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Performance of Dual-Media Down-Flow Rapid Gravity Filters

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Abstract

The present study was conducted to evaluate the effect of variation of influent raw water turbidity, bed composition, and filtration rate on the performance of mono (sand) and dual media (sand and anthracite) rapid gravity filters in response to the effluent filtered water turbidity and headloss development.

In order to evaluate each filter performance, sieve analysis was made to characterize both media and to determine the effective size and uniformity coefficient. Effluent filtered water turbidity and the headloss development was recorded with time during each experiment.

Keywords: water treatment, turbidity, headloss, filtration, dual media.

Introduction

The growing demands on water resources as a result of rapid development in the agriculture, domestic, and industrial sectors, the inevitable consequence of population growth and economic development, an improved standard of living, all necessitate the professional application of fundamental knowledge about the water cycle to ensure the maintains of quality and quantity and need to design water treatment facilities to provide a water of acceptable quality from contaminated surface water.

Water treatment can be defined as the manipulation of a water source to achieve a water quality that meets specified goals or standards set by community through its regulatory agencies. The most critical determinants in the selection of water treatment processes are the nature of water source and the intended use of the treated water. The two principle sources of water are ground water and surface water.

For the most promising household treatment, effective treatment of turbid water remains a challenge [1]. As reconstruction of Iraq begins, water treatment will be one of the most important projects. All water treatment plants in Iraq are on Tigris and Euphrates rivers and their tributaries. Currently, there are 250 large water treatment plants that require rehabilitation or upgrading and large number of new water treatment facilities needed to be built to respond to the demand for water quality.

The city of Baghdad for example, in the central part of Iraq on the Tigris River, and it is now 30x30 km in area with a population of more than 5 million. All its water treatment plants draw their water from the Tigris River and the city is now served by several water treatment plants built during the 20th century with some additional water treatment plants commissioned in stages from 1970 until 1990. While many areas of Baghdad have access to drinking water from a few functional treatment plants, millions of residents remain without a clean reliable source and have little choice but to drink highly polluted water. Too many residents unfortunately turn to the rotten banks of the Tigris, which snakes prominently through the heart of Baghdad collecting toxins as it flow. The river suffers from the increasing levels of salinity due to the discharges from irrigation drains, concentrated cocktail of pesticides, fertilizers, oil, gasoline, and heavy metals. Also, suspended solids of the river may reaches to values up to 30,000 mg/l. The effect of which include nervous system damage, birth defects, and cancer [2,3,4].

According to the previously stated problems, there is a real need to investigate, characterize and implement physical and physical-chemical technologies for practical and low cost pre-treatment or treatment of household water in all of the Iraqi cities, taking into consideration turbid waters of different quality with respect to particle characteristics and their removal efficiencies.

In this study [5], one of the most important processes in water treatment plants that have a major concern in the treatment cycle is the filtration process. Filtration was recognized quite early in recorded technological as a unique process for improving the clarity of water. Modern engineering applications of filters for the purification of water supplies dates from the eighteenth century were considerable controversy surrounded the use of filters for the removal of bacteria. The utility of filtration for the prevention of disease was demonstrated. Since then, the value of granular media filtration has been recognized. The majority of treatment plants treating surface waters have installed filters for the purpose of meeting drinking water standards and providing water of reasonable aesthetic and microbiological quality. The advent of disinfection in the early twentieth century, however, was the final milestone that assured the production of a safe drinking water.

Granular media filters found in water treatment plants in Iraq uses rapid granular media filters with sand as the filtration media. These units are designed to operate with different filtration capacity according to the needs required by each geographical area.

So that, investigation of the formal rapid sand filters and the new suggested rapid dual media filters (which uses anthracite and sand as filtration media) represents a part of a systematic study of filtration through porous media to evaluate the performance of each type of these filters. Hopping to reduce the suffering of Iraqi people and give solutions to the current encountered problems in water treatment process.

Experimental Work

Experimental rig

An experimental rig was constructed in the laboratory as shown schematically in Fig. 1. Tank T1 was used to prepare high turbidity water by the addition of large quantity of kaolin into the tank under manual agitation. After a sufficient period of time (about 10 to 30 min, depending on the required turbidity), large particle were settled and the others still suspended. Then, a quantity of the high turbid water was transferred to the baffled feeding tank, T2, were the required turbidity was adjusted by addition of tap water. Samples were taken continuously from sample taking port until reaching the required turbidity considering that valve V1 and V2 were opened and the solution was agitated via the pump recycle stream to prevent particles settling in order to maintain the turbidity fixed as long as the experiment time.

Two similar Perspex columns (C1 and C2) of 1.5 m long and 7.62 cm internal diameter were used for mono and dual media filter operation. This diameter was selected because wall effects are limited when the diameter of a filter is 50 times larger than the mean particle diameter [6]. The columns were filled with filter media via the media exchange port to fit 55 cm of media height, noting that under normal operation the media exchange ports should be closed. Each column contains two distributors: one at the top to distribute the water equally through the column section and also to prevent media loss under backwash; the other distributor which is fixed at the bottom and made from textile material acts to hold the filter media in place and to prevent sand leakage into the under drain system.

Many valves were included in the experimental rig to control the system operation. Valves V3 and V4 were used to control the feed to the either mono or dual media filter. Under normal filter operation, one of these valves should be opened only and the other should be closed, and both must be closed under backwash. Valves V5 and V6 were used to feed air through the columns under backwash, and must be closed under normal operation. Valves V7 and V8 were used to made a path for backwashed waste water to get out of the system which is further to be collected in tank T3.

Two calibrated rotameters were used for feeding water and air. Water rotameter, R1, have a scale ranged from 0 up to 60 l/hr connected after valve V1. Air rotameter, R2, have a scale ranged from 0.4 up to 1 m^3/hr connected directly to the lab air supply system.

Normal filter operation

The filter was operated on the principle of constant flow rate and variable headloss mode, 50 liter of turbid water (10, 20, 30, 40, or 50 NTU) from tank T2 was pumped through rotameter R1 at different flow rates (36, 42, 48, 54, or 60 l/hr) in either columns per experiment. This quantity was selected experimentally and chosen to be the best value with respect to headloss development across the column. Turbid water enters the column and distributed evenly through a clean media bed, starting the filtration operation. Filtered water then is collected from the bottom of the columns and discharged outside the system. Samples of the filtered water were collected periodically for turbidity measurements.

Filter backwash

Filter backwash was accomplished by injecting tap water and air in the bottom of the columns at a known flow rates (Fig 2a) controlling the fluidization level to be about 140-150% of the actual bed height. This level seems to be sufficient to clean the filter and prevent

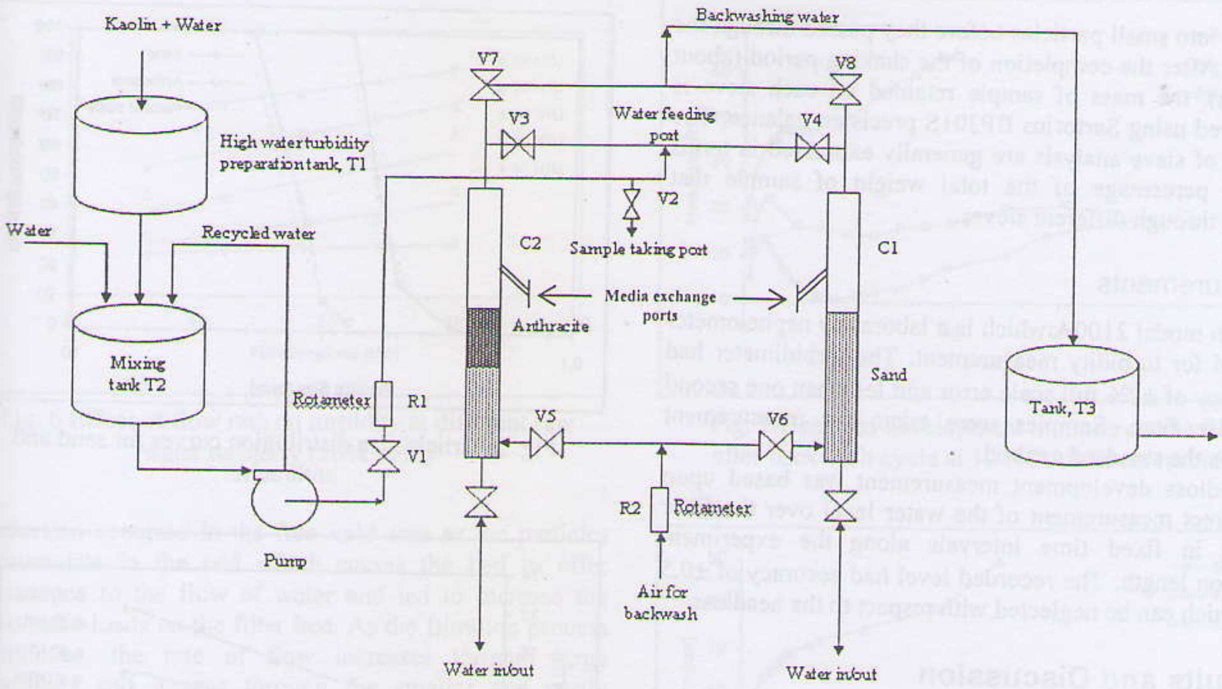

Fig. 1 Experimental rig for mono and dual media filter

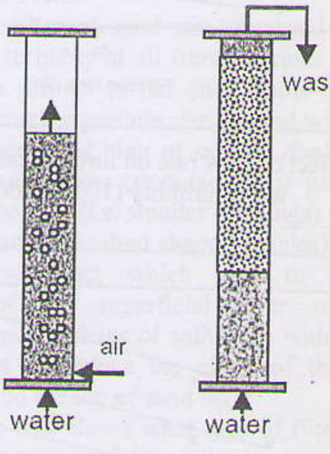

Fig. 2 Backwash cycle: (a) Air and sub-fluidization water injected to fluidize the bed. (b) Fluidization with water injected to restratify the media

media loss during backwashing [7]. The process started by injecting air only followed by subfluidization water. The process takes about 5 min and ended by closing the air stream followed by increasing water stream flow rate to maintain the fluidization about 1 min. This allows air bubbles within the bed to be escaped and to restratify the filter media (Fig. 2b). Water stream then should be closed and the cycle finished with clean and well ordered media bed. Table 1 shows air and water flow rates applied during filter backwash for each filter type.

Table Air and water flow rates for filter backwash

Filter media	*Air flow rate (m^3/hr)*	*Water flow rate (l/hr)*
100% Sand	0.8-1.0	112
75% Sand +25% anthracite	0.4-0.6	250-260
50% Sand +50% anthracite	0.2-0.4	230-240

Materials

Sand and anthracite were especially treated and prepared for filtration use directly. These materials were supplied by the Arabic Centre for Water Treatment. Specific gravity and porosity are 2.6 and 0.4 for sand; 1.5 and 0.44 for anthracite respectively. Industrial grade powdered kaolin was used to prepare the raw water.

Sand and the anthracite were backwashed thoroughly for sufficient period of time after loading to the filter columns to clean the bed from clay, dirts, etc. The process continues until clean media and clear water was observed.

Sieve analysis

Sieve analysis consists of shaking a sample of 500 g (sand or anthracite) using Endicot sieve shaker through a set of sieves [8] that have progressively smaller openings. Table 2 lists the U.S. standard sieve numbers and the sizes of openings used during the analysis.

First of all, dry sample was taken and the lumps were broken into small particles before they passed through the sieves. After the completion of the shaking period (about 25 min), the mass of sample retained on each sieve is measured using Sartorius BP301S precision balance. The results of sieve analysis are generally expressed in terms of the percentage of the total weight of sample that passed through different sieves.

Measurements

Hach model 2100A which is a laboratory nephelometer is used for turbidity measurement. The turbidimeter had accuracy of ±2% full scale error and less than one second response time. Samples were taken for measurement follows the standard method.

Headloss development measurement was based upon the direct measurement of the water level over the filter media in fixed time intervals along the experiment duration length. The recorded level had accuracy of ±0.5 cm which can be neglected with respect to the headloss.

Results and Discussion

Sieve analysis & particle size distribution curves

The geometric mean size, effective size (ES) and uniformity coefficient (UC) calculated from the sieve analysis for both sand and anthracite are tabulated in Table 2. The values listed falls within the desirable and usable parameter ranges for both single and dual media [9, 10, 11].

The particle size distribution curves for sand and anthracite are shown in Fig. 3. It is used for comparing the two media and to determine the sieve analysis parameters. It shows that both media cover a narrow range of particle sizes (about 83% of sand particles lies between 0.5 to 0.8 mm and 90% of anthracite particles lies between 1.0 to 1.2 mm). This indicates that both sand and anthracite used during experiments may be characterized as poorly graded media [8]. The figure also shows the deviation of media from that wanted or required typical slopes for filter media. It is clear that both media have a good agreement with that wanted [9].

Table 2 Sieve analysis parameters for sand and anthracite

Parameter	*Sand*	*Anthracite*
Geometric mean size, mm	0.615	1.360
Effective size, mm	0.46	1.000
Uniformity coefficient	1.417	1.487

Effect of filtration rate on turbidity

Fig. 4 through 6 shows the effect of filtration rate variation on effluent average turbidity (i.e. filtered water turbidity) at different influent turbidities (i.e. raw water turbidity) in mono (100% sand) and dual-media (50% an 75% sand) filter. Generally, all curves show a linea relationship, as the rate of filtration increases, the efflue turbidity increases also. This may be referred to th

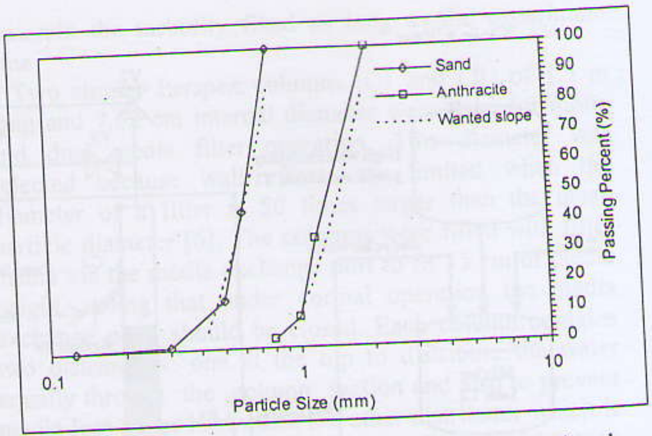

Fig. 3 Particle size distribution curves for sand and anthracite

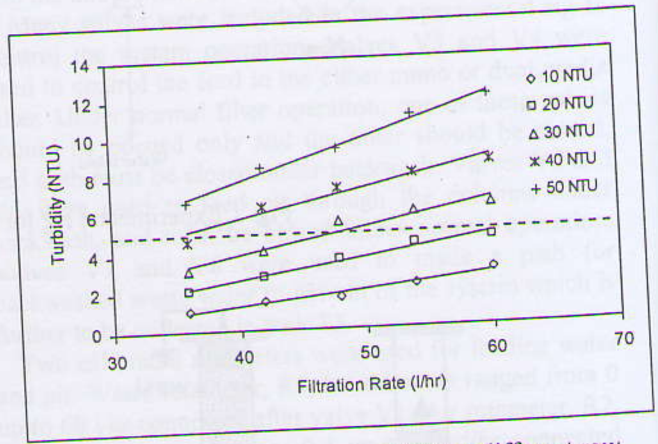

Fig. 4 Effect of flow rate on turbidity at different raw water turbidity (100% sand)

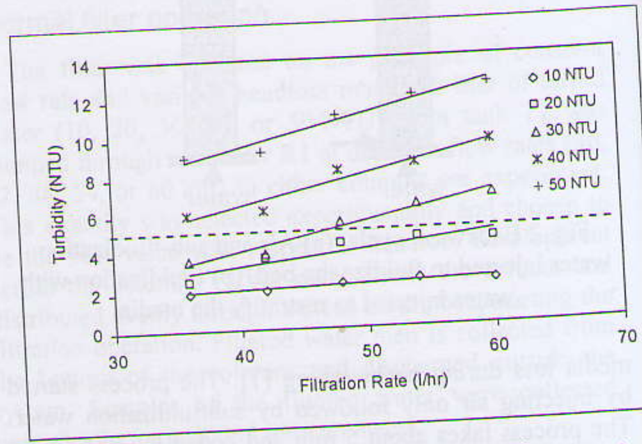

Fig. 5 Effect of flow rate on turbidity at different raw water turbidity (75% sand)

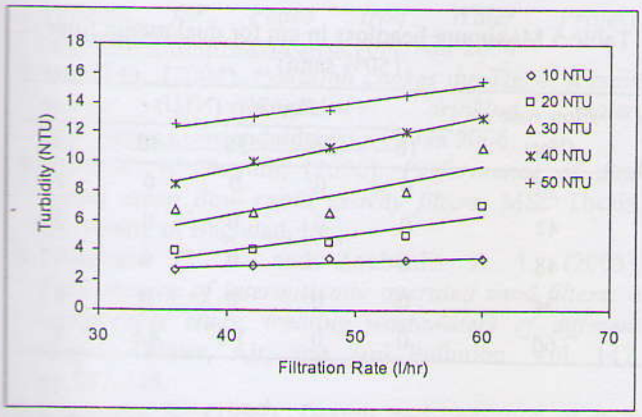

Fig. 6 Effect of flow rate on turbidity at different raw water turbidity (50% sand)

reduction occurred in the free void area as the particles accumulate in the bed which causes the bed to offer resistance to the flow of water and led to increase the hydraulic loads on the filter bed. As the filtration process continues, the rate of flow increases through large openings and lessens through the smaller and partly clogged openings. This causes the larger passageways to remain nearly free of deposits (i.e. prevents the settling or attachment of suspended particles) and may remove the previously settled ones.

Mono-media filter of sand was observed to give the lowest effluent turbidity at all filtration rates and influent turbidities with respect to the dual media bed. This is referred to the smaller particle size of sand with respect to anthracite, reduced bed high of sand in dual media bed, the shape of sand grains (rounded shape particles) also offer smaller porosity (i.e. smaller openings) with respect to that of anthracite (crashed shape particles), and finally the intermixing effect which acts to reduce the performance of the superficial layer of sand by introducing larger particles of anthracite within this layer which eliminate or reduce the effect of the fine sand particles found on the top of sand layer.

These figures also shows what type of filter should be selected and the corresponding filtration rate for a given influent turbidity according to the maximum allowable effluent turbidity of 5 NTU followed the Iraqi standard [12] which is indicated as a dashed line in these figures.

Headloss behavior after backwashing

The headloss development after each backwashing cycle was plotted at different influent turbidity and flow rates for mono-media filter as shown in Fig. 7 through 9. Flow rates selected to be 36, 48, and 60 l/hr for clarity as well as the influent turbidity (10, 30, and 50 NTU).

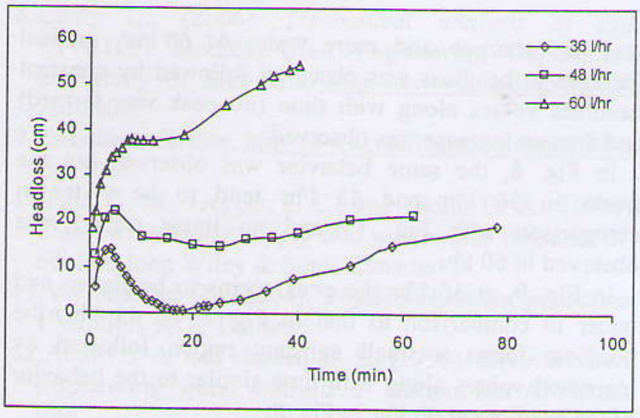

Fig. 7 Headloss development in mono-media filter after backwash cycle at 10 NTU influent turbidity

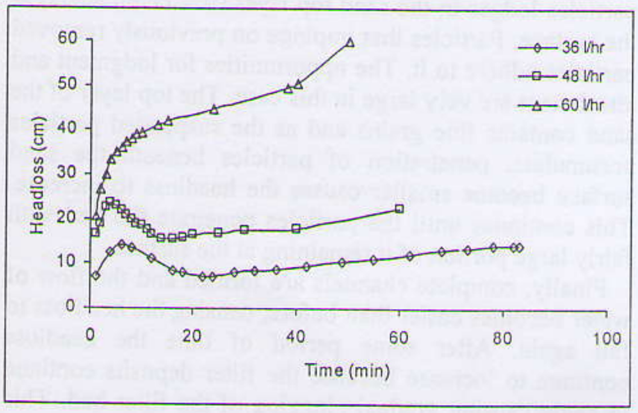

Fig. 8 Headloss development in mono-media filter after backwash cycle at 30 NTU influent turbidity

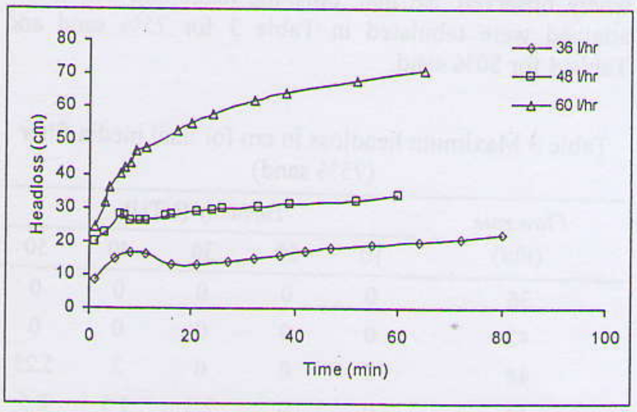

Fig. 9 Headloss development in mono-media filter after backwash cycle at 50 NTU influent turbidity

Observing Fig. 7, it is noticed that the headloss increases at the start of the run and continue to increase until it reaches a point in which the headloss begin to fall gradually (forming a peak). Then it begins to increase again and continue to increase along the filter run. At 36 l/hr this peak was sharp and narrow, at 48 l/hr, the peak was less sharpen and more wide. At 60 l/hr, gradual increase in headloss was observed followed by constant headloss values along with time (no peak was formed) and then an increase was observed.

In Fig. 8, the same behavior was observed but the peaks in 36 l/hr and 48 l/hr tend to be wider in comparison with Fig. 13 and no linear region was observed in 60 l/hr.

In Fig. 9, at 36 l/hr the peak seems to be flatten and wider in comparison to that in Fig. 8. At 48 l/hr, the headloss forms a small constant region followed by increased values along with time similar to the behavior of the headloss at 60 l/hr in Fig. 8.

The above described phenomena may be referred to behavior of the filter at the start-up after a backwash cycle. At the beginning of the filter run nearly all of the particles lodges in the sand top layer (few centimeters) at the surface. Particles that impinge on previously removed particles adhere to it. The opportunities for lodgment and attachment are very large in this case. The top layer of the sand contains fine grains and as the suspended particles accumulate, penetration of particles beneath the sand surface become smaller causes the headloss to increase. This continues until the particles penetrate the bed with fairly large portion of it remaining at the surface.

Finally, complete channels are formed and the flow of water becomes easier than before, causing the headloss to fall again. After some period of time the headloss continue to increase because the filter deposits continue to settle causing gradual clogging of the filter bed. This continues until the bed was completely clogged or reaching the terminal headloss

In dual media filter, only linear headloss development where observed. So that, only the maximum headlosses attained were tabulated in Table 3 for 75% sand and Table 4 for 50% sand.

Table 3 Maximum headloss in cm for dual media filter (75% sand)

Flow rate	*Turbidity* (NTU)				
(l/hr)	10	20	30	40	50
36	0	0	0	0	0
42	0	0	0	0	0
48	0	0	0	2	5.25
54	0	0	2.5	5.5	8.5
60	0	1	5.5	8.0	12.5

Table 5 Maximum headloss in cm for dual media filter (50% sand)

Flow rate	*Turbidity* (NTU)				
(l/hr)	10	20	30	40	50
36	0	0	0	0	0
42	0	0	0	0	0
48	0	0	0	0	0
54	0	0	0	0	0
60	0	0	1.5	4.5	8

The reduction in headloss may be referred to the reduced bed high of sand so that the channels form more rapidly than in the case of mono-media filter and the effect of intermixing. The intermixing occurred with anthracite particles tend to scratch the top layer of the sand whicl contains the fine sand particle and provide smootl transition from anthracite bed to sand bed by sinkin some particles into the surface of the sand. Th intermixing was recorded to be about 3 to 5 cm in all dua media experiments. The gradation from coarse to fin media promotes filtration within the interstitial spaces c the bed rather than filtration by straining at the top of th bed as in the case when a stratified mono-medium filter used. Filtration within the bed rather than on the top of led to reduces the rate of development of headloss.

Conclusions

1. Effluent water turbidity generally increases as tl rate of filtration increases in mono and du media filters. Also, at a fixed flow rate, efflue water turbidity increases as the influent wat turbidity increases.
2. According to the 5 NTU effluent turbidity Ira standard, turbidity of 50 NTU should not applied to any type of filters used because it giv effluent turbidities greater than 5 NTU at all
3. Dual media-filter gives lower headloss but higl effluent turbidity at a fixed bed height. Also, d media filter generally gives longer filter ru before terminal headloss was attained.
4. Mono media filter gives headloss peak at filter startup followed by a linear increase only linear headloss development was obser in dual media filter.

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