

*Full Length Research Paper*

# A study of sand filter capping for turbidity removal for potable water treatment plants of Mosul/Iraq

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Accepted 13 September, 2020

Sand filter capping had been tried as an alternative for the currently practiced rapid sand filters. A 1000 m<sup>3</sup>/day capacity pilot plant constructed similarly to full scale water treatment plants was used for this purpose. Four levels of sand material with respect to grain size and thickness were used. Capping filter was represented by one level of anthracite coal with one thickness. In order to optimize the most efficient combination(s) of the two materials for maximum filter performance in terms of quality and quantity, four filtration rates were tried. A series of forty test runs and experiments exceeding 120 using different filter configurations were tried. Filters were operated in pairs and subjected to the same conditions. Filters consisting of 20 cm anthracite coal (0.91 mm E.S.) over 40 cm of sand (0.69 mm E.S.) appeared to be the best fit configuration among tried filters. Considerable economical consequences could be achieved using sand filter capping. This was reflected in reducing filter numbers or increasing the plant capacity by two folds in the minimum. Economic revenue was gained through reduction of disinfection doses as well as reduction in filter sand material. Runtimes of filters were increased by 2 - 3 folds indicating capability of more furnished water productivity and less amount for backwash need. Above all the water produced was of very good quality that met the most stringent specifications and promoted health. Capping sand filters were proven to suitably operate under varying conditions of influent turbidity and filtration rates.

**Key words:** Drinking water filtration, rapid sand filtration, dual-media filtration, multi-media filters, water treatment, filter media, gravity filtration.

## INTRODUCTION AND LITERATURE REVIEW

The recent constructed water treatment plant in Mosul city (north of Iraq) dated back to 1980s. The designs of this plant and most water treatment plants in the city were based on concepts developed in the early 1960s, when many aspects of the treatment processes were not fully understood. Since then many changes had taken place including guidelines, consumption patterns and life style.

Besides, water quality underwent a great change due to water impoundment to the north of the city. Turbidity - as example- was reduced greatly as this impoundment acted as a huge sedimentation tank. Hardness –on the other hand- increased due to geologic formation of the area of the impoundment. Released water from the dam was loaded with nutrients e.t.c. Further, misconceptions of treatment works as well as lack of specialized personnel complicated these problems (Al-Rawi 2009).

Sand had been traditionally used as the filter medium in conventional water treatment plants because of its wide availability, low cost and the satisfactory results that it had given. Sand filters remained the predominant method

of filtration in most developing countries and Iraq is no exception.

However the grading of sand that might occur in backwashing of rapid filters, leaving the finer sand on top, could restrict the capacity of conventional rapid sand filters. The floc particles removed in filtration might concentrate on the topmost layers of the filters leaving most of the thickness of the filter unused.

Besides, these filters were proven to be inefficient in satisfying the recent stringent quality guidelines (Al-Rawi, 1996; Peavy et al., 1987). Further, the design of these filters was intended to treat high turbidity water and could not tackle low turbidity water.

Based on the above facts, most current existing plants turned incapable of tackling such proper water treatment and provision of sufficient water for various demands. These plants acted merely as a passing-through units. Complaints of the public increased, supplied water was not healthy and tasted bad. Many cases of contamination were recorded. Diseases - particularly among infants – did

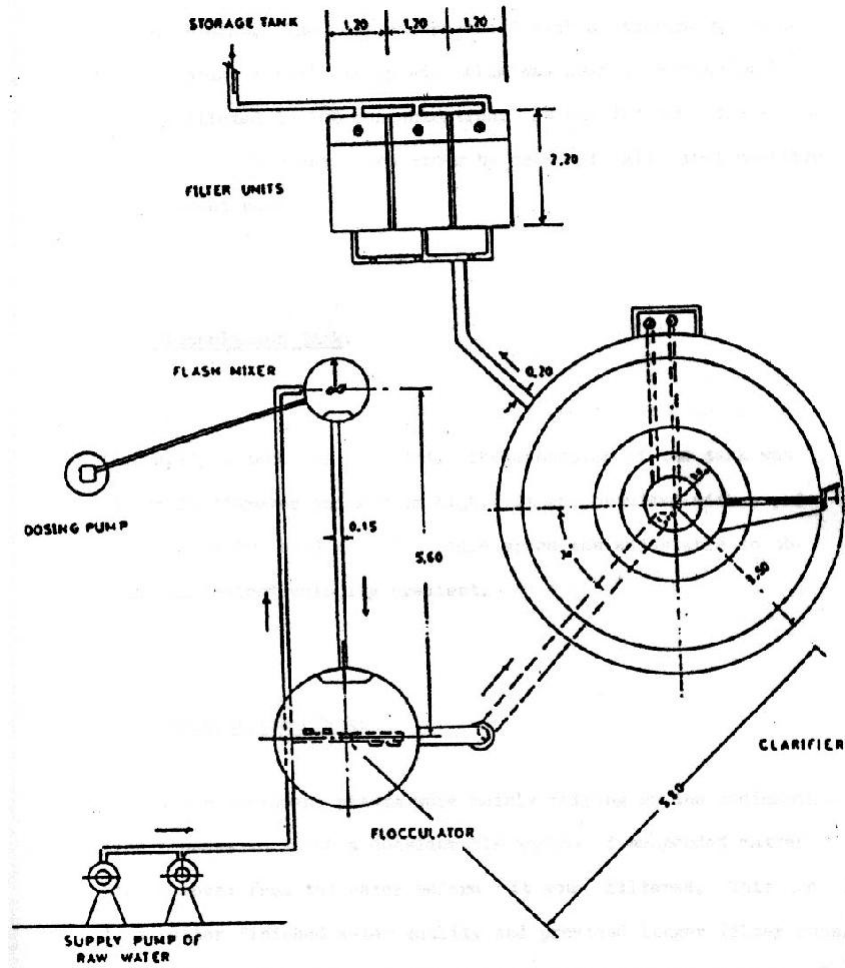


Figure 1. Pilot plant used in the experiments.

not become uncommon (personal communications, 2009).

In order to encounter this situation at present time an additional technology in the water treatment methodology must be -however- introduced to cope with society needs. Such situation suggests upgrading of the existing potable water treatment plants by establishing effective operation and improving unit processes. This will be reflected on plant production and improve the quality of the treated water.

Dual and Mixed media filters have gradually replaced conventional gravity sand filters in many treatment plants in developed countries (Hindricks, 1974; Al-Ani and Al-Baldawi, 1986; Hammer, 1986; Culp, 1974). The idea behind these filters is that the lighter media of larger size occupy the upper layers of the filter, allowing greater penetration of the floc. Floc that escapes the upper layer is caught in the finer sand at the bottom of the filter (Schulz and Okun, 1984).

Usually the thickness of upper lighter layers equals twice that of the bottom heavier layers. However, from

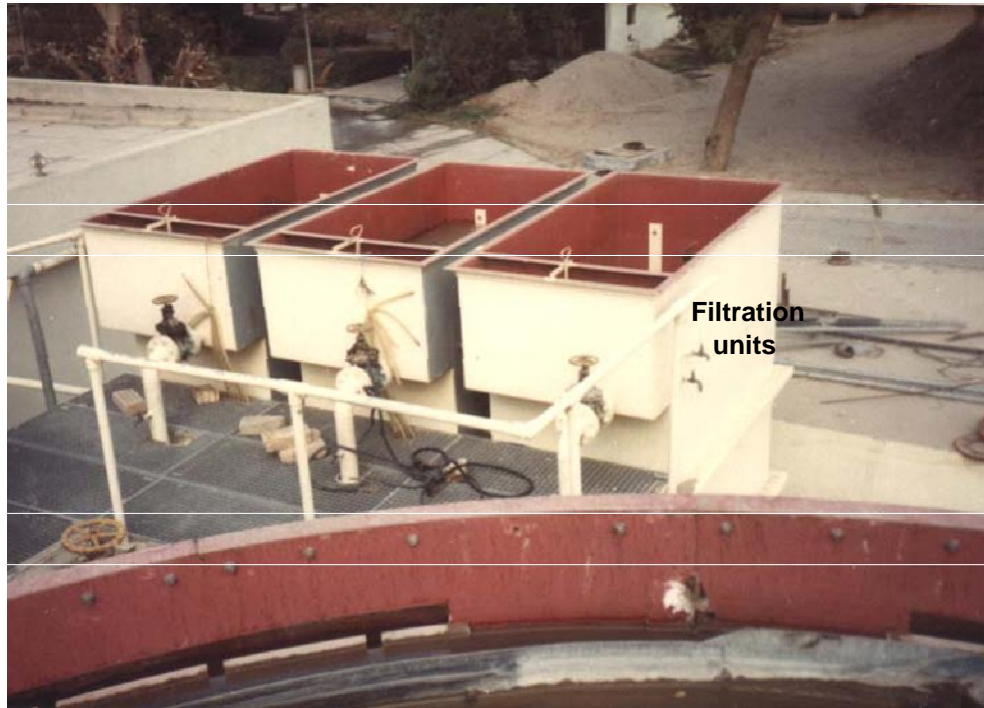
view of cost, the developing countries may use sand filter capping. Here the thickness of the upper layers is often half that of the sand layer.

Sand filter capping is the process in which the top portion of a rapid sand filter is replaced with anthracite coal in order to achieve the improved performance typical to sand/anthracite filter (Tillman, 1996). If an increase in capacity is desired, a larger amount of sand is replaced as such practice will increase filter run as well as it will increase the amount of fines.

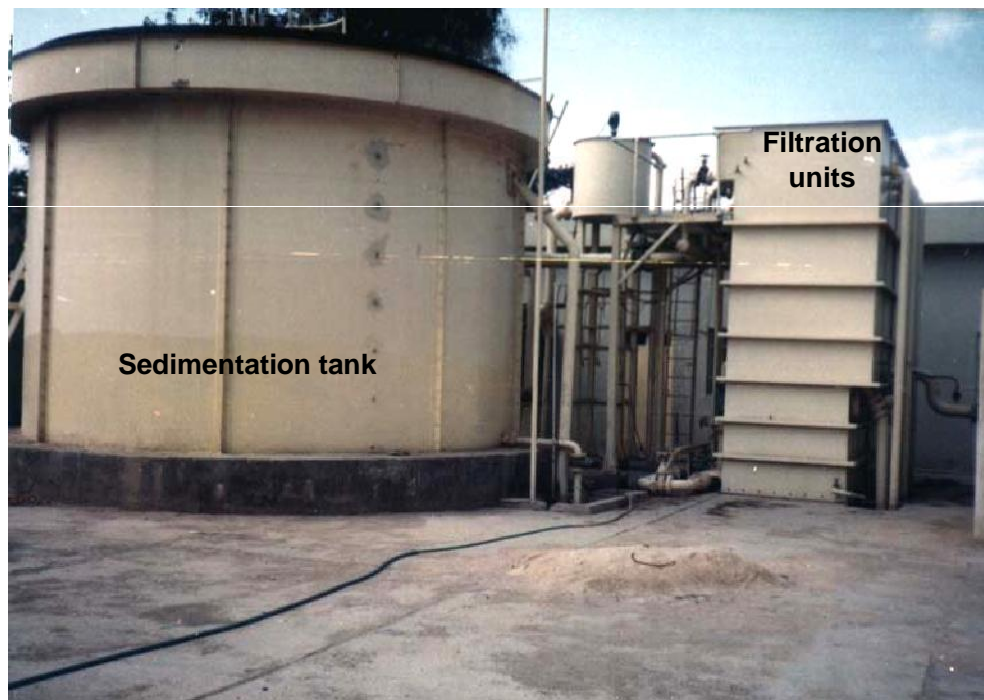
This paper aims to study this technology and revealing some of the merits that can be gained if introduced in water treatment plants.

## MATERIALS AND METHODS

This technique (capping filters) is still unknown in Iraq and its use is restricted on experimental works in laboratories. The distinct feature in this study is that the used pilot plant is very large compared to those usually adopted in labs. Its capacity is  $1,000 \text{ m}^3/\text{day}$  and is built similarly to a full scale water treatment plant. Figure 1 shows a



**Photograph 1.** The used filter units.



**Photograph 2.** Sedimentation tank and filter units of the used pilot plant.

sketch of the used plant. Photographs 1 and 2 show some close illustration of plant units and Table 1 lists its components. It is worthy to mention here that (2) of the (3) filters shown in the

photograph were employed for the purpose of this paper. The third filter unit was employed as a slow sand filter.

Four types of sand materials with different effective size were

**Table 1.** Units of the pilot plant

Unit	Description
Raw water pipe	150 mm diameter conveys Tigris raw water to storage tank for maintaining constant rate of supply
pumps	Two centrifugal pumps (one stand by) of 45 m <sup>3</sup> /hr capacity.
Rapid mix basin	One cylindrical tank of 90 cm diameter and 120 cm high. This unit is provided with a stirring propeller of constant rotational speed.
Flocculation tank	One cylindrical tank 250 cm diameter and 230 cm high. It is provided with a paddle made of two blades.
Sedimentation tank	One tank of 600 cm diameter and 400 cm high. It is equipped with de-slugging system (scraper and flush outlet pipe).
Filters	2 identical filter units each of dimensions 1.0 m x1.50 m with 3.75 m high . the inflow rate is controlled by a weir.

**Table 2.** Media characteristics

Sand type	Effective size mm	Uniformity coefficient	Specific gravity	% loss by weight
No.1	0.92	1.32	2.677	3.3
No.2	0.98	1.58	2.588	3.61
No.3	0.69	1.79	2.617	1.95
No.4	0.46	2.86	2.644	1.72
Anthracite coal	0.91	1.33		

used One type of anthracite coal was used as a capping layer. Table 2 shows the characteristics of these media.

Measurements for turbidity were taken by Hatch turbidimeter type 2100A where measurements were given in NTU. Measurements being determined with each sampling time by appropriate apparatus.

The size distribution of sand and anthracite were made by sieving a sample of known weight through a series of standard sieves. The weight of the material in each sieve was recorded and the accumulative percentages of material retained on each sieve were estimated. Note in the Tables that the loss by weight of sand Nos. 1 and 2 are not meeting authorized guidelines (Degremont, 1991).

#### Plan of experimentation

The first task in the experimental program was to select the proper type of sand filter capping media as regards to size and thickness to be used. The anthracite coal layer available at time of study was of one type only. The sand media prevailing at water treatment plants of the country was imported from Karbala governorate and was of one size. For this reason some mix trials were made to obtain another additional type with respect to gradation.

The next step was to compare the behavior of a set of different sand capping filters. Every two filters were made to run parallel, having the same thickness and subjected to the same field conditions (Table 3).

Later the best pair of sand filter capping types that would appear as to conform to the objectives and goals of the study would be tried under changing conditions of flow rates to check their suitability under such conditions. Measurements were replicated so as to statistically analyze the results.

## RESULTS

For the comparison of sand filter capping investigated in this study, considerations of different turbidity standards were made. These turbidities were recommended by the customary level of (5) NTU adopted by World Health Organization (WHO, 1995) and (Iraqi standards, 1991) as well as (1) NTU adopted by U.S. Environmental protection Agency (EPA) standards (Hindricks, 2006).

More than forty test runs were conducted throughout the period of study. Some grab runs were made to check the adaptability of sand filter capping to tackle uncoagulated suspensions.

The process variables investigated in the study included some raw water characteristics (pH, temperature and turbidity), size and thickness of media, filtration rate, head loss and filter runtimes. Bacterial populations on standard plate count basis were estimated for the conducted test runs.

After getting the results, it was found that filters using 10 cm of anthracite did not show an efficient performance in removing turbidity. Besides, the runtimes were relatively short that made operation unfeasible for backwash and demands needs. These results were excluded.

Turbidity could be the most variable of the water quality parameters of concern in drinking water sources

**Table 3.** Run Configuration as cited in the literature

Experiment group set	Run No.	Media thickness cm <sup>1</sup>	Sand size mm <sup>2</sup>	Experiment group set	Run No.	Media thickness cm	Sand size mm	
A	1	20x20	0.92	C	23	10x20	0.69	
	2	20x20	0.98		24	10x20	0.46	
	3	20x30	0.92		25	10x30	0.69	
	4	20x30	0.98		26	10x30	0.46	
	5	20x40	0.92		27	10x40	0.69	
	6	20x40	0.98		28	10x40	0.46	
	7	20x50	0.92		29	10x20	0.92	
B	8	20x50	0.98	D	30	10x20	0.98	
	9	30x50	0.92		31	10x30	0.92	
	10	30x50	0.98		32	10x30	0.98	
	11	20x20	0.69		33	10x40	0.92	
	12	20x30	0.46		34	10x40	0.98	
	13	20x30	0.69		E	35	10x50	0.92
	14	20x30	0.46			36	10x50	0.98
	15	20x40	0.69			37	10x40	0.69
	16	20x40	0.46		F***	38	10x40	0.46
	17	20x50	0.69			39	20x40	.
	18	20x50	0.46			40	20x40	
	19	20x60	0.69			41	20x40	
	20	20x60	0.46			42	20x40	
	21	30x60	0.69			43	20x40	
	22	30x60	0.46			44	20x40	

1. The first figure denotes anthracite thickness(cm) while the second figure denotes sand thickness(cm)

2. for all filters anthracite coal effective size = 0.91 mm

\*\*\* various filtration rates were applied to best filter configuration in terms of performance

(Montgomery, 1985) and filter performance was based on how much removal of it could be achieved. Besides, turbidity and various harmful organisms usually could occur together in surface water, any removal of turbidity would mean removal of organisms (Conley and Pitman, 1960). Further, turbidity would exert a significant chlorine demand. The World Health Organization (WHO, 1985) strongly recommended that from public health point of view, it was vitally important to produce safe, pathogenic-free drinking water using chlorine as a disinfectant that turbidity be kept low, less than (1) nephelometric turbidity unit NTU. Focus would be made on sand filter capping using 20 cm anthracite (Table 4).

Relative performance of all tried filter configurations based on the percent removal of turbidity of filters using sand No.3 and 4 were shown in Table 5.

One of the factors that affected filter performance was - intermix- (Table 6). This intermix was a function of ( $D_{90}/D_{10}$ ) of the media. Intermix was increased as this ratio approaches (3).

The effects of increasing sand thickness on filter performance was also dealt with (Table 7).

## DISCUSSION

The author et al published a series of papers concerning various aspects of studied parameters. Most of the concerned variables were covered in depth. Readers are requested to refer to such works elsewhere (Al-Layla et al., 1989; Al-Rawi, 1987; Al-Ani et al., 1988) . Focus in this paper will highlight the advantages and economic merits drawn by application of sand filter capping in Mosul treatment plants.

Table 4 listed the results obtained throughout the period of study. These results were encouraging. They were so good when compared with the above standards. Turbidities less than the stringent guideline were obtained.

Sand filter capping consisting of 40 cm of 0.69 mm of sand overlain by 20 cm of 0.91 mm anthracite coal showed superiority among tried filter configurations in terms of quality and runtime. Filter of 40 cm of 0.46 mm of sand and 20 cm of 0.91 mm anthracite came next in this comparison. The latter filter showed higher percentage removal of turbidity for some period of operation (98.6%) as shown in Table 5. The above judgement is

**Table 4.** Percent removal of turbidity in function of runtime\*.

Sand type No.	Coal thickness cm	Sand thickness cm	24 h		36 h		44 h	
			Effluent ntu	Percent removal	Effluent ntu	Percent removal	Effluent ntu	Percent removal
No.1	20	20	1.33	60.80	1.55	56.71	1.78	53.08
	20	30	0.98	75.01	1.17	61.31	1.70	67.84
	20	40	0.81	63.95	0.92	51.57	0.88	44.21
	20	50	0.45	80.43	0.78	61.84	3.26	64.96
No.2	20	20	1.60	52.94	1.79	50.45	1.92	49.77
	20	30	1.21	69.87	1.37	54.64	2.03	60.05
	20	40	0.84	62.36	1.00	47.36	0.93	41.07
	20	50	0.51	78.31	0.78	61.84	3.20	65.65
No.3	20	20	1.37	60.28	2.15	59.76	3.73	61.92
	20	30	1.05	78.90	3.65	90.88	5.25	81.40
	20	40	0.20	98.00	0.5	96.50	0.80	95.50
	20	50	0.49	92.00	0.6	89.65	0.73	83.59
No.4	20	20	1.48	56.95	2.45	53.34	3.37	52.61
	20	30	1.13	77.30	4.05*	90.00	3.6	83.35
	20	40	0.14	98.60	0.8	94.30	1.6	91.06
	20	50	0.50	91.85	0.59	89.65	0.73	83.59

\*Note: the indicated runtimes are selected as to cope with max. Operation of one of the tried filters category of compared filters and for the purpose of comparison. It does not imply that they are the max. runtimes of various filter configurations.

**Table 5.** Relative percent efficiency for turbidity removal in terms of sand type in sand filter capping (%).

Run length h	Filters using sand 1	Filters using sand 2	Filters using sand 3	Filters using sand 4
12	72.3	68.8	100.0	100.00
24	66.6	65.6	100.0	100.50
36	53.6	49.3	100.0	97.03
44	46.7	43.4	100.0	95.50

**Table 6.** Intermix probability.

Filter type	Filter with sand No.1	Filter with sand No.2	Filter with sand No.3	Filter with sand No.4
D <sub>90</sub> /D <sub>10</sub>	1.68	1.602	2.27	3.41

**Table 7.** Effect of increasing sand depth upon filter performance.

Configurations cm x cm	Percent removal of turbidity		
	12 h	24 h	
Coal x sand	20 x 50	92.80	92.01
	20x60	98.51	96.00
	20 x 50	91.20	91.85
	20 x 60	98.60	96.00

based on the fact that the runtime of filter using sand No.3 is about 1.8 times that of filter using sand No. 4. Further the increase in turbidity removal of the latter filter is very slight compared to that of earlier filter. Both types of filter produce turbidity less than (1) NTU.

Based on original data of influent turbidity received by the filter units, it was noted that most of the incoming water to the filters could be described as “tough water”.

Such water was hard to tackle as far as turbidity removal was concerned. Obviously a filter could remove the maximum raw turbidity when the incoming turbidity was high. On the contrary, the filters could remove very little when received turbidity was low.

As stated earlier, sand filter capping were proven to tackle quite good with such situation. Again filters using sand Nos. 3 and 4 showed superiority among other tried filters. The effluent turbidity was so low where influent turbidity to filters amounted to 10 ntu.

Some other quality merits of sand filter capping was the probability of intermix that might occur among anthracite coal and sand grains. Intermix provided more uniform decrease in pore size with thickness. This allowed more efficient use of storage space in the media and consequently provided longer runs (Cleasby, 1975). A decrease in the uniformity coefficient would reduce the amount of intermix since larger particles would not be present. This strongly confirmed in Table 6.

By referring to original results obtained by this work showed that tried sand filter capping could also tackle situation of relatively high influent turbid water to filter units. Some influent turbidity to filter units amounted to (16) NTU). The latter value was relatively high for conventional current rapid sand filters. However, it was quietly well tackled by used sand filter capping. This situation highly confirmed the flexibility and reliability, etc. of the sand filter capping and gave a good indication of proper purification.

In the light of above findings, the encouraging results of highly reduced effluent turbidity are reflected on health. Consumers will be very satisfied by the water they are drinking. The quality is palatable, wholesome and satisfies the most stringent standards in terms of turbidity.

The upper layer of sand filter capping contributes a lot in achieving these excellent results. The angularity of the anthracite results in a large void ratio and allows more solids holding capacity than the most rounded sand. The latter yields a consistency better filtrate quality throughout a filter run. The capping media system more fully utilizes the entire bed for storage of filtered solids since water passing through a capping filter contacts the coarser anthracite offering ample void ratio to effect removal and storage of the suspended solids.

The lower uniformity coefficient anthracite has less oversized and undersized particles resulting in a very uniform bed. The low uniformity coefficient anthracite coal requires much lower backwash rate which results in a substantial savings to the treatment plant due to the reduced monthly/annual wash water requirements.

From the other side, the clear quality means that the addition of disinfectants will be minimum. This in turn suggests a good signs from health points of view. Reduced turbidity also means that the added disinfection can operate effectively and efficiently. In other words, an economic revenue may be achieved through reducing costs of added disinfectants as the finished water is almost clear.

On the contrary, an elevated record of turbidity necessitates addition of considerable amounts of disinfection. Excessive disinfectant doses may give rise to Trihalomethane (THM) to occur. The latter is very carcinogenic and may be fatal to organisms.

It is well accepted that the plant production of finished water is a function of its filtration rate. Keeping this in mind, operation of filtration rate at 8.3 m/h may add another positive point. Such rate will enable water supply authority to save in two aspects. First: treatment plants can produce at least two folds the amount currently achieved when using 4 m/h rate. This will avoid the idea of constructing new treatment plant to satisfy required demands. Second, if the produced amount of water is thought to be sufficient, then a reduction by 50% or more in filter unit numbers can be saved. Both of above cases will help to reduce the cost of water treatment plants.

Further, it is seen that increasing filtration rate above 8.83 m/h showed a decline in filter efficiency (Figures 2 and 3). This was attributed to increased collision between removed particles and the media. At the same time it increased the hydraulic shear force which tended to push the particulate matter deeply in the filter where it ultimately emerged with effluent. However, turbidity of effluent for all rates was kept below (1) NTU.

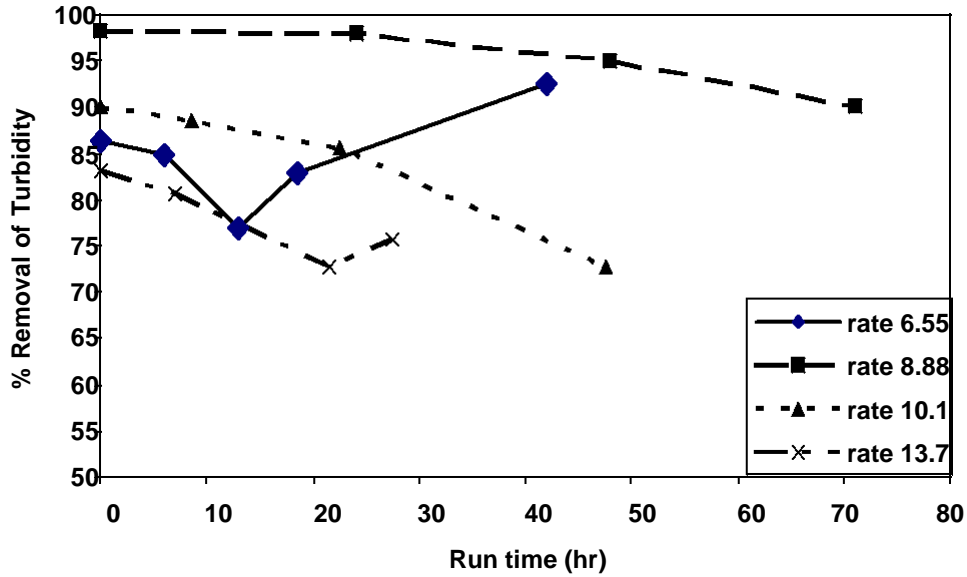
Further, sand filter capping may reduce the amount of sand media as some of this media replaced by anthracite. Current plants use as much as 100 cm of sand as a filter medium. The selected configuration indicated that 40 cm of sand could be used in sand filter capping. This means that 60% of sand can be saved. Generally the accumulated amounts of saved sand from many operating filters will be considerable.

Filter runtime were approved to be longer. This would be reflected on producing more clear water. The breakthrough of impurities would be uniform and lasts longer. The latter encouraged gradual head loss buildup and consequently longer runtimes. This was attributed to the fact that the whole filter thickness was utilized in the filtration process compared to the 10 - 15 cm in the current conventional filters. Running filters for 83 h (more than 3 folds the current runtime in existing Iraqi plants) meant uniform head loss, more water and less backwash. These advantages collectively added to the economy of the process.

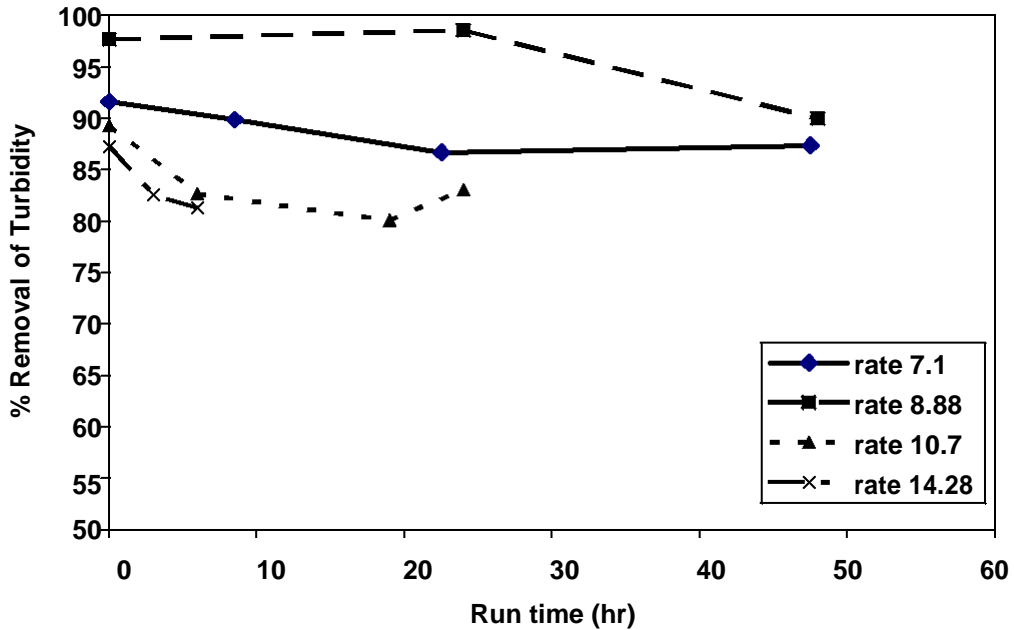
Longer runtimes reduced the backwash amount of water. The capping media also required a lower backwash rate to achieve fluidization with filtration rates of 2 - 3 times higher than those of rapid sand filters.

Using sand filter capping does not need further experience or skilled labor. It is simple, easy to operate and needs no complications.

All the above facts suggest the shining or positive aspects of introducing this technology. A question may arise concerning the extra cost incurred by using anthracite. This is quite reasonable. However, this will be taken care by one of the many achieved advantages of using sand filter capping. Irrespective of all mentioned



**Figure 2.** Capping filter performance throughout operation runtime using 20 cm anthracite and 40 cm sand No.3.



**Figure 3.** Capping filter performance throughout operation runtime using 20 cm anthracite and 40 cm sand No.4.

merits the provision of clear aesthetic and palatable water is solely sufficient and invaluable.

### Conclusion

The following conclusions are drawn:

1. A sand filter capping consisting of 40 cm of 0.69 mm sand and 20 cm of 0.91 mm anthracite coal was found to show superiority in turbidity removal among more than 120 filter configurations tested. This filter achieved 90 - 98% of turbidity removal over 83 h of service time. Influent turbidity as much as 16 NTU had been successfully handled in the filter.



2. The whole thickness of the media was utilized in the filtration process as opposed to the top layers of conventional rapid sand filters.
3. Produced effluent satisfied most stringent quality standards, offers a satisfaction for consumers as well as it was healthy.
4. Intermix that might occur in sand filter capping provided reliability and flexibility towards shock loads of turbidity,
5. A considerable revenue could be gained through reduction of sand thickness and reducing disinfection doses.
6. A great economical burden could be achieved through operating at higher rates. Consequently more water was produced which avoids construction new plants and/or reducing number of filter units by 50% in the plants and thus reducing the plant cost.
7. Another merit concerning plants located downstream an impoundment represented by adopting direct filtration mode of purification. This is because the received turbidity is considerably low as raw water stays long in the impoundment upstream.
8. The sand filter capping could operate for much longer periods of time (three or more times as long at the same filtration rate), before backwashing was necessary because the bed could hold more turbidity.
9. The extra cost of importing anthracite coal could be substituted excessively by any of the listed merits.
10. The study highly stressed on necessity of introducing this technique in the country water treatment plants for the various merits gained.

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