ترشيح ثلاثي لمياه الصرف الصحي باستخدام رمل محلي

وليد محمد كامل زاهــد

قسم الهندسة المدنية، كلية الهندسة، جامعة الملك سعود، ص ب ٨٠٠

الرياض ١١٤٢١، المملكة العربية السعودية

(مجلة جامعة الملك سعود للعلوم الهندسية، ١٦ (١)، ص ص: ٢٣-٣٦، ٢٠٠٣م)

ملخص البحث. يتوقع أن يزداد استعمال الترشيح الرملي السريع للمعالجة الثلاثية لمياه الصرف الصحي في المملكة العربية السعودية بتطبيق النظام المعتمد حديثا لمياه الصرف الصحي المعالجة وإعادة استعمالها. وحيث أن معظم محطات المعالجة الثلاثية تستعمل حالياً رملاً مستورداً، فان هذا المشروع البحثي يهدف إلى البحث عن رمل محلي مناسب للترشيح الثلاثي ومن ثم تقييم أدائه في ترشيح مياه الصرف الصحي بإجراء تجارب ترشيح حقلية.

وباختبار عينات رمل من مدينتي الرياض وحائل يتراوح حجم حبيباتها بين ١,١ و٣,٣ ملم لمعرفة مدى موافقتها لمواصفات المواد المرشحة، تبين موافقة رمل حائل للمواصفات. وطبقا للتحليل الحبيبي بالمناخل فان المقاس المؤثر ومعامل انتظام حبيبات الرمل بلغ ١,٨ ملم و١,٤٤ على الترتيب.

وقد أوضحت نتائج تجارب الترشيح بمعدلات ٤، ٨، و١٢ م/ساعة أن رمل حائل مناسب لترشيح المياه المُعالجة حيويا بالمرشحات الحيوية بعد ترسيبها. فعند معدلات الترشيح ٤ و ٨ م/ساعة بلغ أقصى تركيز للمواد الصلبة العالقة والعكارة في المياه المرشحة ٩ ملجرام/لتر و ٣ وحدة عكارة نفلومترية على الترتيب، محققة بذلك مواصفات جودة المياه المعالجة لأغراض الري غير المقيد والأغراض الترفيهية. وبترشيح المياه بمعدل ١٢ م/ساعة أمكن الحصول على مياه مرشحة بمواد عالقة مطابقة للمواصفات بينما تجاوزت قيم العكارة المواصفة قليلا.

Tertiary Filtration of Wastewater Using Local Sand

Waleed M Zahid
Civil Engineering Department, College of Engineering
King Saud University, P.O. BOX 800, Riyadh 11421, Saudi Arabia
wmzahid@ksu.edu.sa (2003)
(Journal of King Saud University, Vol. 16, Engineering Sciences (1), pp. 23-36, 2003)

Abstract

The use of rapid sand-filtration for tertiary treatment of wastewater in Saudi Arabia is expected to increase dramatically with the implementation of the lately approved Saudi code of reclaimed wastewater and reuse. Almost all-existing tertiary wastewater-treatment plants in the Kingdom utilize imported sand for filtration. The objectives of this research project were to search for appropriate local sand, and to assess its performance in tertiary filtration of wastewater by conducting a pilot-scale filtration study.

Sand samples with a size range of 1.1-3.3 mm from Riyadh and Hail cities were tested for conformity to AWWA standards for filtering materials. Hail sand was found to meet the requirements of the standards. According to sieve analysis, the effective size and uniformity coefficient of Hail sand averaged 1.8 mm and 1.44, respectively.

Results of the pilot study at three filtration rates of 4, 8, and 12 m/hr, have shown that Hail sand is suitable for filtration of settled stone-trickling-filter effluents. At the rates of 4 and 8 m/hr, effluent suspended solids (SS) concentrations and turbidities as high as 9 mg/L and 3.0 NTU were obtained, satisfying the Saudi reuse quality criteria for unrestricted irrigation and recreational purposes. Results of filtration at the rate of 12 m/h showed that the turbidity criterion was exceeded slightly but the SS criterion was met.

1- Introduction

Reuse of wastewater often requires, after the conventional secondary processing, advanced/tertiary treatment so as to meet stringent water quality objectives for reuse and to protect public health. Among advanced treatment processes, gravity granular-media filtration has clearly emerged as one of the most efficient and simple processes for removing suspended and colloidal materials including pathogenic microorganisms [1]. Tertiary filtration involves passing secondary treated wastewater through a stationary bed of granular media of silica sand, anthracite coal, or garnet sand used singly or in combination.

In Saudi Arabia, some of the existing wastewater treatment plants are now employing rapid sand filters after the secondary stage of treatment for improving the quality of plants` effluents before discharge or reuse [2]. These plants utilized imported sand with the exception of the Riyadh Wastewater Treatment Plant, which uses local sand procured from the eastern province of the Kingdom. The use of sand filtration in the Kingdom wastewater treatment plants is expected to increase significantly with the implementation of the lately approved Saudi code of reclaimed wastewater and reuse which requires the use of tertiary sand filtration for unrestricted irrigation and recreational purposes [3].

Granular media filtration of wastewater is a complex process as the effectiveness of the process is dependent on many interrelated variables and thus there is no generalized approach to the design of full-scale filters [4]. The most important design factors are the characteristics of the filter media including type of filter media, grain size and gradation, properties of wastewater solids to be filtered, and the rate of filtration. Generally, pilot scale studies are usually undertaken to evaluate the performance of the filter media to be used for filtering the wastewater in question. In the absence of a pilot study, the design must be based on experience with similar filter influent wastewater at other installations.

Although dual- and multi-media filtration systems are becoming more popular particularly in the United States [5], mono-media deep-bed filtration is still widely used for tertiary treatment of wastewater [6]. Mono-media are favored over dual- or multi-media because of simplicity of construction and operation and longer filtration runs [7-8]. Deep rapid filters, now in use, typically involve sand depths up to 2.0 m with an effective size ranging from 2.0 to 3.0 mm and uniformity coefficient of 1.2-1.6 [4]. If bed is to be backwashed by water alone, a uniform medium {uniformity coefficient of less than 1.3 [5]} is best for allowing full use of the bed but high backwash velocities are required to fluidize the bed for effective cleaning. If the medium is composed of grains of varying sizes, a combined air-water backwash is required to avoid the stratification of the non-uniform medium. The random pore size distribution through the bed depth will increase the potential for the removal of suspended particles in the lower portions of the filter, resulting in longer filter runs. Filtration rates for gravity mono-medium filters used for tertiary treatment of wastewater range from 5 to 24 m/h [4]. The length of filter runs should be a minimum of 6 hr to avoid excessive use of wash water and shorter than 40 hr to reduce bacterial decomposition of organics trapped in the media [9]; these limits provide an average run length of about 24 hr.

Al-Jadhai and Misbahuddin [10] tested the characteristics of local sand obtained from Al-Safaniyah in the eastern province of Saudi Arabia, and performed a field pilot-filter study to estimate the performance of this sand in tertiary filtration of wastewater from an activated sludge plant in Riyadh city. In their work, the effective size and uniformity coefficient of the sand were found to be 2.4 mm and 1.2, respectively, with a size range of 2.0-3.4 mm. Operating a pilot filter at three filtration rates of 2, 4, and 20 m/h, they showed that the sand could be used for tertiary filtration of wastewater to produce good quality effluents. In another pilot study [11], the previous sand was evaluated for tertiary filtration of trickling filter effluents with an objective to determine optimum values for flow rates and media depths relevant to local conditions. Results showed that filtration rates of 8 and 12 m/h can be used as an average and peak filtration rates, respectively. Increasing media depth beyond 100 cm had little if any effects on filtration efficiency.

2- Objectives

The objectives of this research project were:

- To search for an alternative local sand, other than Al-Safaniyah sand, with properties conforming to specifications and characteristics of sands used for tertiary filtration of sanitary wastewater, and
- To assess the suitability of the selected sand for tertiary gravity-filtration of sanitary wastewater. The availability of such sand from locations other than Al-Safaniyah is of significance in terms of money and time saving.

3- Materials and Experimental Methods

3-1 Filter Sand Procurement and Testing

Sand samples in the size range of 1.1- 3.3 mm were procured from two different locations at Al-Thumamah area, north of Riyadh city, and from Al-Rasaf tributary 25 km south west of Hail city. Samples were tested, in the Environmental Engineering Laboratory of King Saud University, for acid solubility, specific gravity, sieve analysis, organic impurities, and fine particles less than 75 micrometers in size. All tests were performed in duplicates for accuracy, and in accordance with the methods of the American Water Works Associations Standard for Filtering Material B-100-80 [12]. The porosity of sand medium was also determined experimentally on the basis of an immersion procedure in water.

3-2 Pilot Filtration System

To investigate the performance of the selected sand in tertiary filtration of wastewater, a pilot filtration system was designed and set-up in the Environmental Engineering Research Station which is adjacent to King Saud university Wastewater Treatment Plant (KSUWWTP). The system incorporates a filtration column mounted on a steel stand, and a 2-m^3 water tank receiving settled secondary effluent from the final-clarifier effluent chamber of the KSUWWTP. The tank was equipped with a mixer to keep all but heaviest solids in suspension. A pump was used to feed the filtration unit continuously from the tank at constant flow rate. Fig. 1 shows a schematic diagram of the experimental arrangement of the pilot filtration system.

The filtration column was made of transparent Plexiglas, 9 cm by 9 cm in cross sectional area and 2.5 m in height. The sand was packed in the column to a height of 98 cm over a 9-cm layer of gravel with size range of 5 to 8 mm. Seven piezometers were installed along the filter media at 3, 13, 28, 43, 58, and 88 cm from the top of the media. Another piezometer was installed 2 cm above the media. Filtrate sampling ports were also provided at the same depths.

3-3 Experimental and Analytical Procedure

Filtration experiments were carried out at three different filtration rates: 4, 8, and 12 $m^3/m^2.h$. Prior to each filtration run, the filter medium was backwashed three to four times with tap water so that the sand became stratified after settling. The filter was then operated with tap water until the water level above the sand surface became stable. Thereafter, the filtration experiment started with settled secondary effluent and continued until the available water head was exhausted (the maximum level the water can reach in the column – the level of the filter effluent tube). It should be noted that the effluent tube was raised to a level close to the sand surface so as to prevent the development of negative pressure in the medium during filtration. Head losses at different medium depths were measured continually during the course of filtration. Samples of filter influent and effluent were collected periodically and analyzed for turbidity, suspended solids (SS), chemical oxygen demand (COD), pH, and temperature. Samples of filtrates at different depths of the medium were also collected regularly and analyzed for turbidity.

Turbidity measurements were carried immediately after sample collection utilizing a HACH Co., Model Ratio/XR Turbidimeter. Samples for SS and COD were collected in glass bottles, acidified with sulfuric acid to pH of about 2.0, and stored in a cooler filled with ice until they were transported the day after to a laboratory for analysis. All analyses were performed according to procedures described in the Standard Methods for the Examination of Water and Wastewater [13].

3-4 King Saud University Wastewater Treatment Plant (KSUWWTP)

The KSUWWTP is designed to treat an average flow of 10,000 m^3/day. The plant treats sanitary wastewater generated within the university campus. It provides preliminary, primary, and secondary treatment in addition to chlorination. The preliminary stage consists of pre-aeration, comminuting, bar screening, and grit removal. The primary treatment includes two plain-sedimentation tanks. The secondary treatment is provided by four trickling-filters (stone media) in conjunction with two clarifiers. The treated wastewater is also chlorinated before it is being used for landscape irrigation and/or for cooling purposes.

During the course of the study, only one of the primaries, two of the trickling filters, and one of the final settling basins were in operation due to wastewater shortage. The plant inflow ranged from 4315 to 7210 m^3/day with an average of 5706 m^3/day.

According to the plant measurement, the primary-influent BOD was in the range of 118-197 mg/L; the final effluent BOD and SS were in the range of 15.2-45 mg/L and 5-12 mg/L, respectively.

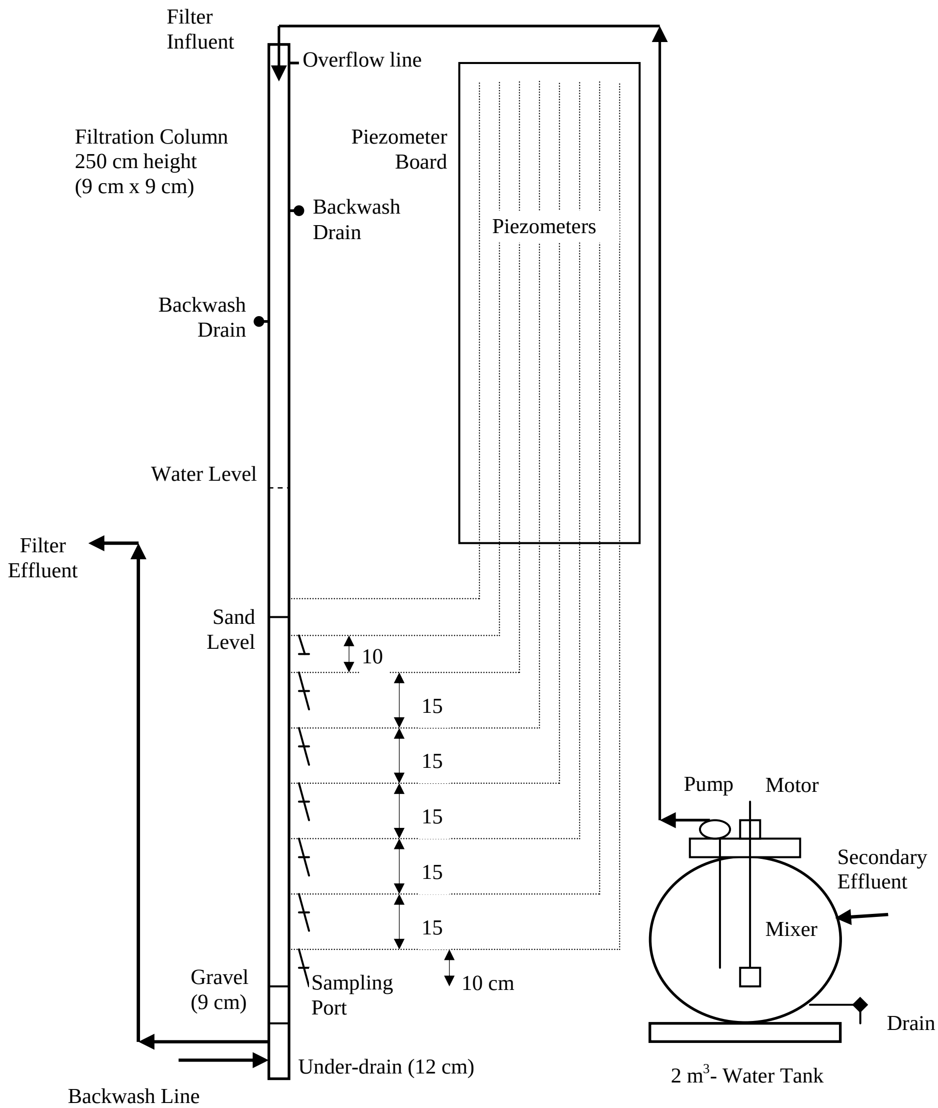

Fig. 1. Schematic diagram of pilot filtration system

4- Results and Discussions

4-1 Sand Characteristics

Sand samples obtained from Al-Thumamah area north of Riyadh were found unsuitable for tertiary filtration as they contained significant quantity of acid soluble materials (20%-22%), exceeding the maximum allowable limit of acid solubility set by the AWWA standards of 5%. However, sand samples from Al-Rasaf in Hail city satisfied the AWWA standards for filtering materials. Therefore, Hail sand was then subjected to pilot filtration to test its suitability for tertiary filtration of wastewater. Table 1 presents results of tests conducted on two samples of Al-Rasaf sand, along with the recommended limits required by the AWWA standards for filtering materials B 100-80 [12].

Table 1. Results of tests conducted on Al-Rasaf sand from Hail city

Test	Sample no. 1	Sample no. 2	AWWA Standards (B 100-80)
Sieve analysis			
Effective size (d_{10}), mm	1.8	1.8	-
Uniformity coefficient	1.44	1.44	-
Size range, mm	1.1 - 3.3	1.1 - 3.3	-
Acid solubility	0.88%	1.10%	< 5%
Specific gravity	2.59	2.60	> 2.5
Organic impurities	Lighter than standard	Lighter than standard	Lighter than standard
Fine particles	0.06%	0.08%	< 2%
Porosity of sand medium	43%		-

4-2 Pollutants Removal

Table 2 summarizes influent and effluent water qualities of the sand filter at the filtration rates of 4, 8, and 12 m/h. As can be seen, influent concentrations were not controlled and differed in each experiment as conditions at the treatment plant changed. Comparisons of filter performance at these filtration rates are shown in Fig. 2 on the basis of average values of turbidity, SS, and COD, and their removal efficiency. It is apparent from Table 2 and Fig. 2 that solids loadings on the filter operating at the rates of 8 m/h and 12 m/h were higher than that at the rate of 4 m/h. On the average, the influent turbidity and SS for the rate of 8 m/h and 12 m/h were 8.6 NTU and 35 mg/L, and 10 NTU and 15 mg/L, respectively. As for the rate of 4 m/h, the corresponding values were 4.8 NTU and 11 mg/L. Nonetheless the removal efficiencies for all quality parameters at the rate of 8 m/h were better than those at the other rates. The turbidity, SS, and COD removal efficiencies at the rate of 8 m/h averaged 85%, 72%, and 43%, respectively. The average removal efficiency values for the same parameters at the rate of 4 m/h were 70%, 50%, and 40%, and were 45%, 56%, and 29% at the rate of 12 m/h. In terms of temperature and pH, no substantial differences were observed between influent and effluent values during all the experiments.

Table 2. Influent and effluent water qualities of sand filter at different filtration rates

Filtration Rate (m/h)	Turbidity (NTU)		SS (mg/L)		COD (mg/L)		Temperature (^oC)		pH	
	In	out	in	out	in	out	In	out	in	out
4	3.2–6.6	0.64-3	10-14	3-8	28-52	12-36	25-27	24-27	7.5-7.8	7.5-7.7
8	7.2-10.1	0.65-1.8	20-46	8-9	28-40	13-28	24-27	25-27	7.5-7.7	7.5-7.6
12	7.3-13.9	2.9-7.9	14-16	5-8	92-96	64-70	23-27	23-27	7.5-7.8	7.6-7.9

SS: suspended solids – COD: chemical oxygen demand

The available literature indicates that for a given filter media, both the filtration rate and influent concentration affect the effluent quality attainable and headloss development although the effects vary depending on the experimental and/or operational conditions used. Based on the results of many tests, Culp et al. [14] stated that the effluent quality produced by plain filtration of secondary effluents is essentially independent of filter rate within the range of 12-37 m/h because of the high strength of biological flocs as compared to weaker flocs resulting from chemical coagulation. Also, Dawda et al. [15] found that increasing the filtration rate from 7 to 15 did not affect suspended solids removal. Darby et al. [16], however, found that doubling the filtration rate from 6.5 to 13.3 m/h reduced slightly the removal efficiency but resulted in more uniform capture throughout the filter depth and less overall increase in headloss due to the deeper penetration of particles into the bed before capture. According to Cikurel et al. [6] the overall turbidity removal is higher for higher initial turbidities for a given filtration rate. During both early stages of filtration (i.e. pre-ripening and ripening stages) and the post-ripening stage, removal efficiency increases with an increase in influent concentration [17].

It should be noted here that ripening, that is, increased solids removal with time, was observed to occur in all filtration experiments. Nonetheless, it was more apparent with the filtration rate of 4 m/h. In addition, no solids breakthrough was obvious with any of the three filtration-rates employed.

Data examination revealed also that for filtration rates of 4 and 8 m/h, the filtration efficiency based on turbidity was higher than that based on suspended solids removal (70% vs. 50% for the rate of 4 m/h, and 85% vs. 72% for the rate of 8 m/h). As turbidity is more affected by small particles and suspended solids by larger particles, these results are indirectly indicating the preferential removal of small particles when operating the media at the filtration rates of 4 and 8 m/h. However, the turbidity removal for the rate of 12 m/h was lower than the SS removal, and in fact was the lowest in comparison with turbidity removals for other rates (4 and 8 m/h); 45% vs. 70% and 85%, respectively. But it should be noted that filter influent for the rate of 12 m/h was much more turbid, and thus contained more small particles, than influents for the other rates (10 NTU vs. 4.8 NTU and 8.6 NTU on the average). Pertinent studies indicate that solids removal efficiency depends on the size of suspended solids, and there is a critical particle size of about 1-2 micrometers for which filter removal efficiency is a minimum but removal increases with an increase in particle size particularly during the post-ripening stages of filtration [16, 18-21]. Exploring operational problems with the use of granular-media filters for wastewater treatment, Young [8] noted also that particles less than 20 micrometers are not removed efficiently even with media sizes as small as 0.2 mm. It is plausible, therefore, that a large portion of the turbidity-causing particles present in the feed of the experiment with the filtration rate of 12 m/h, had passed the filter bed without capture due to their high concentration and the high filtration rate.

An additional observation can be made from Fig. 2 in regard to COD removal efficiency. Good removal efficiencies (about 40%) were achieved at filtration rates of 4 and 8 m/h, but the removal decreased to 29% at the rate of 12 m/h. It is known that part of the COD is soluble and the only mechanism for its removal would be microbial degradation. At the filtration rate of 12 m/h, the detention time for degradation to take place in the filter was very small which affected biodegradation and in turns COD removal efficiency. Furthermore, the organic loading on the filter at the rate of 12 m/h (92-96 mg/L COD) was much higher than those at other rates (28-52 mg/L COD).

The Saudi Arabian wastewater-reuse criteria for unrestricted irrigation [22], require an effluent with suspended solids and turbidity of less than or equal to 15 mg/L (weekly average) and 5 NTU, respectively. Thus, running local-sand filters at either 4 or 8 m^3/m^2.hr would meet these requirements. The effluent SS levels at the filtration rate of 4 m^3/m^2.hr were between 3 and 8 mg/L, while the levels at the rate of 8 m^3/m^2.hr varied between 8 and 9 mg/L. Effluent turbidity values were respectively in the range of 0.64-3 NTU and 0.65-1.82 NTU, and effluent COD levels were in the range of 12-36 mg/L and 13-28 mg/L. Results of filtration at the rate of 12 m/h showed that the reuse criterion for turbidity of 5.0 NTU was exceeded slightly (2.9-7.9 NTU), but the SS criterion of 15 mg/L was met (5-8 mg/L).

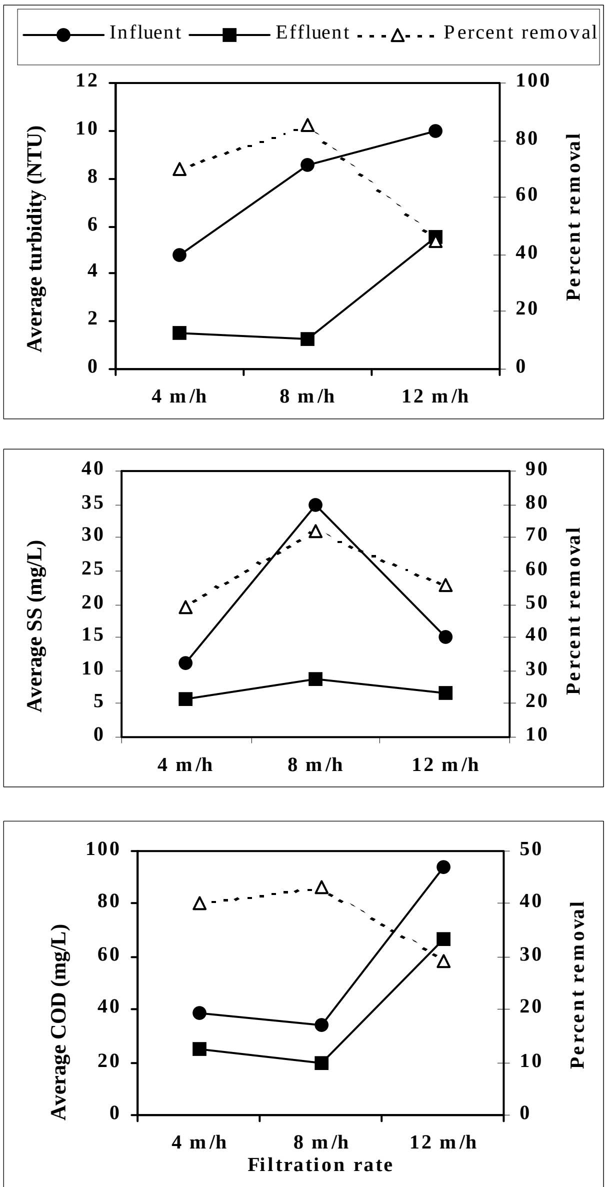

Fig. 2. Filter performance at different filtration rates

4-3 Headloss Development and its Variation with Depth

Fig. 3 compares the development of total headloss during filtration at the three filtration-rates employed in this study. At the rate of 4 m/h, the available total headloss of about 189 cm was utilized in about 2.5 days (62 hrs), whereas at the rates of 8 and 12 m/h it was exhausted in about 23 hrs and 21 hrs, respectively. It is obvious that as the filtration rate increased, the hydraulic headloss increased, rendering less headloss capacity for solids retention. One can also infer from Fig. 3 that the headloss buildup at the rate of 4 m/h increased at a small rate during the first 24 hours of operation but then increased at a higher rate and lasted for about 30 hr after which it increased drastically until it reached the predetermined headloss of about 189 cm. According to visual observation during the experiment, the first transition point corresponds to the outset of solids mat formation on the top surface of sand bed; the second point of transition coincides with the formation of a thick mat of solids on the sand column and heavy accumulation of solids within the grain pores in the upper portion of the media. At the rate of 8 m/h, the headloss increased at a small rate during the first 6-7 hours of filtration and then increased rapidly when a layer of deposited solids started to form on the top of the sand bed, and then increased at dramatic rate shortly before the terminal headloss was reached. The high concentration of suspended solids in the filter influent at this rate of filtration (20-46 mg/L) apparently contributed to the early formation of solids mat on the top of the sand media. A relatively similar pattern of headloss development was also observed in the experiment at the rate of 12 m/h but the formation of solids mat took place after a period of 10-12 hr. This is probably due to the lower concentration of SS in the filter influent (14-16 mg/L) in comparison with that at the rate of 8 m/h (20-46 mg/L). Apparently, the development of headloss during filtration is very dependent upon the concentration of solids to be filtered and filtration rate [18].

As for the variation of headloss with media depth during filtration, measurements have shown that the patterns of headloss development in all experiments were almost identical. Fig. 4 depicts the relation between headloss and depth from the sand surface at different elapsed filtration-times for the filtration rate of 12 m/h, which is typical of results in all experiments. It can be seen that the rate of headloss increase with respect of depth was almost linear during early stage of operation indicating that filtration was occurring throughout the filter medium. However, during later stages, the headloss increased drastically at the top part of the sand column in comparison with the headloss increase at the bottom of the medium as a result of the formation of a solids mat on the sand surface and the accumulation of solids particles within that top portion.

About 28%, 68%, and 91% of the headloss measured at the last port (88 cm from the medium top) after 4 hrs, 22 hrs, and 58 hrs of filtration at the rate of 4 m/h occurred within the first 3 cm of the medium (the first port), respectively. The depth of solids penetration as measured at the end of the experiment at the rate of 4 m/h was approximately 7 cm. Operating the filter unit at the rate of 8 m/h increased the penetration of the solids into the filter bed to about 20 cm, thus allowing more use of the medium depth. Four hours after the start of the experiment at the rate of 8 m/h, the headloss measured at the port located 13 cm from the top of the sand column accounted for 53% of the headloss measured at the last port; by 21 hr, however, the percentage mounted to about 91%. As for the rate of 12 m/h, the depth of solid penetration exceeded 30 cm by the end of the filter run. About 57% of the headloss measured by 10 hr for the filter run of 12 m/h was due to headloss within the first 13 cm of the medium; the value increased to about 84% just one hour before the end of the run (i.e. by 20 hr). Actually, Young [8] recommended increasing the filtration rate as a means to increase the penetration of solids into the filter media so as to reduce surface straining and allow better use of the media depth.

Turbidity measurements of filtrates sampled from different ports along the filter bed during all filtration experiments substantiated the penetration of solids particles through the top portion of the medium. As a typical example, Fig. 5 presents variation of turbidity values of filtrates from different medium depths during the filtration experiment of 12 m/h. Obviously, the turbidities of filtrates from the first two ports (3 and 13 cm from the sand surface) started to increase shortly after the start of the run and continued to mount as time progressed. The turbidity values of filtrates from other deeper ports were generally decreasing throughout the filter run.

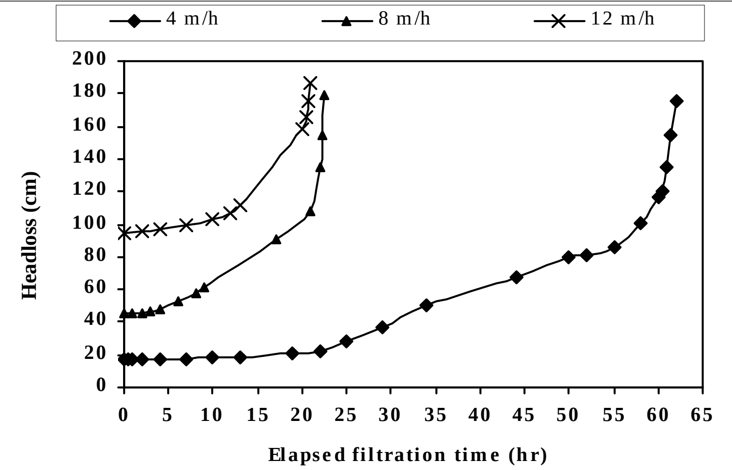

Fig. 3. Total headloss for different filtration rates

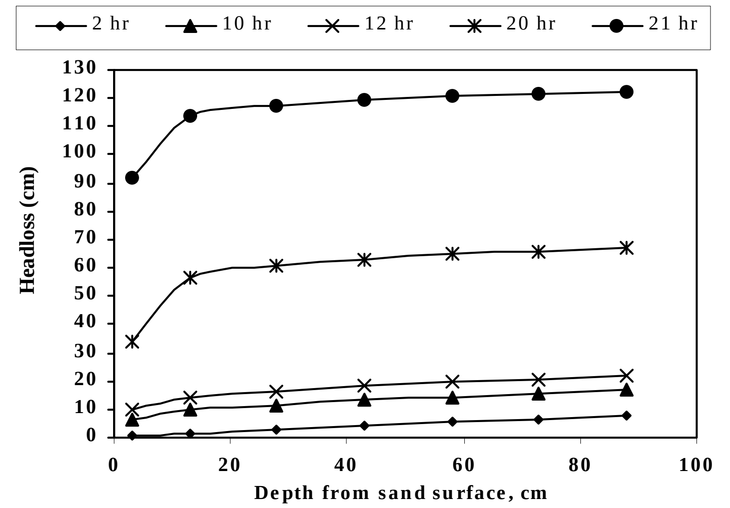

Fig. 4. Headloss through sand bed as a function of elapsed filtration time for filtration rate of 12 m/h

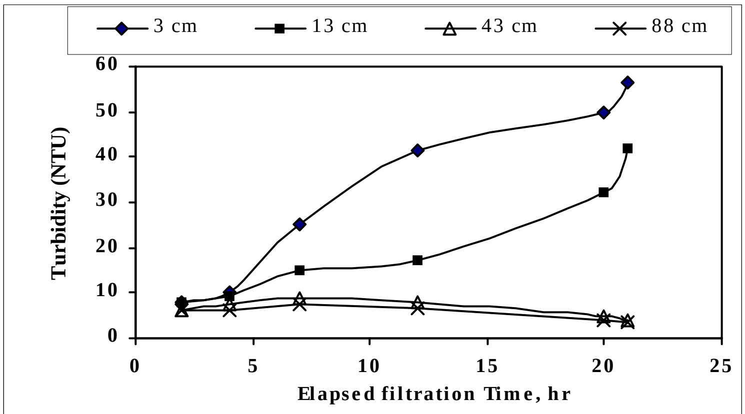

Fig. 5. Turbidity of filtrate at different media depths during filtration at the rate of 12 m/hr

5- Conclusions

On the basis of the study results, the following conclusions are derived:

1. Sand with a size range of 1.1-3.3 mm procured from a site at the Al-Rasaf tributary 25 km south west of Hail city was found to conform to the specifications of tertiary-filtration sand. The average acid solubility, specific gravity, organic impurities, and materials finer than 75 micrometers were respectively 0.99%, 2.60, lighter than standard, and 0.07%. The sand effective size and uniformity coefficient were 1.8 mm and 1.44 respectively. Porosity of the sand medium was found to be 43%.

2. Pilot filtration using this local sand at three filtration rates, 4, 8, and 12 m^3/m^2.hr, has shown that the sand is suitable for tertiary filtration of settled stone-trickling-filter effluents as filtrates with satisfactory quality could be obtained. However, the lengths of filter run at the rates of 8 and 12 m/h were shorter than that at the rate of 4 m/h (21-23 hr versus 62 hr).

3. Removal efficiencies for all quality measures at the filtration rate of 8 m/h were better than those at the other rates although the 8 m/h-influent SS concentrations were higher during filtration. Average turbidity, SS, and COD removals at the rate of 8/h were approximately 85%, 72%, and 43%, respectively. The corresponding values at the rate of 4 m/h were 70%, 50%, and 40%, and were 45%, 56%, and 29% at the rate of 12 m/h.

4. SS concentrations and turbidities as high as 9 mg/L and 3.0 NTU in effluents from filters using this local sand at the rates of 4 and 8 m^3/m^2.hr would be obtained, satisfying the Saudi Arabian wastewater reuse quality criteria for unrestricted irrigation and recreational purposes of less than or equal to 15 mg/L SS (weekly average) and 5 NTU turbidity. Results of filtration at the rate of 12 m/h showed that the turbidity criterion was exceeded slightly (2.9-7.9 NTU) but the SS criterion was met (5-8 mg/L).

5. Headloss and turbidity measurements throughout the filter bed during the course of filtration revealed that both surface and depth filtration are involved although surface filtration was the predominant mechanism of solids removal during the later stages of filtration.

Acknowledgment. The financial support provided for this research project by the Research Center at College of Engineering, King Saud University, is greatly acknowledged.

References

[1] Mujeriego, R. and Asano, T. “The role of advanced treatment in wastewater reclamation and reuse.” *Wat. Sci. Tech*., 40, No. 4-5 (1999), 1-9.

[2] Zahid, W. M. K. and Al-Rehali, A. M. “Reuse of municipal wastewater in Saudi Arabia: treatment systems, reuse activities and criteria.” *Arab Gulf Journal of Scientific Research*, 18, (2000), 134-142.

[3] Shura Council in Saudi Arabia. “Code of reclaimed wastewater and reuse.” Riyadh: Shura Council, 2000.

[4] Metcalf & Eddy, Inc. “*Wastewater Engineering: Treatment, Disposal, and Reuse*.” 3th edition, New York: McGraw-Hill, Inc., 1991.

[5] Water Environment Federation, and American Society of Civil Engineers. “*Design of Municipal Wastewater Treatment Plants, Volume 2: Liquid treatment Processes*.” WEF Manual of Practice 8, 4th edition. Alexandria, VA: WEF, 1998.

[6] Cikurel, H., Rebhun, M., Amirtharajah, A. and Adin A. “Wastewater effluent reuse by in-line flocculation filtration process.” *Wat. Sci. Tech*., 33, No. 10-11 (1996), 203-211.

[7] Siemak, R. C. “Tertiary filtration: practical design considerations.” *J. Wat. Pollut. Control Fed*., 56, No. 8 (1984), 944-949.

[8] Young, J. C. “Operating problems with wastewater filters.” *J. Wat. Pollut. Control Fed*., 57, No.1 (1985), 22-29.

[9] Viessman, Jr., W. and Hammer, M. J. “*Water Supply and Pollution Control*.” 4th edition, New York: Happer & Row Inc., 1985, 671-672.

[10] Al-jadhai, I. S. and Misbahuddin, M. “Suitability of local sand for tertiary filtration of wastewater.” *Proceedings of the Fourth Saudi Engineering Conference*, Vol. 2, 1995, 561-567.

[11] Al-Dhowalia, K. H. and Al-Mutlak, A. A. “Optimization of sand filtration process for tertiary treatment.” *Proceedings of the WSTA 4th Gulf Water Conference*. Vol. 2, 1999, 886-902.

[12] American Water Works Association. “*AWWA Standard for Filtering Material: AWWA B-100-80*.” Denver, Colorado: AWWA, 1980.

[13] American Public Health Association. “*Standard Methods for the Examination of Water and Wastewater*.” 16th edition, Washington D.C.: APHA, 1985.

[14] Culp, R. L., Wesner, G. M. and Culp, G. L. “*Handbook of Advanced Wastewater Treatment*.” 2nd edition, New York, N.Y.: Van Nostrand Reinhold Company, 1978.

[15] Dawada, M. M. and Ddavidson, M. L. “Granular media filtration of secondary effluent.” *J. WPCF*., 50, No. 9 (1978), 2143-2156.

[16] Darby, J. L., Lawler D. F. and Wilshusen, T. P. “Depth filtration of wastewater: particle size and ripening.” *Research J. WPCF*, 63, No. 3 (1991), 228-238.

[17] Prasanthi, H., Vigneswaran, S. and Dharmappa, H. B. “Effect of particle concentration on the entire cycle of filtration.” *Wat. Sci. Tech*., 35, No. 8 (1997), 91-102.

[18] Yao, K. M., Habibian, M. T. and O`Melia, C. R. “Water and wastewater filtration: concepts and applications.” *Environ. Sci. Tech*., 5, (1971), 11052-1112.

[19] Aim, R. B., Vigneswaran, S., Prasanthi, H. and Jegatheesan, V. “Influence of particle size and size distribution in granular bed filtration and dynamic microfiltration.” *Wat. Sci. Tech*., 36, No. 4 (1997), 207-215.

[20] Kaminski, I., Vescan, N. and Adin, A. “Particle size distribution and wastewater filter performance.” *Wat. Sci. Tech*., 36, No. 4 (1997), 217-224.

[21] Adin, A. “Particle characteristics: a key factor in effluent treatment and reuse.” *Wat. Sci. Tech*., 40, No. 4-5 (1999), 67-74.

[22] Ministry of Water and Agriculture, Saudi Arabia. “Code regulations of sanitary wastewater reclamation and reuse.” The 6th draft, Riyadh, 1987.