlet end for determining turbidity and TSS values for the purpose of monitoring. Amount of water filtered away during each run was also recorded.

This whole cycle was repeated 3 times for each media and results were obtained.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Characteristics of the filter medium used

Characteristics of the filter medium (filtralite, sand and anthracite) to be used in pilot scale study obtained from sieve analysis are shown in table 4.1. Porosity values and weight loss on acid treatment results are shown in table 4.2 below. Other characteristics (such as density, bulk density, shape, water absorbing properties, e.t.c.) are obtained from literature on filtralite media. Characteristics of the graded gravel used in the underdrain system of pilot scale filter are provided in table 4.3.

From the results obtained it has been found that the filtralite is heavier than anthracite but lighter than sand. Hence the backwash velocity required for filtralite will be less than sand. Being lighter filtralite can be used together with high density media such as sand for making dual media filters.

Comparing the porosity values of the three media tested it has been found that the porosity of anthracite is maximum, whereas sand and filtralite both are having almost same values. Porosity determines the headloss across the filter. As sand and filtralite are having almost same porosity values so there may be possibility that both are having same clogging properties. Anthracite being more porous may take more time in clogging.

The value of uniformity coefficient (d_{60}/d_{10}) is found to be almost same for each of the media tested. It is found to be highest for anthracite and lowest for sand. It is recommended that sand used in Rapid filters should have uniformity coefficient value 1.3 to 1.8. Higher value of uniformity coefficient allows higher flow rate, but it should be less than 4 for the media used in Rapid filters. Media having uniformity coefficient 1.8 to 2 are preferred.

Table 4.1: Showing d₁₀, d₆₀, d₉₀, and value of uniformity coefficient for different media analyzed

Media	Min	d ₁₀	D ₆₀	d ₉₀	Max	d ₆₀ /d ₁₀
FiltraliteHC2.5-5	1.1	1.47	3	4.3	5.95	2
FiltraliteHR3-6	1.00	2.62	5.32	8.20	9.00	2.00
FiltraliteHC1.5-2.5	0.22	1.25	1.90	2.20	2.35	1.52
FiltraliteHC.8-1.6	0.15	0.6	0.95	0.66	2.36	1.58
Filtralite MC 1.5-2.5	0.15	0.86	1.66	2.2	2.35	1.9
FiltraliteMC 0.8- 1.6	0.15	0.55	0.95	1.84	2.35	1.7
FiltraliteNC1.5-2.5	0.15	0.86	1.66	2.2	2.35	1.9
Sand	0.6	1.3	1.9	2.2	2.36	1.4
Anthracite	0.3	0.65	1.71	2.2	2.36	2.6

Table 4.2: Porosity and weight loss after treating with concentrated acid for different media size are given.

S.R. No	Media size	Porosity	Weight loss after treating with acid (%)
1	Filtralite HC 2.5-5	0.32	<2%
2	Filtralite HR 3-6	0.44	<2%
3	Filtralite MC 0.8-1.6	0.35	<2%
4	Filtralite MC 1.5 -2.5	0.36	<2%
5	Filtralite HC 1.5-2.5	0.40	<2%
6	Fitralite HC 0.8-1.6	0.36	<2%
7	Filtralite NC 1.5-2.5	0.37	<2%
8	Sand	0.40	<2%
9	Anthracite	0.56	<2%

Table 4.3: Different sizes of gravels used in pilot scale filter

S.R. No	Gravel layer	Size of the layer (mm)	Thickness of the layer (mm)
1	Top layer	1.2-2.5	50
2	Second layer	2.5-4.5	75
3	Third layer	4.5-2.5	75
4	Bottom layer	9.6-19	150

4.2. Pilot scale experimentation

Pressure filter with filtralite MC 0.8 -1.6 as medium was run at 20m/hr rate on water with turbidity created through addition of Bentonite clay. Once break through of the turbidity into the filtered water occurs or once the head loss across the filter crossed a set value the filter run was stopped and the filter was backwashed. A backwashed filter was then used for the next run. The filter was run for 3 times. During the filter run, turbidity and the TSS changes, head loss across the filter at the different depths, pressure building up parameters was monitored. Similarly during backwash the backwash water was monitored for TSS and the turbidity. Results obtained from such monitoring are given in tables 4.4, 4.5, 4.6 and figures 4.1, 4.2, 4.3.

Results shown that after 12 hours of run filter needs to be backwashed as the overall pressure and turbidity in treated effluent started increasing at that time. Turbidity was found to be beyond 18 FTU at the time of filter termination. Head loss across the filter bed keeps on increasing and the time of filter termination it was found to be .45m, see table 4.7. Backwashing was done at the rate of 50m/hr. Total time required for backwashing was found to 15 to 20 minutes. Total amount of water required for backwashing was about 560 litres.

Table 4.4: Results of first run

Hours	Sample	Turbidity(FTU)	TSS(mg/l)	Pressure(psi)	Flow Rate (L/min)	Remarks
0 hour	Inlet	117	194	11	11.5	
	Outlet	11				
2 hour	Inlet	100	156	11	11.5	
	Outlet	8				
4 hour	Inlet	87	106	11 to12	11.3	
	Outlet	6				
6 hour	Inlet	80	92	12	11.3	
	Outlet	6				
8 hour	Inlet	68	73	12	11.2	
	Outlet	6				

10 hour	Inlet	75	80	12	11.2	
	Outlet	6				
12 hour	Inlet	80	94	12	11.2	Clay added
	Outlet	18				
14 hour	Inlet	74	80	12 to13	11	
	Outlet	20				
16 hour	Inlet	80	92	14	11	
	Outlet	22				

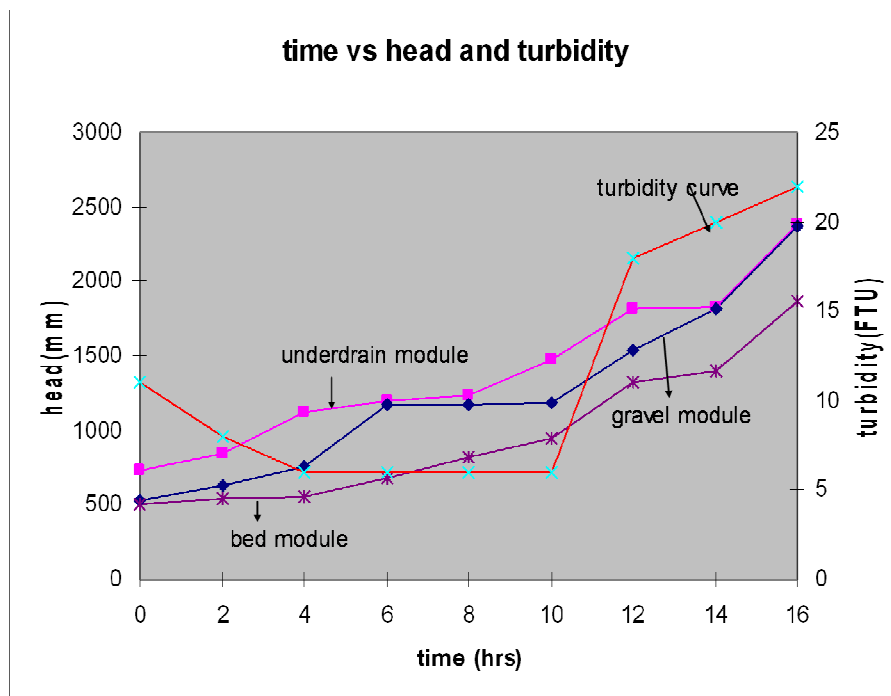


Fig 4.1: Time Vs head and turbidity plot for first run

Results of second run were found to be almost similar as in the first run. Head loss across the filter bed in the run at the time of filter termination was found to be .5m, whereas turbidity of treated water was beyond 20 at that time. Total time required for backwashing is found to be same in this case also. Amount of water utilized during backwashing was also same.

Table 4.5: Results of second run:

Hours	Sample	Turbidity(FTU)	TSS(mg/l)	Pressure	Flow Rate(L/min)	Remarks
0 hour	Inlet	113	190	10	11.5	
	outlet	22				
2 hour	Inlet	90	122	10 to 11	11.5	
	outlet	17				
4 hour	Inlet	72	74	11	11.3	
	outlet	16				
6 hour	Inlet	107	162	11	11.3	Clay added
	outlet	16				
8 hour	Inlet	102	154	12	10.4	
	outlet	14				
10 hour	Inlet	81	96	12	11.5	
	outlet	14				
12 hour	Inlet	99	142	12	11.3	Clay added
	outlet	22				
14 hour	Inlet	93	122	12 to 13	11.2	
	outlet	29				
16 hour	Inlet	80	92	13	11	
	outlet	29				

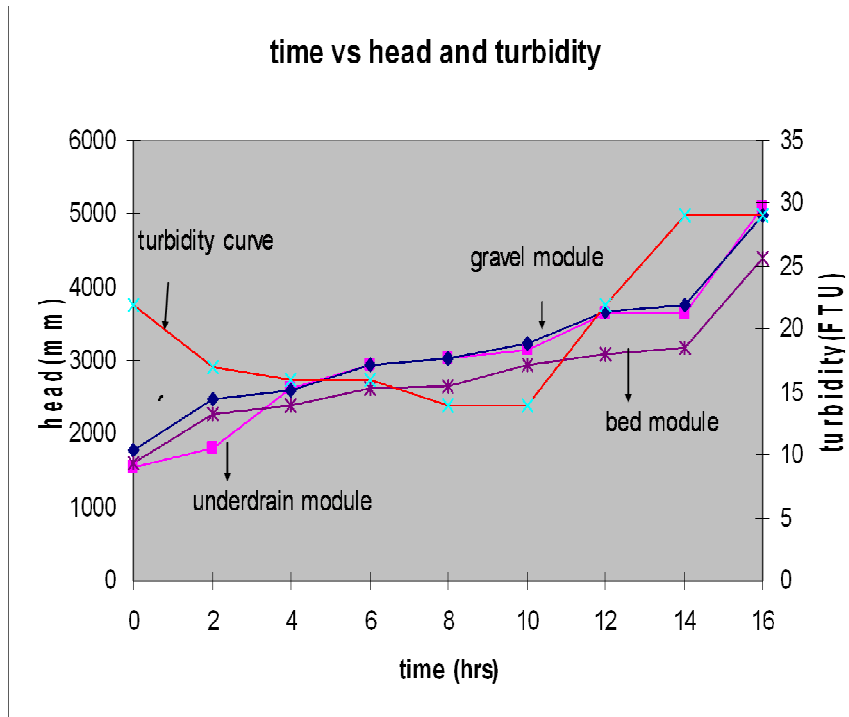


Fig4.2. Time Vs head and turbidity plot for second run

In the third run although filter had been terminated after 12 hours because of increase in pressure as well as turbidity in outlet water. But there were certain problems that aroused during the run. The headloss across the filter was found to be less as compared to first and second run. This was because of the leakage of mercury from manometers. Also flow rate was found to be declined drastically because pump was not working properly due to some technical fault.

Table4.6: Result of third run

Hours	Sample	Turbidity(FTU)	TSS(mg/l)	Pressure(psi)	Flow Rate (L/min)	Remark
0 hour	Inlet	102	150	10	11.5	
	Outlet	24				
2 hour	Inlet	91	122	11	11.3	
	Outlet	23				
4 hour	Inlet	51	62	11	11.3	
	outlet	16				
6 hour	Inlet	74	106	11 to 12	11.1	
	outlet	16				
8 hour	Inlet	84	112	12	11.1	Clay added
	outlet	11				
10 hour	Inlet	57	68	12	10	
	outlet	17				
12 hour	Inlet	51	64	13	8.5	
	outlet	21				

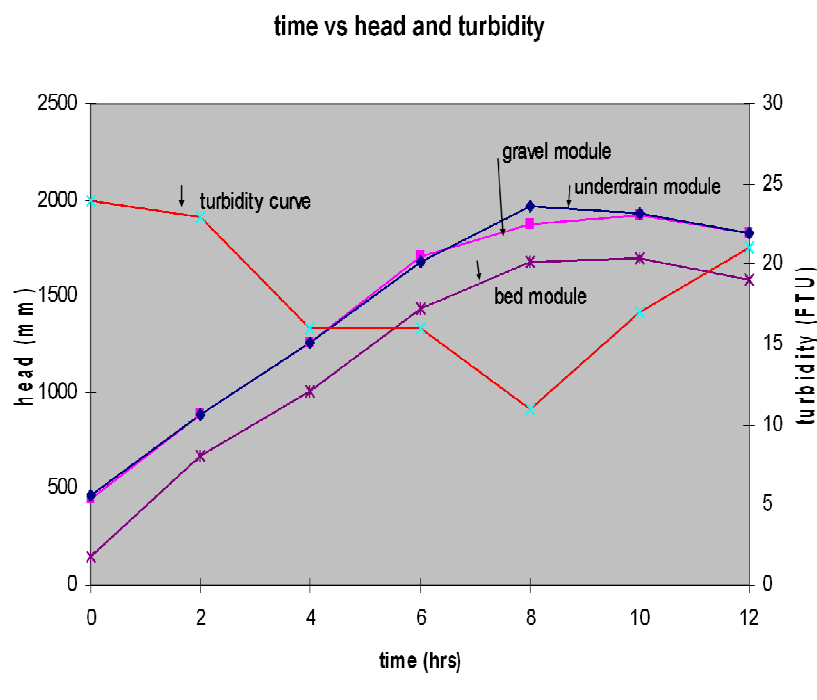


Fig4.3: Time VS head and turbidity plot for third run

Table4.7: Conditions at the time of filter run termination

Run	Pressure (psi)	Pressure drop across the filter (mm)	Turbidity of the outlet water(FTU)
1	12	435	18
2	12	540	22
3	13	240	21

Turbidity and TSS were related for the influent water and the relationship obtained is presented in figure 4.4. This relationship can be used for quick measurement of TSS through monitoring turbidity. The relationship developed has been used whenever required.

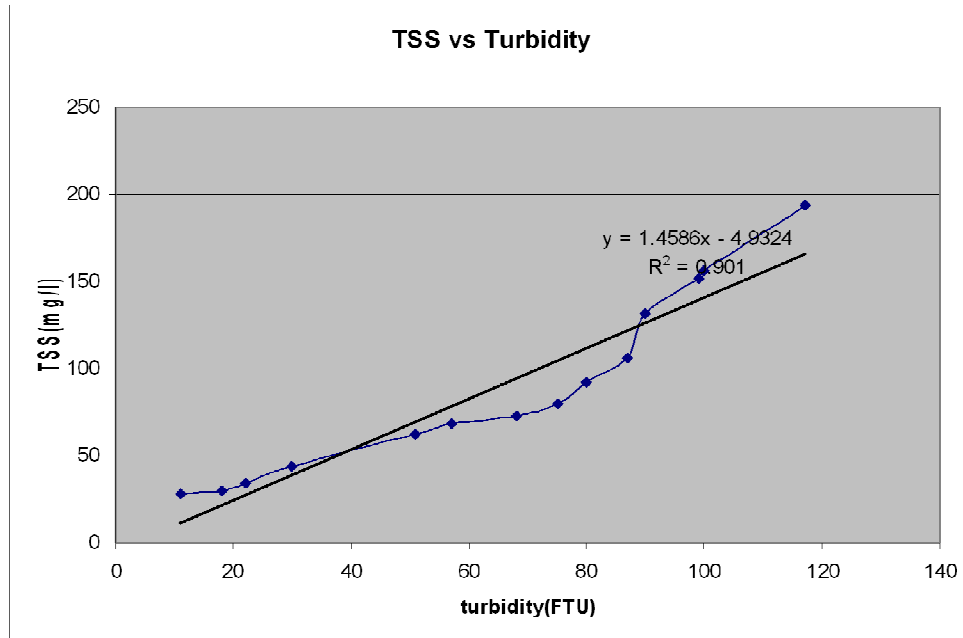


Fig4.4: Relationship between turbidity and TSS

Total amount of water filtered in first run was about 10902 litres. It was calculated on average flow basis. Results are shown in figure 4.8. The amount of solids accumulated in the first run was about 869 g on an applied load of 1392 g/ run. See table 4.9.

Table4.8: Total amount of water filtered during first run

Time (hrs)	0	2	4	6	8	10	12	14	16
Desired flow rate (L/min)	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Actual flow rate(L/min)	11.5	11.5	11.3	11.3	11.2	11.2	11.2	11	11
Average flow rate (L/min)	11.5	11.5	11.4	11.4	11.35	11.35	11.35	11.25	11.25
Average flow filtered (Litres)	0	1380	1368	1368	1362	1362	1362	1350	1350
Cumulative flow filtered (litres)	0	1380	2748	4116	5478	6840	8202	9552	10902

Table 4.9: Total solids accumulated during first run

Time (hrs)	0	2	4	6	8	10	12	14	16
Solids concentration In inlet(mg/l)	194	156	106	92	73	80	94	74	80
Solids concentration in outlet (mg/l)	11	7	4	4	4	4	22	25	28
Average flow rate (L/min)	11.5	11.5	11.4	11.4	11.35	11.35	11.35	11.25	11.25
TSS accumulated (gm)	0	205	140	119	91	102	97	65	69
Cumulative TSS accumulated (gm)	0	205	345	464	563	665	762	827	869

Total amount of filtered in the second run was about 10851 litres in 16 hours and the total amount of solids accumulated during the run was 869g, on an applied TSS load of 1392g. Refer table 4.10 and 4.11.

Table4.10: Total amount of water filtered during second run

Time (hrs)	0	2	4	6	8	10	12	14	16
Desired flow rate (L/min)	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Actual flow rate(L/min)	11.5	11.5	11.3	11.3	10.4	11.3	11.3	11.2	11
Average flow rate (L/min)	11.5	11.5	11.4	11.4	10.95	11.4	11.4	11.25	11.125
Average flow filtered (Litres)	0	1380	1368	1368	1314	1368	1368	1350	1335
Cumulative flow filtered (litres)	0	1380	2748	4116	5430	6798	8166	9516	10851

Table 4.11: Total solids accumulated during second run

Time (hrs)	0	2	4	6	8	10	12	14	16
Solids conct. in inlet(mg/l)	113	90	72	107	102	81	99	93	80
Solids conct in outlet (mg/l)	28	20	19	18	16	16	28	39	39
Average flow rate (L/min)	11.5	11.5	11.4	11.4	10.95	11.4	11.4	11.25	11.125
TSS accumulated (gm)	0	97	75	120	116	81	93	73	55
Cumulative TSS accumulated (gm)	0	97	172	292	408	489	582	675	710

Third run was carried out for 12 hours and the amount of water filtered during the run was found to be 7938 litres. Total amount of solids accumulated in this run was found to be 358g on an applied TSS load of 560g.

Table4.12: Total amount of water filtered during third run

Time (hrs)	0	2	4	6	8	10	12
Desired flow rate (L/min)	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Actual flow rate(L/min)	11.5	11.3	11.3	11.1	11.1	10	10
Average flow rate (L/min)	11.5	11.4	11.4	11.3	11.3	10.75	10
Average flow filtered (Litres)	0	1368	1368	1356	1356	1290	1200
Cumulative flow filtered (litres)	0	1368	2736	4092	5448	6738	7938

Table 4.13: Total amount of solids accumulated during third run

Time (hrs)	0	2	4	6	8	10	12
Solids conct. In inlet(mg/l)	102	91	51	74	84	57	51
Solids conct in outlet (mg/l)	30	28	18	18	11	20	25
Average flow rate (L/min)	11.5	11.4	11.4	11.3	11.3	10.75	10
TSS accumulated (gm)	0	86	44	61	97	44	26
Cumulative TSS accumulated (gm)	0	86	130	191	288	332	358

Table4.14: Results of backwashing

Time (min)	Run1		Run2		Run3	
	Turbidity(FTU)	TSS (mg/l)	Turbidity(FTU)	TSS(mg/l)	Turbidity(FTU)	TSS(mg/l)
0	208	458	3630	7730	50	56
5	2608	4900	880	1700	5100	5080
10	134	286	221	515	570	750
15	11	28	22	36	30	44
20	11	28	18	30	22	34



Fig 4.5: Samples collected during backwashing

CHAPTER-5

CONCLUSION

A pilot scale study on pressure filtration system was carried out for the evaluation of filtralite media. Filtralite was compared with sand and anthracite on the basis of porosity, density, uniformity coefficient. Value of uniformity coefficient for filtralite was found to be 2 and less than 2, hence it can be used as an alternative to conventionally used sand and anthracite. Since the filtralite is a light weight media it can be used together with high density media to make dual or multimedia filters. Also the required backwash velocity will be less for filtralite as compared to other high density media.

For the pilot scale study, filtralite MC 0.8-1.6 was evaluated. Efficiency of the media was found to be 92%. The required backwash velocity was estimated to be 50 m/hr for the media and the total run length was found to be 12 hours, on an applied TSS load of 829 g/12hours.

From the study it can be concluded, that run length can be increased if TSS load will decrease and conversely the run length will be decreased if TSS load will increase.

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