Evaluation of Horizontal Flow Roughing Filtration Performance

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Abstract

The HRF was studied by using pilot plant. This pilot plant was designed and applied in Al – Wehda Water Treatment Plant which treats the raw water of Tigris River in Al – Karradah in Baghdad city. Design characteristics of the pilot HRF are 5.5m length × 1m width × 1m depth , the HRF length consists of inlet (0.5 m) , outlet (0.5 m) and three compartments (2m , 1.5m and 1m) filled with three different size of gravel (15mm , 10mm and 5mm) respectively . The HRF was continuously operated (24 h in a day) during the period from 15/ May / 2007 to 15/ July / 2007. Operated done in two stages. In the first stage, raw water (free from any addition) was used, with three different flow rate 1.3, 1.1 and 0.9 m^3/h. While in the second stage, coagulated water (raw water + alum) was used, with flow rate 1.3 m^3/h. To assess the performance of HRF, the required tests were carried out. These tests are Turbidity, S.S, Temperature, pH and Bacteriological tests. The results of tests were analyzed statistically. The mean of removal efficiency of turbidity for first stage with discharges 1.3 , 1.1 and 0.9 m^3/h is 92% , 94% and 95% respectively , and for second stage is 97% . These results indicate the high performance of HRF in turbidity removal.

Keywords: HRF (Horizontal Flow Roughing Filtration) , turbidity removal , S.S (Suspended Solid) removal , influent discharge , Temp. (Temperature).

تقـــــــييــم اداء الترشــــــــيــح الافقــــــــــــــــــي الحصـــــــــوي

الخلاصة

أن نظام الترشيح الحصوي الافقي قد صمم و نفذ انشائياً في محطة مشروع الوحدة لمعالجة مياه الشرب و التي تعالج مياه نهر دجلة و الكائنة في منطقة الكرادة في مدينة بغــداد . الابعاد التصميمية للمرشح الافقي الحصوي كانت (5.5 م طول , 1 م عرض , 1 م ارتفاع) و ان حوض الترشيح يتكون من مدخل المياه (0.5 م) و مخرج المياه (0.5 م) و من ثلاث اجزاء طول الاول 2 م و الثاني 1.5 م و الثالث 1 م , ملئت بثلاث احجام مختلفة من الحصى الخاص بالترشيح 15 ملم و 10 ملم و 5 ملم على التوالي . ان نظام التشغيل كان مــستمر (24 ساعة في اليوم) للاشهر من15/ مايس / 2007 الى 15/تمــوز /2007 و كــان علــى مرحلتين , المرحلة الاولى تمت بإستخدام الماء الخام (خالي من أي اضافات) و بإستخدام ثلاث تصاريف مختلفة للمياه (1.3, 1.1 , 0.9) م^3/ساعة . اما المرحلة الثانية فكانت بإستخدام الماء المشبب (ماء خام + شب) و كان التصريف 1.3 م^3/ساعة . لتقييم فعالية أداء المرشح الافقي الحصوي , فأنه تم إجراء جميع الفحوصات المختبرية اللازمة . و هذه الفحوصات هي : فحص الكدرة , فحص المواد العالقة , قياس الــرقم الهيــدروجيني pH , قيــاس درجــة الحــرارة و

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الفحوصات البكتريولوجية . أن نتائج هذه الفحوصات تم تحليلها إحصائيا ً 0 ان معدل كفـــاءة الازالة للكدرة في المرحلة الاولى للتصاريف 1.3 , 1.1 و 0.9 م^3/ساعة كانت 92% , 94% و 95% على التوالي و المرحلة الثانية كانت 97%. أن هذه النتائج تبين فعالية الاداء العالية للمرشح الافقي الحصوي على ازالة الكدرة 0

1- Introduction

1-1: Background :-

Drinking water is supplied via surface and groundwater resources all around the world. Countries which are dependent on surface water resources as drinking water supply are always encountered with high amounts of colloidal, dissolved and suspended solids in the bulk of raw water. Accordingly , total costs of conventional drinking water treatment process including initial , operation and maintenance costs have been always under debate in these regions , especially ,in developing countries where supplying required chemicals as well as expert man power are posed as major controversial financial problems. This fact is more highlighted when we are dealing with small scale societies with low population where implementation of a multipart treatment system is not economically justified . **[1]**

1-2 :Roughing Filtration :-

Roughing filters have achieved peak turbidity removals roughly from 60 to 90%; generally, the more turbid the water initially, the greater the reduction that can be achieved. These filters can achieve also 60 to 90% reductions of coliform bacteria. Pilot studies on various roughing filter configurations (horizontal-flow, up-flow and down-flow) reduced faecal coliform bacteria by (93 -99.5%) . **[2]**.

A roughing filter is a coarse media (typically rock or gravel) filter used to reduce turbidity levels before processes such as slow sand filtration , diatomaceous earth (DE) or membranes filtration . **[3]**

Roughing filtration has the potential to be sustainable in small and rural communities. The absence of coagulation makes practical applications of roughing filtration limited to less than 150 NTU raw water with easily settled S.S. High turbidity and colloidal raw water is bound render roughing filters ineffective. **[4]**

1-3: Horizontal Flow Roughing Filtration :-

The main characteristics of the process are its horizontal flow direction and the graduation of the filter material. This specific flow direction enables to construct a shallow and structurally simple filter of unrestricted length. Three to four subsequent gravel packs, ranging from course to fine material; affect a gradual removal of the solids from the water. HRF is very similar to slow sand filtration. Since both filter techniques make use of natural purification processes, no chemicals are necessary to assist the treatment process. The installation of such filters requires only local resources such as construction material and manpower. Furthermore, no mechanical parts are required to operate or clean the filter. A well – designed filter combination will work for several months between two subsequent cleanings. [5]

The principal disadvantage of roughing filters is in emergence of the filter medium which is commonly gravel. Gravel may be unavailable in some locations and difficult to transport long distances because of its weight. [6]

Horizontal flow roughing filters (HRFs) have the simplest hydraulic filter layout of rouging gravel filters. The water runs from the inlet compartment in horizontal direction through a series of differently graded filter material separated by perforated walls. Filter cleaning is also carried out with hydraulic filter flushes. Either a single drainage gate or several gates can be opened simultaneously to achieve shock drainage of the entire filter. The top of HRF is dry and the free water table remains under the gravel surface in order to prevent algal growth. Due to their considerable filter length and silt storage capacity, HRF can handle raw water of high turbidity. [7]

1- 3-1 : HRF Technology :-

As illustrated in Figure (1), the significance is to improve the solid removal efficiency of sedimentation tanks. The fine solids crossing a rectangular sedimentation tank have to overcome a vertical settling distance of 1 – 3 m before coming into contact with the tank bottom. Due to small settling velocities, a large portion of the fine solids might not reach the tank bottom and hence, will not be separated. The same sedimentation tank can be filled with HRF material of approx. 4 – 20 mm. The fine solid particles flowing through the filter are now touching the gravel surface already after a few millimeters of settling distance. Since the settling distance is drastically reduced by the filter material, HRF is thus a more effective process for solids removal than plain sedimentation. [9]

1-3-2 : Main Features of a HRF :-

The schematic lay-out of HRF is illustrated in Figure (2). The filter is divided into three parts: the inlet structure, the filter bed and the outlet structure. In and outlet structures are flow control installations required to maintain a certain water level and flow along the filter as well as to establish an even flow distribution across the filter .The main part of a HRF consists of the filter bed composed of 3 to 4 gravel packs of different sizes fraction which range from coarse to fine . A single HRF unit might be appropriate for small water supply schemes treating water of periodically low turbidity. [5]

1-3-3 : The HRF Material :-

The coarse filter material, contained in the first part of the filter, retains all the large particles and the same the finer matter, while the last filter part with the finest filter material has to cope with the remaining smallest particles since the effluent of a HRF is virtually free from any solids .The coarse and most of the finer suspended solids are removed by the first filter pack (coarse gravel). A large pore volume should therefore be provided in this part of the filter. This is best achieved by locating a coarse filter material along a substantial part of the filter length. The subsequent filter material is of finer size and the packs of shorter length. The last filter fraction should only resume polishing functions as it is supposed to remove the last traces of the finest suspended solid found in the water. The average size of the gravel should not be smaller than 4 mm to enable regeneration of the filter efficiency. [5]

The filter material originally used is gravel, however, according to the laboratory results; it can be replaced by any inert, clean, insoluble and mechanically resistant material. [10]

The main advantage of HRF is that when raw water flows through it , a combination of filtration and gravity settling takes place which invariably reduces the concentration of suspended solid . In the direction of flow, water passes through various layers of graded coarse material in the coarse – fine – coarse sequences. Each layer of gravel is separated by a strong wire–mesh. [11]

1-3-4 : The HRF Cleaning :-

Drainage facilities are required for filter cleaning and filter efficiency regeneration. Filter efficiency decreases with progressive accumulation of solid matter in the filter. Hence, periodic removal of this accumulated matter restores filter efficiency and keeps the filter in good running condition.

HFR can be cleaned in two ways :

- Hydraulically.
- Manually.

Hydraulic Cleaning :

The natural drift of accumulated matter towards the filter bottom can be enhanced by filter drainage. The retained solids are washed down when the water level in the filter is lowered. The upper part of the filter bed is thereby cleaned and regenerated while an additional accumulation of solid mater takes place at the filter bottom. These solids can be flushed out of the filter by an adequate drainage system. It is very important to start the cleaning procedure at the first part of HRF (coarse gravel) as most of the solids are retained in this part of the filter. The time interval between two hydraulic cleanings can also be estimated by a mass balance of the solid matter . HRF should be cleaned hydraulically at a filter load of 10 g/L filter volume as filter efficiency decreases progressively thereafter .

Manual Cleaning :

It must be applied when the solids accumulated at the filter bottom or, at worst, all over the filter, can no longer be removed hydraulically. This occurs if a drainage system is absent under the filter bed, if proper hydraulic cleaning has been neglected or if solid matter has cohered to the filter material or at the bottom. A slimy layer might cover the filter material if there is biological activity in the filter caused by high loads of dissolved mater in the water. This biological layer will most probably increase the filter efficiency at the beginning, but will subsequently hinder the drift of deposited matter towards the filter bottom. [5]

HRF cleaning was intended to be carried out manually. This might be appropriate for small filter units and for situations where wash water disposal is difficult. However, the installation of a drainage system is still recommended since regular filter drainage restores the filter efficiency and prolongs the running time before manual filter cleaning is required. [8]

1-3-5 : Bacteria Removal by HRF :-

Pilot studies of various roughing filter configuration (HRF – URF –

DRF) reduced faecal coliform bacteria by 93 – 99.5%. [2]

HRF is not only used for improving the physical water quality in order to meet the slow sand filter (SSF) requirements but also for removing some bacteria and viruses ranging in size from approximately 10 to 20 µm and 0.4 to 0.02 µm , respectively . [4]

HRFs is also combined with a dynamic roughing filter to pretreat high turbidity events, and achieve faecal coliform removal of 86.3%. When followed by SSF, the removal reaches 99.8%, with an overall combined treatment efficiency of 4.9 – 5.5 log units. [12]

2- Field Work

HRF was built in Al-Wehda water treatment plant (for period from 29 / March to 14 / May / 2007) near the intake of the project as shown in Figure (3). This location is convenient for supplying raw water to the HRF**.** Design characteristics of the pilot of HRF are 2 m , 1.5 m and 1 m length for one , two and three compartment respectively , 0.5 m length for inlet and outlet , 1 m depth of filter and 1m width of filter .

The HRF was built from reinforced concrete with thickness (20 cm) for walls, (25 cm) for base and covering the internal surface of filter with layer of cement mixed with sica material for water proofing. The separation walls between each size of gravel were built from pierced bricks in vertical direction for crossing water through filter media horizontally.

For inlet , outlet and three drainage channels at the bottom of each gravel chamber of filter use pipes made from steel with diameter of aqQ(2 inch) and gate valve to control the flow .

As shown in Figure (4), the head loss between the inlet and outlet is (5 cm) to keep the top of HRF dry and the water level remains under the gravel surface in order to prevent algal growth. Both of head loss (ΔH) and the efficiency of removal are the two important factors for filter cleaning , in other words when the head loss increases to (5 cm) and the efficiency of removal decreases that means the voids between gravel are occlusion , this will be a sign to clean the filter **.**

2-1 : Filter Media :-

The choice of media sizes and the length of the three compartments of the HRF was according to [5] .The filter is filled with the following gravel size **:**

1- First compartment (2 m) 15 mm. (coarse)
2- Second compartment (1.5 m) 10 mm (medium)
3- Third compartment (1m) 5 mm . (fine)

2-2 : *<u>Operation of System :-</u>*

The filter is operated continuously (24 hr a day) . The system is operated in two stages according to the quality of the influent as follows :

1- The 1st stage : Raw water (free from any addition) , by using three different discharges ; 0.9 , 1.1 , and 1.3 m^3/h .
2- The 2nd stage: Coagulated water (raw water + alum), with discharge 1.3 m^3/h.

2-3: Cleaning of HRF :-

Cleaning of HRF is very simple this is done by opening the drainage valve at the bottom of each compartment with maximum flow rate to remove the settling materials in the HRF.

To know that the filter needs cleaning, the measurement of the head losses (ΔH) and turbidity level must be done continuously.

3- Experimental Work

The experimental work during the months of May to July / 2007 depend on the experimental tests of influent (raw water) and effluent (filtered water) from HRF by measuring the important parameters : turbidity , S.S , pH , Temp. and bacteriological tests .All apparatuses are calibrated before using them in this research.

4- Results and Discussion:

4-1:Turbidity :

4-1-1: Turbidity data for 1st Stage (raw water):

Figures (5), (6) and (7) show the effect of the HRF on raw water turbidity for three influent discharges 1.3, 1.1 and 0.9 m^3/h respectively. The level of raw water (influent) spanning from 56 to 307 NTU. The level of effluent water turbidity (filtered water) spanned from 1.8 to 51 NTU. At last days of operation period, the effluent turbidity became within the limits of Iraqi standard (5 NTU).

Figure (5) shows that the removal efficiency spanned from 83% at the beginning of the continuous operation to 96% at the end of the operation (26 days) .The mean is found to be 92%. Modification of removal efficiency with time is due to the size reduction of voids of filter media (gravel). Also this figure indicates that on 23/May/2007 , the level of effluent turbidity is rises to 51 NTU and the head losses of (ΔH = 5 cm) rise to 9.5 cm and the removal efficiency decreases to 77% , this means that the HRF must be cleaned .

Figure (6) shows the removal efficiency spanned from 90% to 96%, and the mean is found to be 94%. This figure shows that the HRF did not need to clean at all this operation period (10 days)

Figure (7) shows that the HRF does not need to be cleaned during all the operation period (10 days). The removal efficiency spanned from 90% to 97%, and the mean is found to be 95%.

4-1-2:Turbidity data for 2nd Stage (coagulated water):

Figure (8) shows the effect of the HRF on influent water (coagulated water) turbidity, when the influent discharge was 1.3 m^3/h for period 18 days. The level of the influent water turbidity spanned from 71 to 192 NTU. The level of the effluent water turbidity (filtered water) spanned from 0.8 to 6.6 NTU. The figure shows clearly that the levels of the effluent turbidity are within the limits of Iraqi standard (5 NTU) . This high modification in removal efficiency is due to the alum presence which helps the suspended solids to flock and settled quickly. The removal efficiency spanned from 95% to 99% and the mean is found to be 97%.

From above it is clear that the treatment of coagulated water as a comparison with the first stage (raw water) is better.

Also figure (8) shows that on 18/June/2007 the effluent turbidity rise to 5.9 NTU and the head losses (ΔH = 5 cm) rise to 11 cm and the removal efficiency decreases to 95% that means the HRF must be cleaned. For worth mentioning in this stage the HRF needs to be cleaned more than in the first stage. This is due to the coagulated mater is within the influent water.

4-2 :Suspended Solids :-

4-2-1: S.S Data for 1st Stage (raw water) :-

Figures (9), (10) and (11) show the effect of the HRF on raw water S.S . For three influent discharges 1.3, 1.1 and 0.9 m^3/h respectively. It is observed that the S.S values for raw water fluctuated between 32 mg/L and 168 mg/L , which indicates the high concentration of S.S in Tigris River . The S.S of the effluent water (filtered water) ranged from 1 mg/L to 15 mg/L.

It is important to note from these figures the good ability of HRF to removal of S.S , whereas the removal efficiency ranged from 86% to 98% and the mean is found to be 93% .

4-2-2: S.S Data for 2nd Stage (coagulated water):

Figure (12) shows the effect of the HRF on influent water (coagulated water) S.S, when the influent discharge was 1.3 m^3/h .It is observed that the S.S values for raw water fluctuated between 43 mg/L and 115 mg/L, which indicates the high concentration of S.S in Tigris River. The S.S of the effluent water (filtered water) ranged from 1 mg/L to 5 mg/L. It is important to note the removal efficiency with coagulated water as a comparison with the first stage (raw water) is better. The removal efficiency spanned from 95% to 98% and the mean is found to be 96%.

4-3: Bacteriological Tests :-

4-3-1: Bacteriological Tests Data for 1st Stage (raw water) :-

Figure (13) shows the ability of HRF to reduce (treatment) T.P.C, Total Coliform and E.Coli with time, when the discharge of influent is 1.3 m^3/hr. The T.P.C/ml values of raw water (influent) spanned from 400 cell/ml to 42 400 cell/ml , the T.P.C/ml values of effluent (filtered water) spanned from 300 cell/ml to 5000 cell/ml and the removal efficiency ranged between 25% to 88% .

The M.P.N of Coliform/100ml values of raw water (influent) spanned from 2000 cell/100ml to 70 000 cell/100ml , the M.P.N of Coliform/100ml values of effluent (filtered water) spanned from 200 cell/100ml to 14000 cell/100ml and the removal efficiency ranged between 65% to 90% .

The M.P.N of E.Coli/100ml values of raw water (influent) spanned from 9 cell/100ml to 40 000 cell/100ml , the M.P.N of E.Coli /100ml values of effluent (filtered water) spanned from 9 cell/100ml to 20 000 cell/100ml and the removal efficiency ranged between 0% to 90%

4-3-2:Bacteriological Tests Data for 2nd Stage (coagulated water):-

Figure (14) shows the ability of HRF to reduce (treatment) T.P.C, Total Coliform and E.Coli with time, when the discharge of influent is 1.3 m^3/hr.

The T.P.C/ml values of influent water spanned from 2000 cell/ml to 16 800 cell/ml , the T.P.C/ml values of effluent (filtered water) spanned from 800 cell/ml to 2624 cell/ml and the removal efficiency ranged between 31% to 93% .

The M.P.N of Coliform/100ml values of influent water spanned from 2000 cell/100ml to 70 000 cell/100ml, the M.P.N of Coliform/100ml values of effluent (

filtered water) spanned from 0 cell/100ml to 13000 cell/100ml and the removal efficiency ranged between 81% to 100% .

The M.P.N of E.Coli/100ml values of influent water spanned from 100 cell/100ml to 20 000 cell/100ml , the M.P.N of E.Coli /100ml values of effluent (filtered water) were always 0 cell/100ml and that means the removal efficiency was 100% .

It is important to note that the results of bacteriological tests of this stage (coagulated water) as a compared with the first stage (raw water) are better.

3- Conclusions

From the results demonstrated in this study , the following conclusions could be drawn :

1- The HRF has a good performance in treating turbidity of raw water and coagulated water (Tigris River), whereas the mean of removal efficiency of turbidity ranges between 92% and 97 % .

2- The HRF has a good performance in treating S.S of raw water and coagulated water, whereas the mean of removal efficiency of turbidity spanned from 93% to 96 % .

3- The HRF has a good removal efficiency of pathogens by reducing E- Coli , Coliform and total plate count of raw water and coagulated water , whereas the mean of removal efficiency of turbidity ranges between 25% and 100 % .

4- The value of removal efficiency and the head loss are the most important criteria for filter cleaning . The cleaning of HRF is very simple as compared with the other types of filters , the HRF works for a long times (many days) between two subsequent cleanings.

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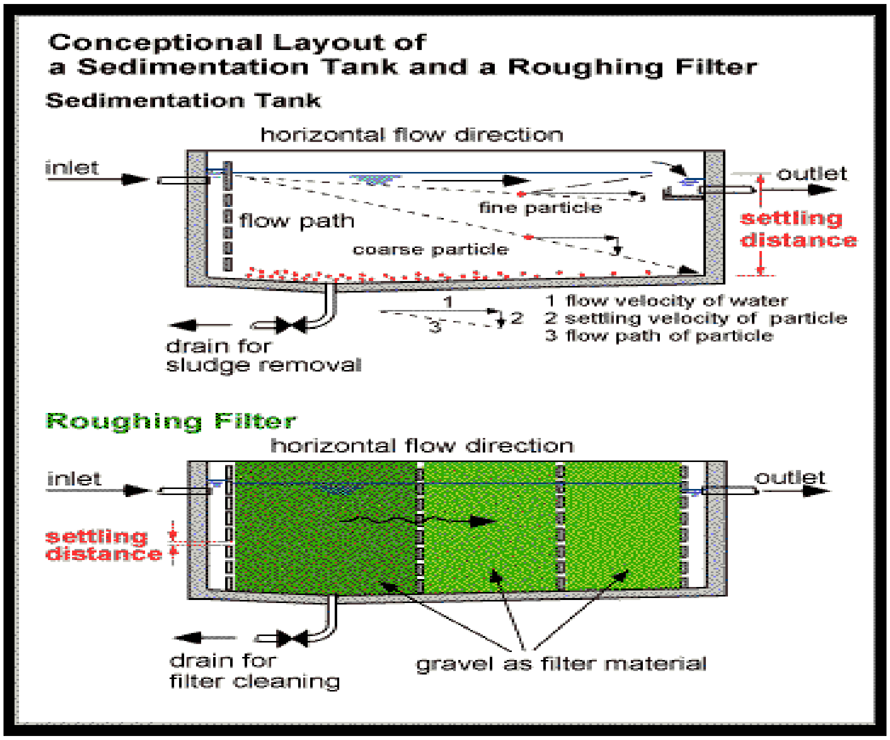

Figure (1) Application of HRF and the idea behind it (RWT , 1998)

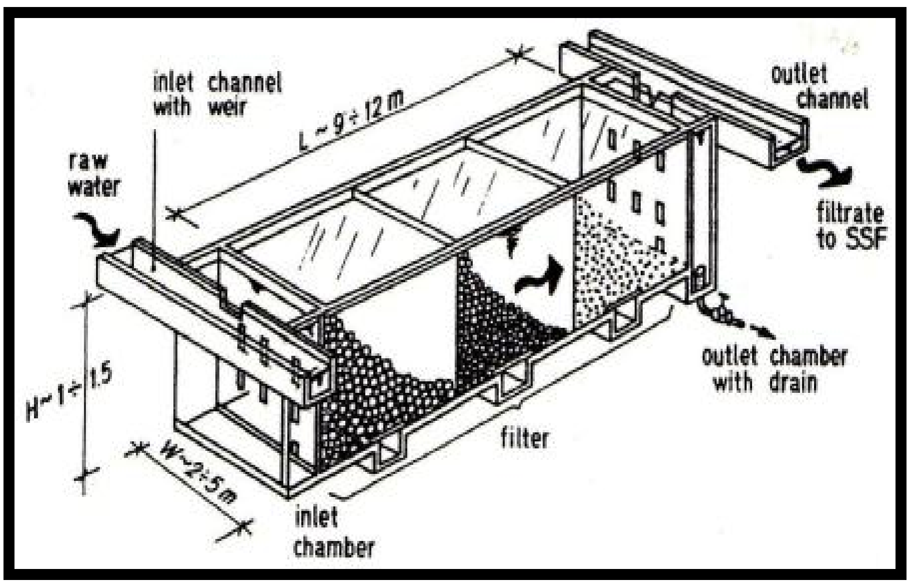

Figure (2) Main Features of HRF (Wegelin , 1986)

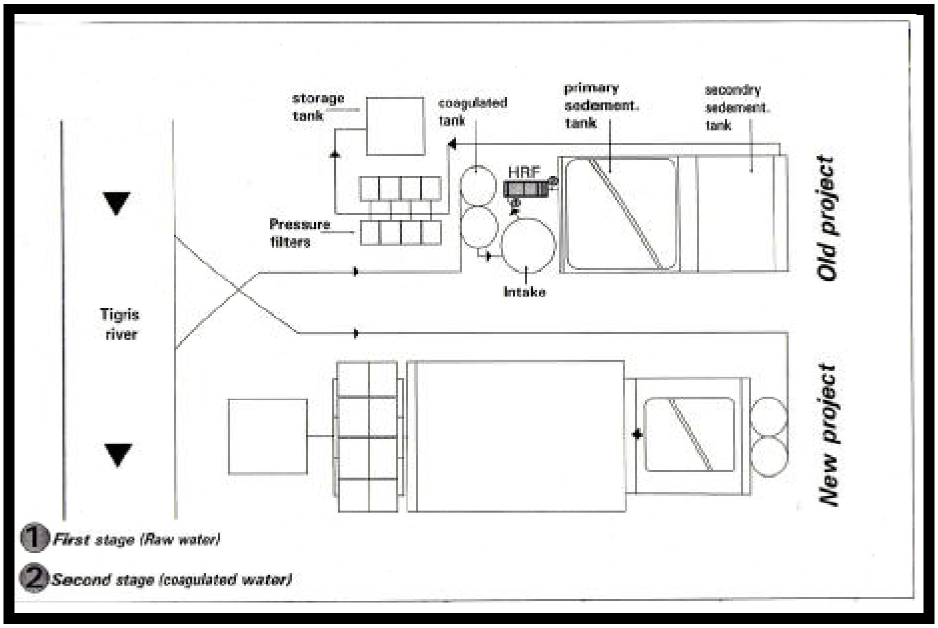

Figure (3) The layout of Al-Weda Plant for Water Treatment with the location of HRF

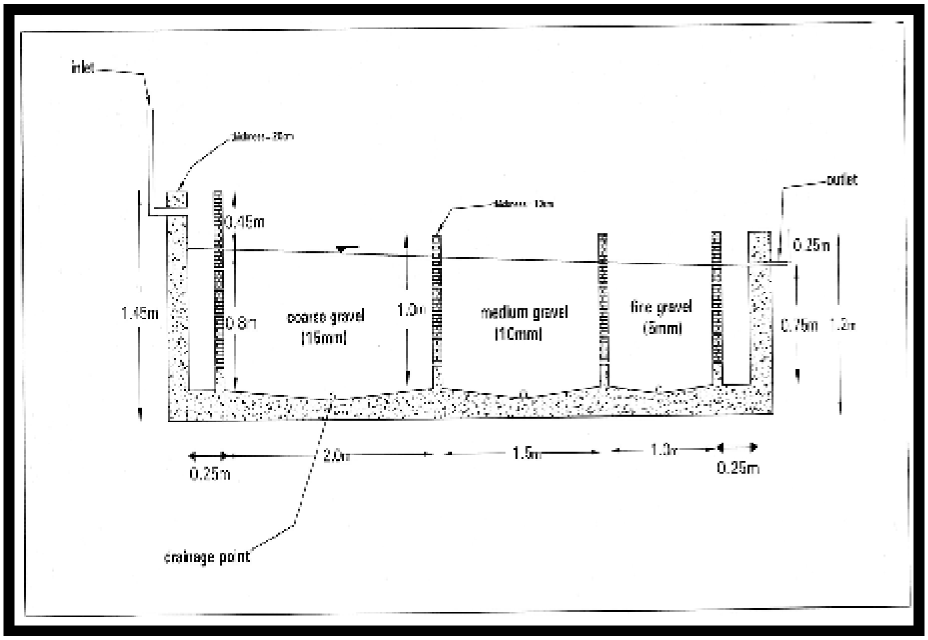

Figure (4) Layout of the Horizontal flow Roughing Filtration (HRF)

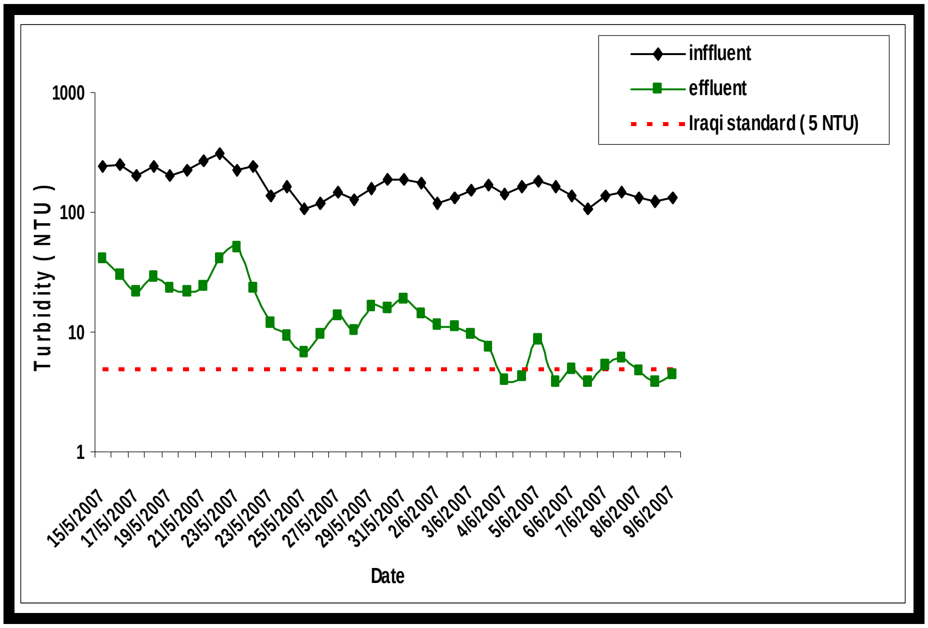

Figure (5) Treatment of the raw water turbidity with time when $Q = 1.3\ m^3/h$

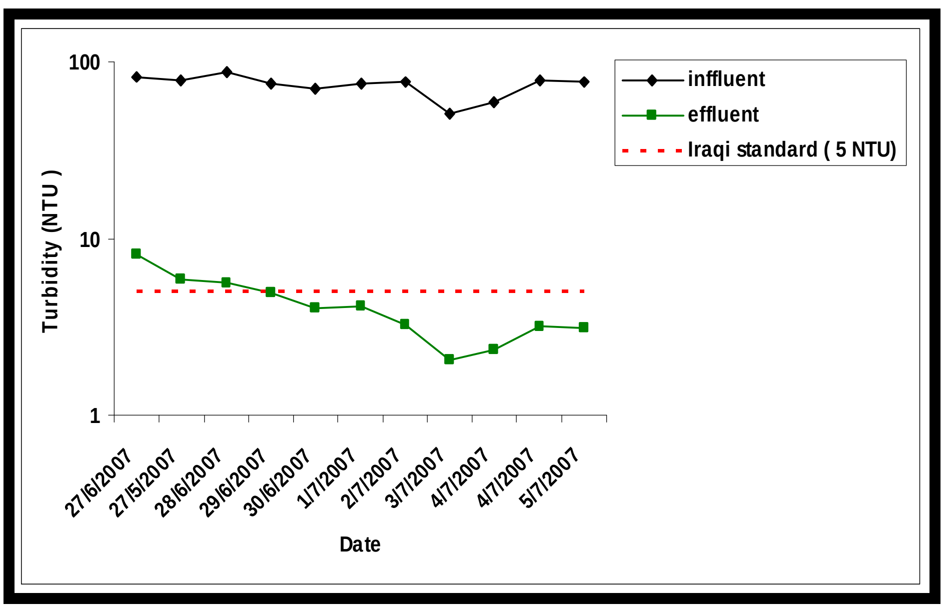

Figure (6) Treatment of the raw water turbidity with time when $Q = 1.1\ m^3/h$

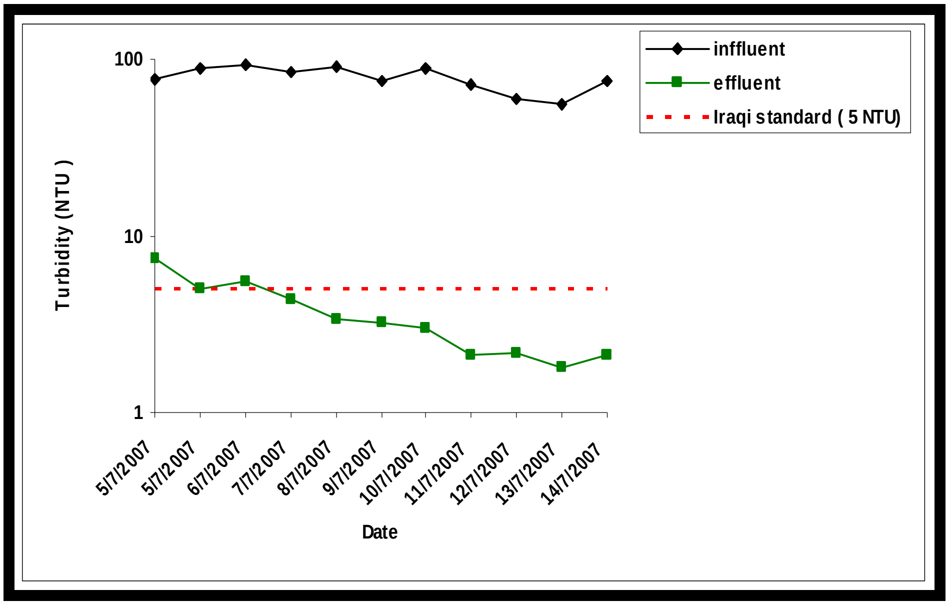

Figure (7) Treatment of the raw water turbidity with time when $Q = 0.9\ m^3/h$

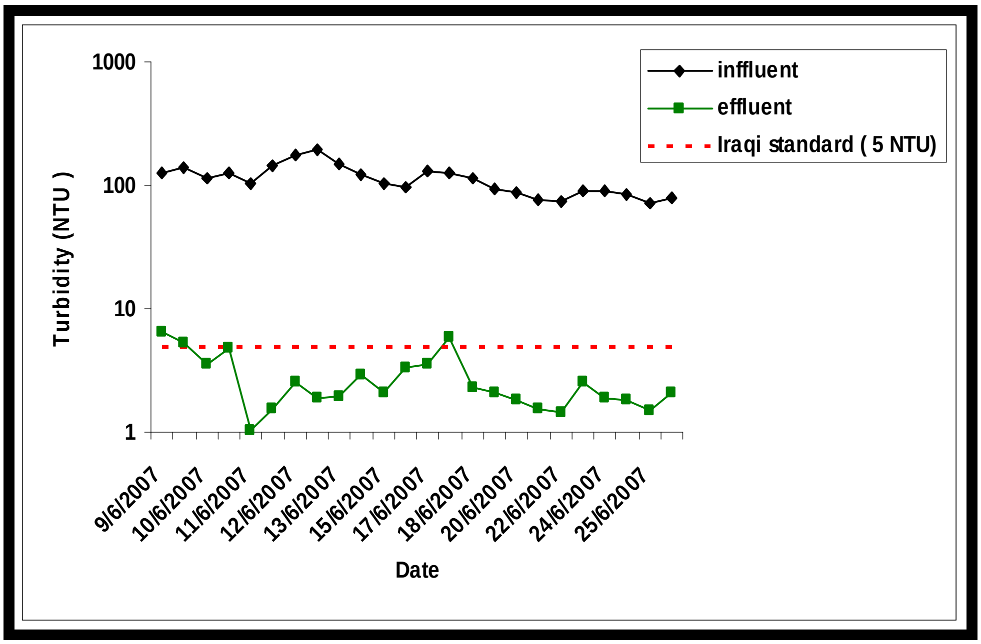

Figure (8) Treatment of the coagulated water turbidity with time when $Q = 1.3\ m^3/h$

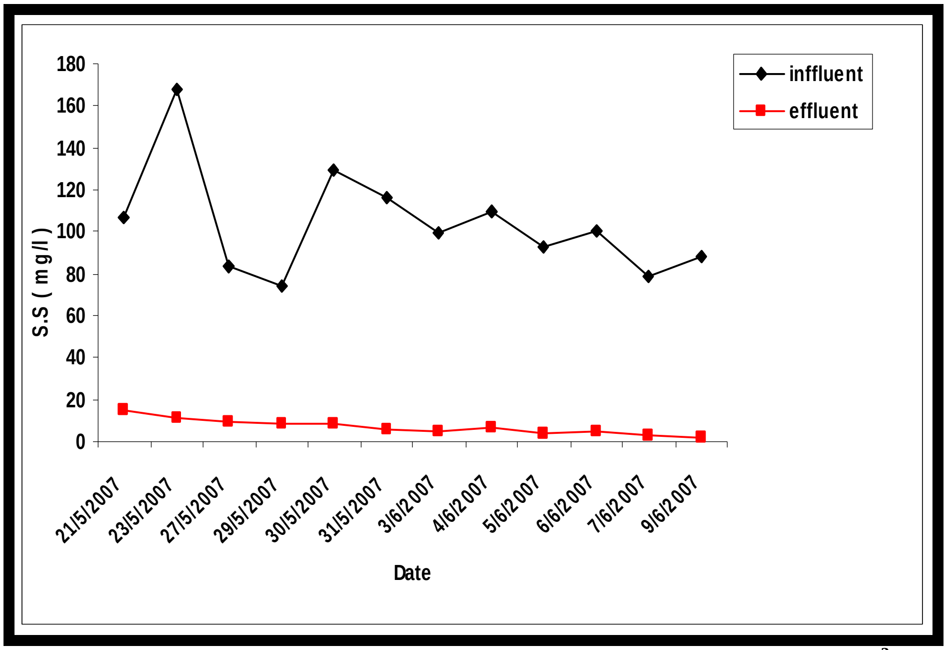

Figure (9) Treatment of the raw water S.S with time when Q = 1.3 m^3/h

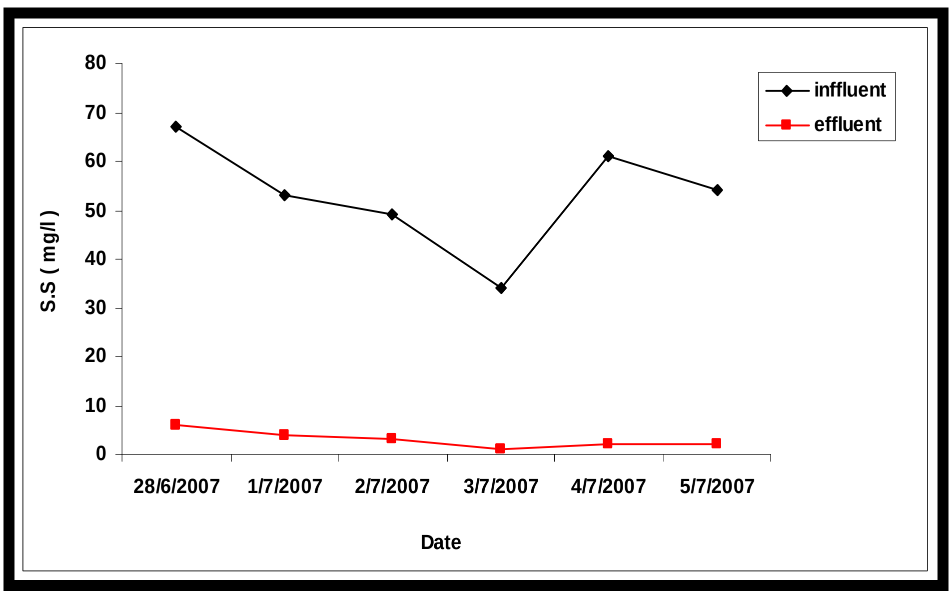

Figure (10) Treatment of the raw water S.S with time when Q = 1.1 m^3/h

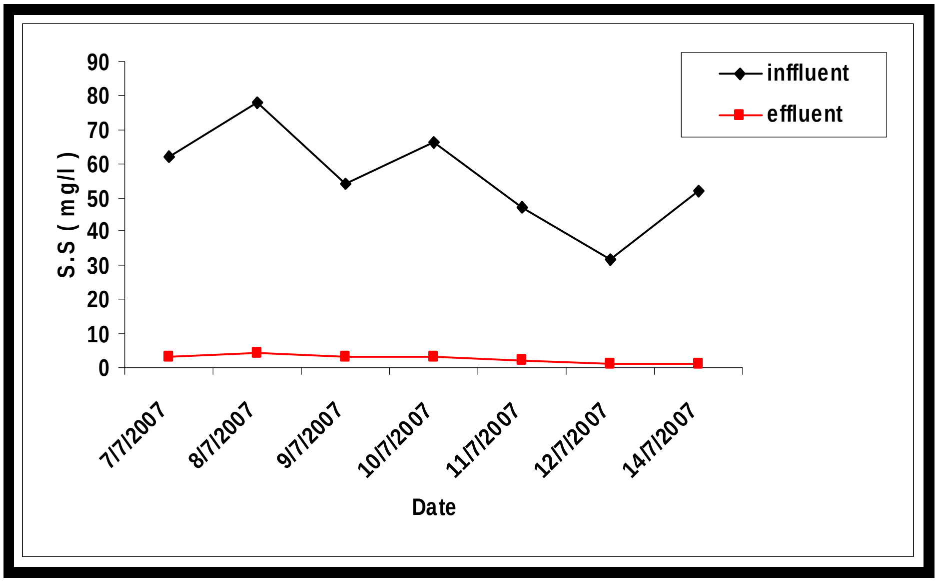

Figure (11) Treatment of the raw water S.S with time when $Q = 0.9\ m^3/h$

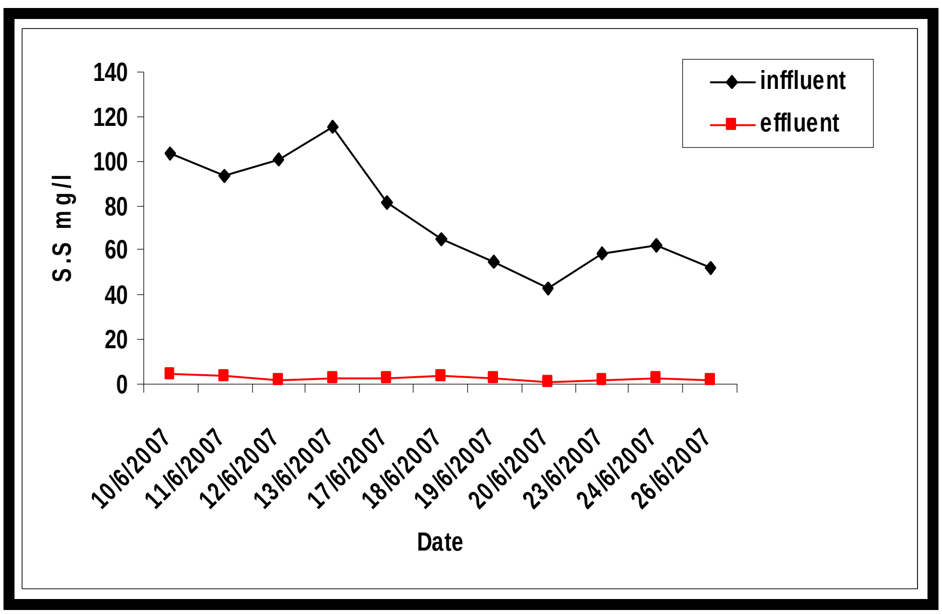

Figure (12) Treatment of the coagulated water S.S with time when $Q = 1.3\ m^3/h$

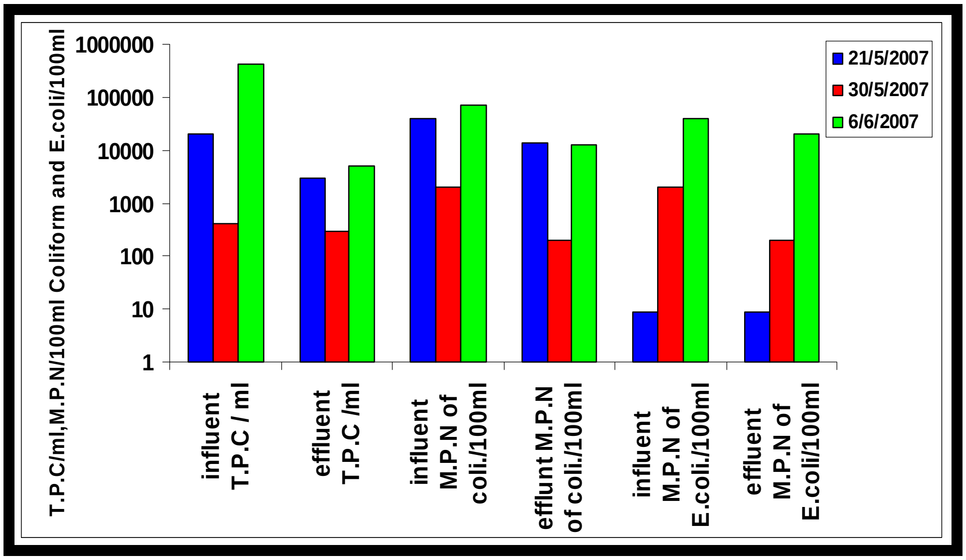

Figure (13) Bacteriological treatment of the raw water with time when Q = 1.3 m^3/h

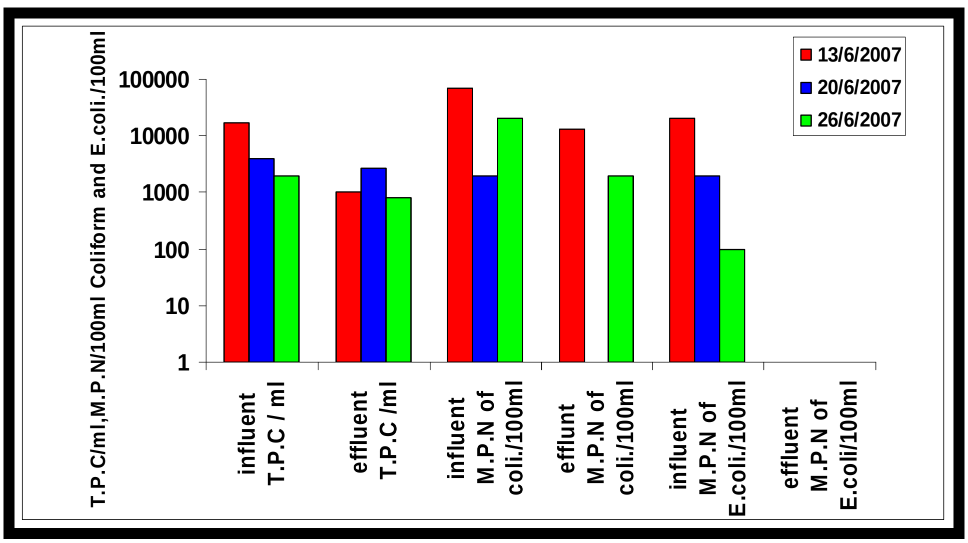

Figure (14) Bacteriological treatment of the coagulated water with time when Q =1.3 m^3/hr