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Water Purification using Multiple Stage Filtration Technology

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Abstract

An experimental model for the multiple stage filtration (MSF) process has been designed which consists of Roughing Filter (RF) and Slow Sand Filter (SSF) and located at Giza Water Treatment plant. The results indicated the purification of water with levels of contamination well above those treated by SSF alone, and high efficiency in turbidity removal (90-99%). The overall efficiency is increased by reducing filter media size or rate of filtration. Turbidity removal contribution of RF to overall removal is around 77% and around 19% for SSF. MSF can handle turbidity level up to 30 NTU and give effluent turbidity less than 0.5 NTU. At rate of filtration higher than 0.25 m/hr, removal of turbidity deceases significantly. The SSF should be cleaned every two months to maintain a maximum head loss of 63cm.

Key Words: Multiple Stage Filtration; Roughing Filter; Slow Sand Filter; Turbidity Removal.

Introduction

The Slow sand filtration (SSF) is the oldest water treatment technique used in water treatment plant (WTP) and has been successfully implemented in Europe and North America for treating surface water with relatively low levels of contaminations. Experience with SSF has not been successful in Latin American countries such as Brazil and Colombia, where high turbidity levels in the rivers caused premature clogging of the filters, resulting in the need for frequent cleaning system. The clogging problem of SSF contributed to increase worldwide interest in Rapid Sand Filter (RSF) using chemical coagulation which is considered the most commonly used method for increasing the efficiency of water purification specially when using sedimentation and filtration process but this system need skilled operators and high operating cost in addition to water increased losses when using this system (1, 2).

MSF Configuration

There are various types of Roughing filters (RFs) to improve raw water before it reaches the SSF unit; Figure (2) shows different types of pretreatment options that are differentiated by their direction of flow as follows:

- Dynamic gravel Filter (DyGF)
- Up-flow filters in series (UGFS)
- Down-flow filters in series (DGFS)
- Horizontal flow gravel filters (HGF)
- Up-flow gravel filter in layers (UGFL)

Advantages and Limitations of MSF

MSF offers several technical and economical advantages such as high efficiency in turbidity removal (organic and inorganic) (90-99%), effective in terms of initial investment practically in small systems where land cost is low, operation and maintenance costs are significantly simple and low compared to costs accompanied by the use of chemical coagulation, no need for any chemical coagulation to increase the efficiency of the treatment, system use local material and labor easily, removal of 99% of bacteria, removal of iron and manganese, and removal of odor and color.

There are some limitations that should be considered when using MSF system such as high levels of turbidity of values (above 150 NTU for pretreatment system and above 20 NTU for SSF) may cause difficulties for SSF treatment, high concentrations of iron and manganese (above 1 mg/L) may contribute significantly to SSF clogging, the high growth of algae can cause filters to clog very quickly especially filamentous type, low temperature (below 20°C) increases the viscosity of water, which reduces the biochemical activity in the sand bed, low concentrations of dissolved oxygen (below 6 mg/L) may create anaerobic condition, which causes serious water quality problems such as bad smell and tasty water (5, 6).

Previous Experience

The municipality of Mizque, with a population of about 3,000 is located in the department of Cochabamba, Bolivia, and obtains its water from the River Uyuchama, which has high turbidity peaks lasting longer than 24 hours. To overcome these problems, MSF has been developed. The filter can capture a flow of 8 L/s. It has been built with 50 m wide and 5 m length. The depth of the filtering media is 2.26 m with gravel layers. The SSF is made up of three filtering units. The filtration area per unit is 33 m2 and the filtration rates for these units are 0.30 m/h. The system gave removal values for turbidity of 99%, for untreated water (4, 6).

A pilot plant study was undertaken and MSF performance was evaluated against the existing conventional system in Kenya. The efficiency of MSF system was also evaluated, including its use of locally available material, such as gravel, improved agricultural waste (charcoal maize cobs) and broken burnt bricks for pre-treatment filter. Results showed that MSF systems perform better than conventional systems under similar raw water quality and environmental conditions. Locally available materials can also be effectively used as pre-treatment media, and can therefore serve as alternatives where natural gravel is not readily available (4, 6).

Experimental Setup:

The experimental setup consists of RF at the beginning to cope with high turbidity load, and followed by SSF as a final stage of the filtration system. The RF and SSF are made of acrylic material with thickness of 8 mm and supported on metallic frame with media of suitable sizes (7).

All filters are fitted with interconnecting plastic pipes, water sampling tape, and collection port and drainage outlet as shown in Figure (3). The pilot plant is designed such that the RF can be bypassed and raw water fed directly to SSF according to turbidity loads. Figure (4) shows the method of feeding the pilot Plant at Giza water treatment plant.

Collection of raw water samples from field

During the experimental run, raw water was collected everyday from River Nile in constant head tanks and sometimes was mixed with a small portion of sludge from sedimentation tank of the WTP in order to increase the turbidity level and study its affect on the removal efficiency. Continuous mixing was done to maintain homogenous condition and keep the turbidity particles in suspension.

Experiments runs were conducted under variable flow rates, different range of turbidity levels in raw water and filter bed conditions. Four experimental Groups were conducted under different conditions during the period of experimental works and summarized in Table 1.

Group I - Effect of Filter Bed Media

To investigate the effect of media size on the performance of MSF, the turbidity level is maintained at constant level at the entrance of RF, and the rate of filtration is maintained at low rate value through three runs of the experiments. The media depth and water depth are maintained constant through the four runs. The effect of media size on turbidity reduction is presented in Table 2, and figures (5&6).

- The overall efficiency increased by reducing filter media size.
- Although the coarse media of SSF fulfills the required levels of standards [8]. however fine media is generally recommended for higher efficiencies.
- Overall turbidity removal efficiency of MSF ranges from (97.39% to 98.49%).
- The average turbidity removal efficiency of RF is 79%.
- The average turbidity removal efficiency of SSF is 90.61%.

Average Turbidity Removal Contribution of RF to Overall Removal is 79%.
 Average Turbidity Removal Contribution of SSF to Overall Removal is 19%.
 The recommended media size to be used at SSF is 0.15mm, which is called fine media.
The results in Table 2 indicate that the contribution of RF in turbidity removal is more significant compared to SSF. This means that the coarse media pre-filtration step is effective for the reduction of turbidity.
 Figures (5& 6) shows graphical plot of the above results.

Group II - Effect of Raw Water Turbidity

To investigate the effect of raw water turbidity on the performance of MSF, media size is maintained with constant size with fine media for SSF and the rate of filtration is maintained at constant value with low rate through the variation of turbidity levels. The media depth and water depth are maintained constant through the four runs.

Variation of turbidity value through different unit filtration stages under different raw water turbidity levels is presented in Table 3, and figures (7 & 8).
 Overall turbidity removal efficiency of MSF ranges from (94.71% to 98.49%).
 The average turbidity removal efficiency of RF is 78.71%.
The average turbidity removal efficiency of SSF is 83%.
Average Turbidity Removal Contribution of RF to Overall Removal is 78.71%.
 Average Turbidity Removal Contribution of SSF to Overall Removal is 17.85%.
 The results in Table 3 indicate also that MSF can handle turbidity level up to 30 NTU and give effluent turbidity less than 0.5 NTU, which is below the required standards.
 Figures (7& 8) shows graphical plot of the above results.

Group III - Effect of Rate of Filtration

To investigate the effect of rate of filtration on the MSF performance, the media size is maintained constant with fine media size and turbidity level is maintained with constant value low through the variation of rates of filtration. The media depth and water depth are maintained constant through the four runs.

The performance of different filtration units operated at various rate is summarized in Table 4, and figures (9 & 10).
The overall efficiency decreased by increasing the RoF.
Overall average turbidity removal efficiency of MSF ranges from (92.37% to 97.46%).
 The average turbidity removal efficiency of RF is 74.14%.
The average turbidity removal efficiency of SSF is 82.88%.
Average Turbidity Removal Contribution of RF to Overall Removal is 74.14%.
Average Turbidity Removal Contribution of SSF to Overall Removal is 21.31%.
Overall turbidity removal variations were negliable up to ROF of 0.2 to 0.25 m/h for SSF and however, for rates of filtration higher than 0.25 m/hr, removal of turbidity decreases significantly.
Figures (9& 10) shows graphical plot of the above results.

Group VI - Variation of Head Loss with Time

To investigate the head loss increase along operation period, the media size is maintained constant with fine media size and turbidity level is maintained with constant value low and the rate of filtration is maintained at constant value with low rate. The head loss increasing with time is summarized in Table 5, and figure 11.

The results at Table 5 ndicate that the initial head loss across SSF started at 1 cm and increased to a maximum value at 8cm after four weeks period of operation. The head loss increase curve with time was extrapolated exponentially to determine the maximum expected head loss before cleaning [9].

A head loss of 63 cm was reached after 2 months with filtration rate 0.25m/hr for SSF. Therefore, cleaning should be done every 2 months.

Effect of RF Bypass on Clogging of SSF

RF Bypass has been developed to deliver the raw water to SSF directly in order to investigate the effect of turbidity level on clogging of the SSF filter.

Different Turbidity levels of raw water have been applied on the influent to the SSF, and it has been noted that the rate of filtration decreased gradually by increasing the turbidity level under the same valve control conditions. The rate of filtration almost has a very small value when the turbidity level increased by value higher than 10 NTU.

It is recommended that the SSF filter should be used to treat raw water with turbidity level below 10 NTU.

Effect of Algae Growth on Clogging of SSF

It is has been observed that algae grow wherever the MSF units are uncovered which shall lead to clog the filters and decrease the time interval between cleaning periods. Covering filter is recommended to avoid growth of algae and avoid filter clogging.

Role of Different Filtration Stages

Overall removal performance of different MSF process obtained during all the experimental runs have been summarized in Figure (12) which reveals that regarding reduction of turbidity, the role of pre-treatment process (RF) was very significant and an average of 77% turbidity removal was achieved. The role of SSF unit was significant and an average of 19% turbidity removal was achieved.

Results and Discussions:

The laboratory results will be analyzed and discussed for the four RF configurations. The analysis will show the effect of the filtration rate and influent turbidity verses the efficiency.

The averages of every three readings are taken into considerations. The results are illustrated for the four roughing filter configurations as following:

-First table and figure show the influent and effluent turbidity at various rate of filtration used.

-Second figure shows the efficiency of turbidity removal calculated.

Comparison between Four Roughing Filter:

The average efficiencies for the four configurations are illustrated in the Figure 16 for every filtration rate. The result show that the at rate of filtration 0.3m/h and 0.5m/h the UFRS recorded the highest efficiency followed with the HFRS, DFRS then HFRS-IP.

In the final filtration rate 0.7 m/h the HFRS recorded lower than DFRS but the above mentioned rank remain the same the UFRS recorded the highest followed with DFRS, HFRS and finally the HFRS_IP.

The HFRS-IP recorded the lowest efficiency considered (69.88%-74.1%) but this configuration gives us new way to treat water. Due to cost problems and experiment schedule, only one HFRS-IP configuration was tested.

Design Criteria

With reference to the above results, the design recommended criteria of MSF units are summarized in Table 6.

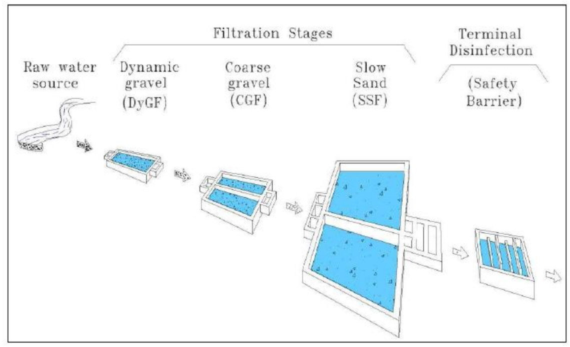

Figure 1: General layout of multiple-stage filtration technology.

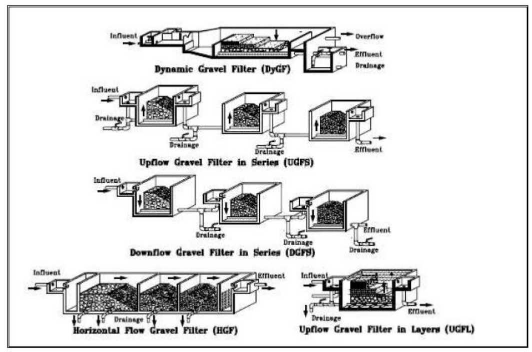

Figure 2: Layout of various types of pretreatment alternatives.

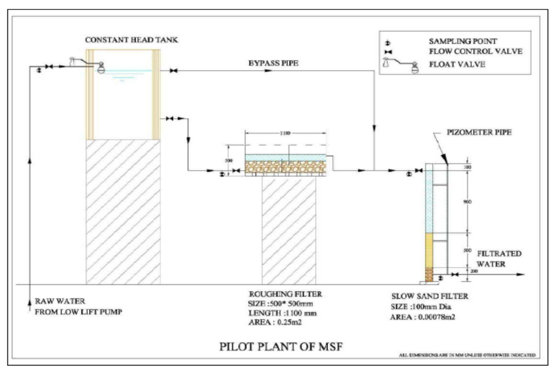

Figure 3: Pilot Plant of MSF

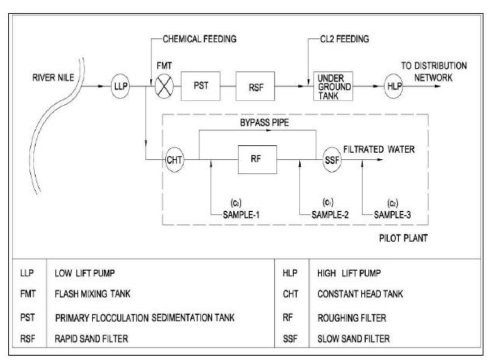

Figure 4: General layout of Giza WTP and MSF pilot plant

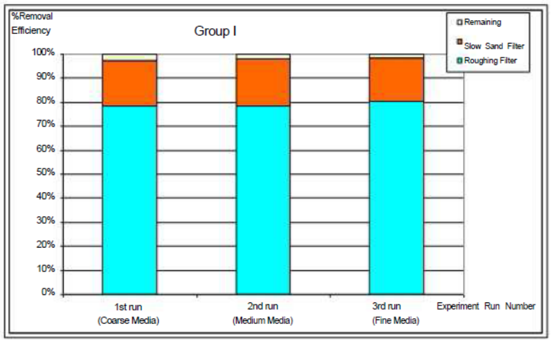

Figure 5: Contribution of RF and SSF in turbidity removal efficiency
" effect of filter bed media"

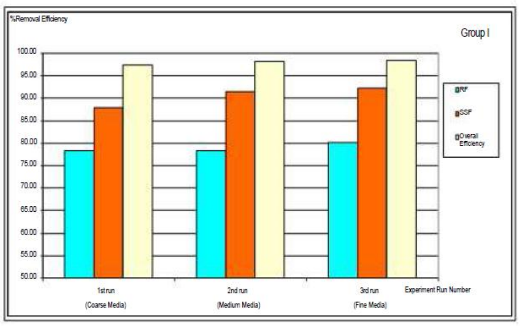

Figure 6: Effect of media size on the turbidity removal efficiency for each filtration unit

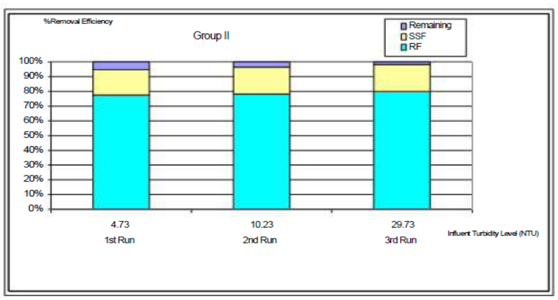

Figure 7: Contribution of RF and SSF in turbidity removal efficiency
"effect of raw water turbidity"

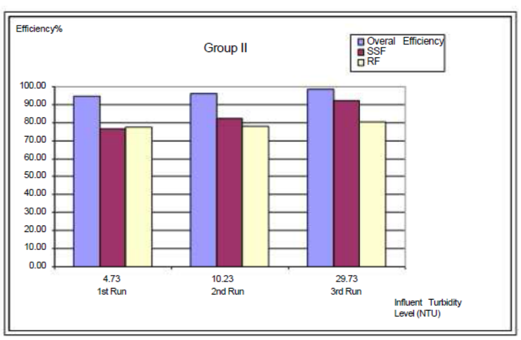

Figure 8: Effect of raw water turbidity level on the turbidity removal efficiency for each filtration unit

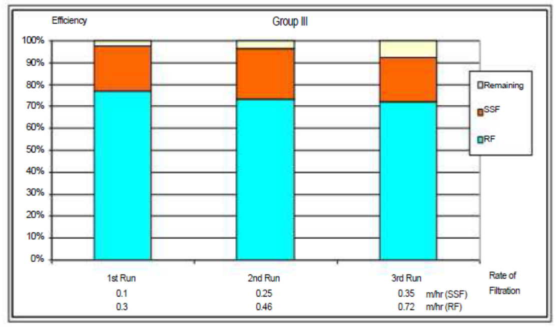

Figure 9: Contribution of RF and SSF in turbidity removal efficiency
"effect of rate of filtration"

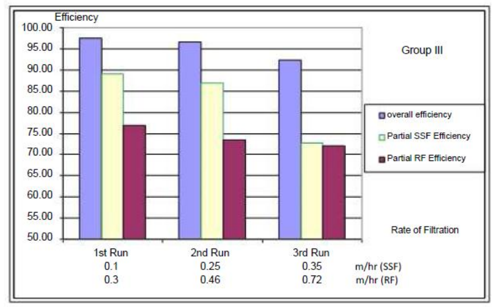

Figure 10: Effect of rote of filtration on the turbidity removal efficiency for each filtration ate unit

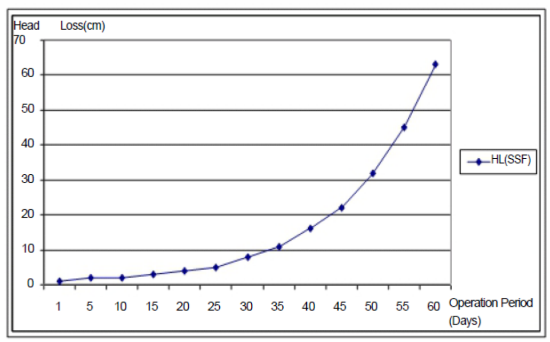

Figure 11: The head loss through MSF with operation Period

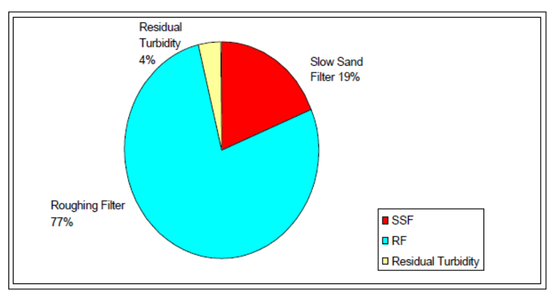

Figure 12: The role of different filtration units

Group	Control Parameter	Media Size	Turbidity Level	RoF	Duration
I	Media Size	Variable (3 Runs)	High	Low	2 Weeks
II	Turbidity Level	Fine	Variable (3 Runs)	Low	2 Weeks
III	RoF	Fine	High	Variable (3 Runs)	2 Weeks
VI	Head loss at SSF	Fine	High	Low	1 Month

Table (1) - Experimental Runs-Duration.

Experimental Run	1	2	3
Control Variables			
Media Size	**Coarse**	**Medium**	**Fine**
Turbidity Level	High	High	High
RoF	Low	Low	Low
Turbidity Level (NTU)			
Raw Water	38.30	35.70	29.73
Effluent of RF	8.30	7.70	5.87
Effluent of SSF	1.00	0.65	0.45
Turbidity Removal Efficiency (%)			
Partial Efficiency of RF	78.33	78.43	80.26
Partial Efficiency of SSF	87.95	91.56	92.33
Overall Turbidity Removal Efficiency	97.39	98.18	98.49
Contribution Removal to Overall Removal (%)			
RF	78.33	78.43	80.26
SSF	19.06	19.75	18.23
Remaining	2.61	1.82	1.51
Total	100.00	100.00	100.00

Table (2) -Effect of media size

Experimental Run	1	2	3
Control Variables			
Media Size	Fine	Fine	Fine
Turbidity Level	**Low**	**Medium**	**High**
RoF	Low	Low	Low
Turbidity Level (NTU)			
Raw Water	4.73	10.23	29.73
Effluent of RF	1.07	2.23	5.87
Effluent of SSF	0.25	0.39	0.45
Turbidity Removal Efficiency			
Partial Efficiency of RF	77.38	78.20	80.26
Partial Efficiency of SSF	76.64	82.51	92.33
Overall Turbidity Removal Efficiency	94.71	96.19	98.49
Contribution Removal to Overall Removal			
RF	77.38	78.20	80.26
SSF	17.34	17.99	18.23
Remaining	5.29	3.81	1.51
Total	100.00	100.00	100.00

Table (3) - Effect of turbidity level

Experimental Run	**1**	**2**	**3**
Control Variables			
Media Size	Fine	Fine	Fine
Turbidity Level	Low	Low	Low
RoF	**Low**	**Medium**	**High**
Turbidity Level (NTU)			
Raw Water	4.73	4.03	3.93
Effluent of RF	1.09	1.07	1.1
Effluent of SSF	0.12	0.14	0.3
Turbidity Removal Efficiency			
Partial Efficiency of RF	76.96	73.45	72.01
Partial Efficiency of SSF	88.99	86.92	72.73
Overall Turbidity Removal Efficiency	97.46	96.53	92.37
Contribution Removal to Overall Removal			
RF	76.96	73.45	72.01
SSF	20.51	23.08	20.36
Remaining	2.54	3.47	7.63
Total	100.00	100.00	100.00

Table (4) - Effect of rate of filtration

Operation Period (days)	**Head Loss(SSF) (cm)**	
1	1	**Measured**
5	2	
10	2	
15	3	
20	4	
25	5	
30	8	
35	11	**Extrapolated**
40	16	
45	22	
50	32	
55	45	
60	63	

Table (5) - The Head Loss Increase with Time

Parameter	**RF**	**SSF**
RoF (m/h)	0.3-0.5	0.15-0.25
Media Size(mm)	10-20	0.10-0.25
Max turbidity level	-	10
Operation Period	-	8 weeks at RoF = 0.1 m/hr

Table (6) - Recommended Design Criteria of MSF Units

Conclusions:

- The recommended media size to be used at SSF is 0.15mm, which is classified fine media.
- The RF treats raw water with turbidity level below 30 NTU gives high turbidity removal efficiencies reach to 75% with an effluent turbidity below 0.5 NTU.
- The maximum Rate of Filtration shall be used for SSF should below or equal 0.25m/hr.
- The SSF should be cleaned every two months to maintain a maximum head loss of 63cm.
- It is recommended to cover the filter to avoid growth of algae and filter clogging.
- The SSF filter should be used to treat water with turbidity level below 10 NTU.

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