Behavior Assessment Of Various Filters Configuration In Removing Water Low Turbidity: A Statistical Treatment

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Abstract

The research focuses on the behavior of laboratory bench-scale filters that receive low-turbidity raw water. The filters have different configuration in terms of materials type, materials size and thickness. These filters operate under in-line and direct mode of filtration with different doses of alum and coagulant aid.

A total of 200 filter runs were conducted. Statistical methods had been used in the determination of best configurations of tried filters. Analysis of variance (ANOVA) and Duncan multiple range test had been employed for this purpose.

The results showed the superiority of filters operating under direct filtration mode compared to those of in-line filtration mode. It was thought that flocculation played a role in this result. Fine sand media of 0.56 mm E.S appeared to surpass the coarse media due to more trapping of impurities at pore spaces. The effect of coagulant aid addition was detected to act positively only with capping media filters, where an improvement in performance did occur. However, such improvement was low and did not justify importation of anthracite coal and coagulant aids and add an economic burden.

Keywords: Filtration modes, Filtration, Water turbidity, Water treatment.

تقييم سلوكية مختلف أنواع المرشحات في إزالة العكورة الواطئة: معالجة إحصائية

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الخلاصة

يركز البحث حول أداء مجموعة من المرشحات المختبرية في معالجة مياه قليلة العكورة. هذه المرشحات ذات اوساط مختلفة المواد والاعماق والاحجام المؤثرة . تعمل المرشحات بطريقتي الترشيح بالمسار والترشيح المباشر وتتغذى بجرع متغايرة التركيز من الشب ومساعدات التخثير.

جرى تحليل النتائج احصائيا باتباع طريقة تحليل التباين واختبار دنكن بقصد تحديد أفضل تركيبة من هذه المرشحات. وقد أظهرت النتائج تفوق المرشحات العاملة بطريقة الترشيح المباشر على نظيرتها العاملة بطريقة الترشيح بالمسار، ويعتقد ان لعملية التلبيد في الترشيح المباشر دورا مهما في هذا التفوق . كما وجد ان المرشحات المتكونة من أوساط من الرمل ذي الحجم المؤثر (٠.٥٦) ملم أظهرت كفاءة أفضل من مرشحات الرمل ذات الحجم المؤثر الأكبر وهذا يعود الى تاثير حجم الفراغات بين حبيبات الرمل في اقتناص المزيد من الشوائب. كما وجد ان استخدام مساعدات التخثير يفيد فقط في حالة استخدام مرشحات ثنائية الوسط إذ تتحسن أداء المرشحات في إزالة العكورة. وبنفس الوقت فان استخدام الأنثراسيت أو مساعدات التخثير لا يبرر استيراد هاتين المادتين لان الفرق ضئيل في مدى التحسن الحاصل في كفاءة الإزالة

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Introduction

Chemically assisted rapid sand filtration of water is a multi-step treatment process. It includes chemical mixing, coagulation, flocculation, solids separation and filtration. This sequence of treatment is adopted worldwide and Iraq is no exception. The importance and necessity of such practices are highlighted by many studies [1-5] .

However, the construction of dams and reservoirs may act as a huge sedimentation tank that reduce turbidity and change the quality of raw water received by downstream water treatment plants.

Such situation encourages introduction of new modes of treatment systems, mainly direct and in-line filtration (Fig. 1).

Each of these systems shall be designed to produce water that meets the drinking water quality standards, with the minimum performance requirements for rapid sand filtration.

Both types of treatment modes may be used for raw water that is consistently very low in turbidity, color, and dissolved organic carbon. The difference between the two types is that the forming pinpoint sized flocs are filterable in direct filtration and are settleable in in-line filtration [6].

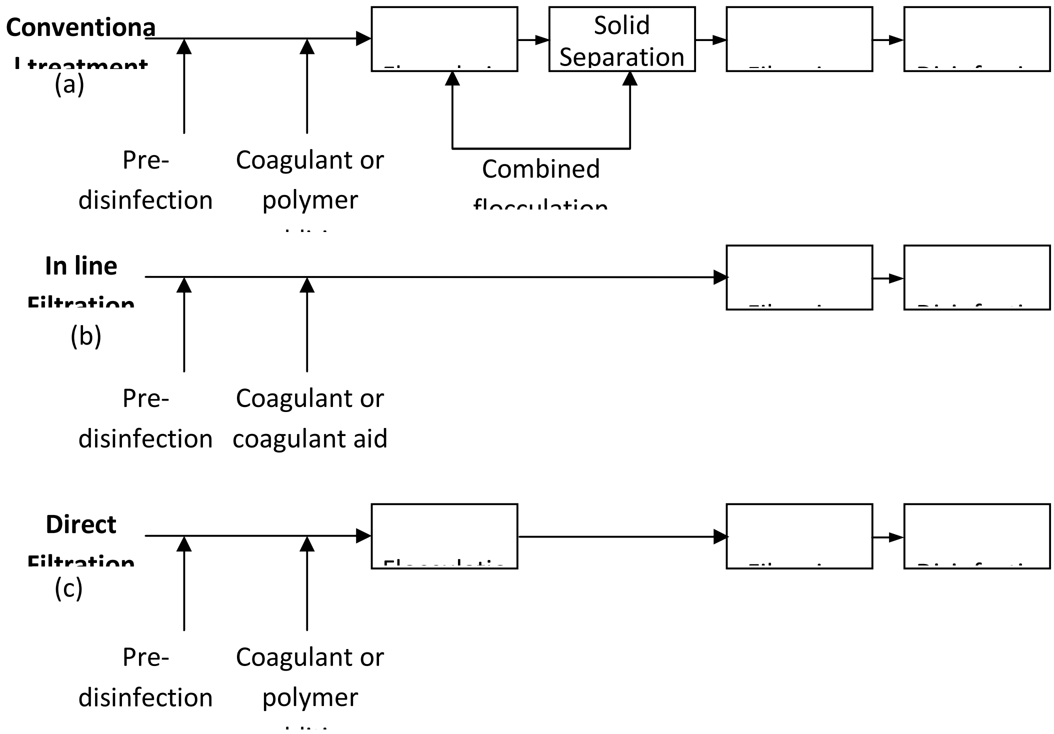

Fig. (1) Water treatment processes for (a) conventional, (b) direct filtration and (c) in-line filtration [6].

These modes had been used and tried extensively in many parts of the world [7-9]. In Iraq most of the works were performed on a laboratory and bench scale experiments [10, 11]. However, none or very few papers tackled statistically the variables involved in the processes. It is the aim of this paper to focus on such issue.

Materials and Methods

A bench-scale laboratory setup was locally manufactured. It consisted of four glass tubes each 53 mm diameter and 73 cm high. Each tube was provided with under-drain system at 25 mm from the bottom. Jar test apparatus, pH meter and thermometer were used to measure related characteristics. The used materials and their characteristics were listed in table (1).

More than 200 test runs were conducted and the results were statistically analyzed using ANOVA and Duncan multiple range test. Such tests are thought to best fit interpretation of the obtained results.

Table (1) **Characteristics of used materials.**

Items	**Characteristics**

Raw water source	**Tigris River**
Raw Turbidity	**Prevailing at water treatment plants.**
Sand material	Two sand types are used with effective size (E.S) of 0.56 mm and 1.1 mm. Uniformity coefficients are 2.32 and 1.48 respectively [5, 13].
Anthracite	One type is used with E.S of 0.93 mm and uniformity coefficient of 1.18 [14, 15].
Filter configuration	Single filters having sand thickness of 25, 35, 45, and 55 cm. Capping media filters having configurations of 15x10, 25x10, 35x10, and 45x10 cm.
Alum	$Al_2(SO_4)_3.16H_2O$, 99.7% pure. Alum is fed to rapid mix unit being diluted to 10% concentration (GT=30000) [14]
Filtration rate	**5 m/hr**
Coagulant aid	**LT22 type with 0.05 mg/l concentration**
pH of raw water	7.84- 8.3
Head loss	Filter run is stopped when effluent turbidity exceeds 1 ntu

Statistical Analysis

The behavior of a set of different single and capping media filters were compared. Each set of (4) filters was run parallel and subject to the same conditions. Statistical methods had been used to help determine the best configuration of used filters in meeting the requirements of this study.

Analysis of variance (ANOVA) and significant difference tests such as, Tukey's test and Schieffe's test are thought to act quite well in this task. However, it is proven that Duncan multiple range test is the most efficient one that may help in this work. The latter test avoids all demerits found in the above-mentioned tests [12]. These tests help finding the effect of the independent parameters included in the study on effluent turbidity and to compare between modes of filtration. The results were considered significant at $p \leq 0.05$.

Fig (2) shows the variable involved in this study. Effluent turbidity is taken as dependent variable and other parameters are independent.

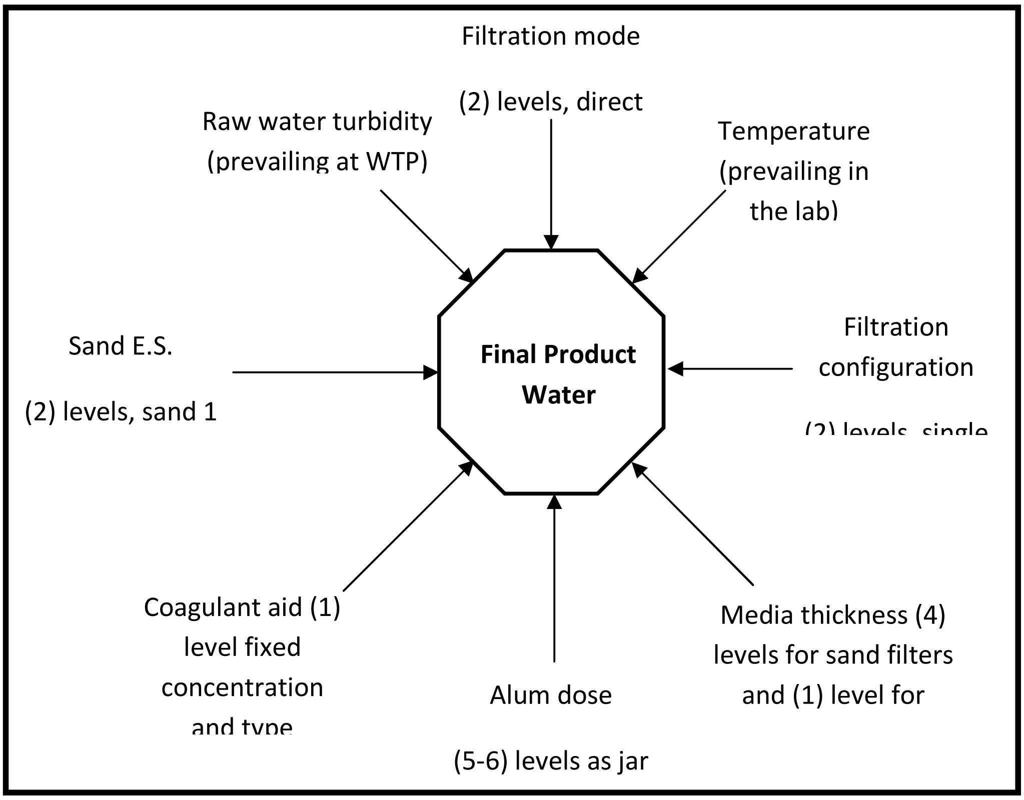

Fig. (2) Variables involved in the experimental design

Results and Discussion

The results of analysis of variance for direct filtration and alum coagulant alone (table 2) show that alum dose has significant effect on effluent turbidity. As shown, when alum dose increases, a better effluent turbidity is obtained for the range of doses used in this research. Additionally, sand effective size has significant effect on effluent turbidity, i.e. the finer sand effective size is better. This is attributed to small pore space that traps more impurities. Also the interaction between alum dose and sand effective size appears to be significant. On the other hand, sand thickness and the existence of anthracite coal with sand show non-significant effect on the dependent variable, since direct filtration is used with low raw water turbidity and all the thicknesses of sand used in this research and anthracite conduct the same effect.

Table (2) Analysis of variance for alum coagulant/Direct filtration.

Source of variation	SS	df	MS	F-value	Sig.
Sand effective size	1.95	1	1.95	44.18	<0.001
Filter type (single or capping)	0.15	1	0.15	3.45	0.07 (NS)
Sand thickness	0.25	4	0.06	1.43	0.23 (NS)
Alum dose	2.82	4	0.70	15.93	<0.001
Sand effective size x Filter type	0.03	1	0.03	0.72	0.40 (NS)
Sand effective size x Sand thickness	0.13	4	0.03	0.74	0.57 (NS)
Filter type x Sand thickness	0.00	2	0.00	0.03	0.98 (NS)
Sand effective size x Filter type x Sand	0.00	2	0.00	0.03	0.97

thickness					(NS)
Sand effective size x Alum dose	2.06	4	0.52	11.66	<0.001
Filter type X Alum dose	0.23	4	0.06	1.28	0.28 (NS)
Sand effective size x Filter type x Alum dose	0.15	4	0.04	0.83	0.51 (NS)
Sand thickness x Alum dose	0.27	16	0.02	0.38	0.98 (NS)
Sand effective size x Sand thickness x Alum dose	0.29	16	0.02	0.41	0.98 (NS)
Anthracite thickness x Sand thick x Alum dose	0.03	8	0.00	0.09	1.00 (NS)
Sand effective size x Filter type x Sand thickness x Alum dose	0.04	8	0.00	0.11	1.00 (NS)
Error	3.54	80	0.04		
Total	12.33	159			

SS = Sum of square, df = degree of freedom, MS = Mean square, Sig. = level of significance, NS = Not significant

When coagulant aid is used, the existence of anthracite coal shows significant effect on effluent turbidity (Table 3). Besides, sand effective size and alum dose still have significant effect on effluent turbidity. Also the bi-interactions between these three parameters show significant effect. These results encourage the use of single media filter with direct filtration for alum coagulant alone, while for capping media filters, coagulant aid is recommended.

Table (3) Analysis of variance for alum and coagulant aid/Direct filtration.

Source of variation	SS	df	MS	F-	Sig.

				value	
Sand effective size	0.03	1	0.03	3.95	0.05
Filter type (single or capping)	0.08	1	0.08	10.40	<0.001
Sand thickness	0.06	4	0.02	2.21	0.08 (NS)
Alum dose	0.19	7	0.03	3.77	<0.001
Sand effective size x Filter type	0.05	1	0.05	6.81	0.01
Sand effective size x Sand thickness	0.01	4	0.00	0.18	0.95 (NS)
Filter type x Sand thickness	0.01	2	0.01	0.87	0.42 (NS)
Sand effective size x Filter type x Sand thick	0.00	2	0.00	0.01	0.99 (NS)
Sand effective size x Alum dose	0.08	4	0.02	2.76	0.03
Filter type x Alum dose	0.11	4	0.03	3.80	0.01
Sand effective size x Filter type x Alum dose	0.02	2	0.01	1.34	0.27 (NS)
Sand thickness x Alum dose	0.03	25	0.00	0.16	1.00 (NS)
Sand type x Sand thickness x alum	0.03	14	0.00	0.28	1.00 (NS)

Anthracite thickness x Sand thick x Alum dose	0.01	8	0.00	0.20	0.99 (NS)
Sand effective size x Filter type x Sand thickness x Alum dose	0.00	4	0.00	0.05	1.00 (NS)
Error	0.61	84	0.01		
Total	1.59	16 7			

NS = Not significant

For the data of in-line filtration and alum coagulant alone, the analysis of the results show that sand thickness and alum dose has significant effect on effluent turbidity, while sand effective size and filter type appears to have non-significant effect (Table 4). This indicates that using single media filter with adequate alum dose and sand thickness will produce better results as they show significant effect on the operation. Also when in-line filtration is used, little importance may be given to sand effective size as it is not significant for this mode of filtration.

Table (4) Analysis of variance for alum coagulant/In-line filtration.

Source of variation	SS	df	MS	F-value	Sig.
Sand effective size	0.02	1	0.0 2	0.75	0.39 (NS)
Filter type (single or capping)	0.02	1	0.0 2	0.71	0.40 (NS)
Sand thickness	0.57	4	0.1	5.61	<0.001

			4		
Alum dose	4.74	8	0.59	23.44	<0.001
Sand effective size x Filter type	0.16	1	0.16	6.39	0.01
Sand effective size x Sand thickness	0.04	4	0.01	0.38	0.82 (NS)
Filter type x Sand thickness	0.04	2	0.02	0.80	0.45 (NS)
Sand effective size x Filter type x Sand thick	0.01	2	0.003	0.11	0.89 (NS)
Sand effective size x Alum dose	0.40	4	0.10	3.94	0.01
Filter type x Alum dose	0.14	4	0.03	1.36	0.25 (NS)
Sand effective size x Filter type x Alum dose	0.07	2	0.03	1.31	0.27 (NS)
Sand thickness x Alum dose	0.28	29	0.01	0.39	1.00 (NS)
Sand effective size x Sand thickness x Alum dose	0.05	14	0.003	0.13	1.00 (NS)
Filter type x Sand thickness x Alum dose	0.07	8	0.01	0.32	0.96 (NS)
Sand effective size x Filter type x Sand thickness x Alum dose	0.02	4	0.01	0.23	0.92 (NS)

Error	2.32	92	0.03		
Total	10.62	183			

NS = Not significant

When coagulant aid is used with alum in in-line filtration, sand effective size shows different behavior and it has significant effect on effluent turbidity (Table 5). Additionally, filter effective size and alum dose are also significant. Based on these results, when it is intended to use coagulant aid with in-line filtration, the type of filter should be considered, in addition to finer effective size of sand and adequate alum dose.

Table (5) **Analysis of variance for alum and coagulant aid/In-line filtration.**

Source of variation	SS	d.f.	MS	F-value	Sig.
Sand effective size	3.16	1	3.16	5.43	0.02
Filter type (single or capping)	9.89	1	9.89	16.99	<0.001
Sand thickness	1.82	4	0.46	0.78	0.54 (NS)
Alum dose	23.90	10	2.39	4.11	<0.001
Sand effective size x Sand thickness	0.09	4	.02	0.04	1.00 (NS)
Filter type x Sand thickness	6.08	2	3.04	5.22	0.01
Sand effective size x Alum dose	1.30	7	0.19	0.32	0.94 (NS)
Filter type. x Alum dose	5.74	2	2.87	4.93	0.01
Sand thickness x Alum dose	18.78	32	0.59	1.01	0.47 (NS)
Sand effective size x Sand thickness x Alum dose	0.12	21	0.01	0.01	1.00 (NS)
Filter type x Sand thickness x Alum dose	11.91	4	2.98	5.11	<0.001

Error	53.57	92	0.58	.	.
Total	133.84	183	.		

NS = Not significant

Table (6) compares the performance of both modes of filtration using different alum doses and sand effective sizes for alum coagulant alone. It is clear that the best effluent turbidity for direct filtration mode can be obtained with alum dose of 7 mg/l or more for sand with ES of 0.56 mm and 9 mg/l or more for sand with 1.1 mm ES. Similarly, when in-line filtration mode is used, the best efficiency is achieved with sand of ES 0.56 mm and an alum dose of (9) mg/l or more only. The same level of effluent turbidity can not be obtained with sand of 1.1 mm ES. These results indicate that direct filtration was more flexible in application with sand effective size and alum dose.

Table (6) Effect of the interaction of type of filtration, sand type and alum dosage on effluent turbidity.

Alum Dose (mg/l)	Direct filtration		In-line filtration	
	Sand Type I	Sand Type II	Sand Type I	Sand Type II
2	-	-	-	0.79 ± 0.07 ij
3	-	-	-	0.63 ± 0.05 h
4	-	-	0.88 ± 0.11 jk	0.65 ± 0.04 hi
5	-	-	0.65 ± 0.04 hi	0.52 ± 0.06 gh
6	-	-	0.44 ± 0.03 fg	0.44 ± 0.03 fg
7	0.23 ± 0.02 a-d	0.93 ± 0.12 k	0.36 ± 0.06 def	0.32 ± 0.02 c-f
8	0.20 ± 0.02 abc	0.38 ± 0.12 d-g	0.31 ± 0.04 b-f	0.43 ± 0.03 fg
9	0.20 ± 0.02 abc	0.25 ± 0.02 a-d	0.15 ± 0.02 a	0.42 ± 0.02 efg
10	0.17 ± 0.01 abc	0.28 ± 0.13 a-e	0.16 ± 0.02 abc	-

11	0.16 ± 0.01 ab	0.28 ± 0.04 a-e	-	-

Means with different letters vertically and horizontally mean significant difference at $p \leq 0.05$.

Filter configurations as related to sand thickness for both modes with alum and coagulant aid are illustrated in table (7). Here when comparing the performance of single media filters, it appears that direct filtration mode show superiority for both sand effective sizes. The performance of in-line mode of filtration gets improved when using capping media filter configuration and sand with 0.56 mm ES. The direct filtration mode does not show any change for both sand effective sizes and filter configuration.

Table (7) Interaction of type of filtration and sand effective size according to sand thickness in capping and single media filters (alum and coagulant aid were added)

Filter Type	Media thickness (cm)	Direct filtration		In-line filtration	
		Sand 0.56 mm ES	Sand 1.1 mm ES	Sand 0.56 mm ES	Sand 1.1 mm ES
Single	25	0.19 ± 0.02 ab	0.16 ± 0.05 a	0.39 ± 0.05 b	0.69 ± 0.13 c
	35	0.17 ± 0.02 a	0.16 ± 0.02 a	0.44 ± 0.06 b	0.62 ± 0.12 b
	45	0.17 ± 0.02 a	0.16 ± 0.02 a	0.41 ± 0.06 b	0.64 ± 0.13 c
	55	0.14 ± 0.02 a	0.14 ± 0.02 a	0.34 ± 0.05 b	0.58 ± 0.11 c
Capping	15 x 10*	0.22 ± 0.03 a	0.32 ± 0.05 a	0.17 ± 0.02 a	0.71 ± 0.12 b

	25 x 10	0.21 ± 0.03 a	0.29 ± 0.04 a	0.14 ± 0.02 a	0.70 ± 0.12 b
	35 x 10	0.19 ± 0.02 a	0.25 ± 0.04 a	0.13 ± 0.01 a	0.58 ± 0.11 b
	45 x 10	0.17 ± 0.02 a	0.22 ± 0.04 a	0.14 ± 0.02 a	0.47 ± 0.09 b

* The first value represents sand thickness, while the second indicates anthracite coal thickness.

Means with different letters horizontally mean significant difference at $p \leq 0.05$.

The interaction between type of filtration and filter configuration for different levels of sand thickness and sand effective sizes (when coagulant aid were used with alum) are shown in table (8). Better results are obtained with single or capping filters when using direct filtration mode for different sand thickness. When in-line filtration mode is used, the same results are obtained with the capping filters only, having sand with effective size of 0.56 mm. From these results it is preferable to use direct filtration since its performance has the flexibility with sand effective size and type of filter. Similarly, capping media filters having finer sand effective size is needed for in-line filtration mode

Table (8) Interaction of type of filtration and filter effective size according to sand thickness and sand effective size (alum and coagulant aid was added).

Sand E.S. (mm)	Media thickness (cm)	Direct filtration		In-line filtration	
		Filter type			
		Single	Capping	Single	Capping
0.56	25	0.19 ± 0.02 a	0.21 ± 0.03 a	0.39 ± 0.05 b	0.14 ± 0.02 a
	35	0.17 ± 0.02 a	0.19 ± 0.02 a	0.44 ± 0.06 b	0.13 ± 0.01 a
	45	0.17 ± 0.02 a	0.17 ± 0.02 a	0.41 ± 0.06 b	0.14 ± 0.02 a
	55	0.14 ± 0.02 a	-	0.34 ± 0.17 b	-
1.10	15 x 10*	-	0.32 ± 0.01 a	-	0.71 ± 0.12 b

	25 x 10	0.16 ± 0.01 a	0.29 ± 0.04 a	0.69 ± 0.13 b	0.70 ± 0.12 b
	35 x 10	0.16 ± 0.01 a	0.25 ± 0.03 a	0.62 ± 0.12 b	0.58 ± 0.11 b
	45 x 10	0.16 ± 0.02 a	0.22 ± 0.03 ab	0.64 ± 0.13 c	0.47 ± 0.09 b
		0.18 ± 0.01 a	0.22 ± 0.01 a	0.51 ± 0.03 c	0.38 ± 0.04 b

The first value represents sand thickness, while the second indicates anthracite coal thickness.

Means with different letters horizontally mean significant difference at $p \leq 0.05$.

Conclusions

Treating the obtained data statistically, it appears that:

1. The effect of anthracite coal is needed only when coagulant aid is used with alum.

2. Filters operating under direct filtration mode show better performance in turbidity removal compared to those acting under in-line mode.
3. Filters working on direct filtration with finer sand effective size are proven to achieve better performance.
4. For filters operating under in-line filtration and alum coagulant alone, little importance is given to sand effective size. However, when coagulant aid is used with alum, filters with finer sand effective size get better performance.
5. Direct filtration mode requires flocs that are less treated with alum than in-line filtration mode.
6. The performance of capping media filters is little improved with in-line filtration mode by adding coagulants. Besides, less sand thickness of filters can be used.
7. For both modes it is not justified to import anthracite as the difference in performance between single and capping media filters is very little. Coagulant aids may improve the performance of filters. However such improvement does not also justify importing these materials and add an economic burden.

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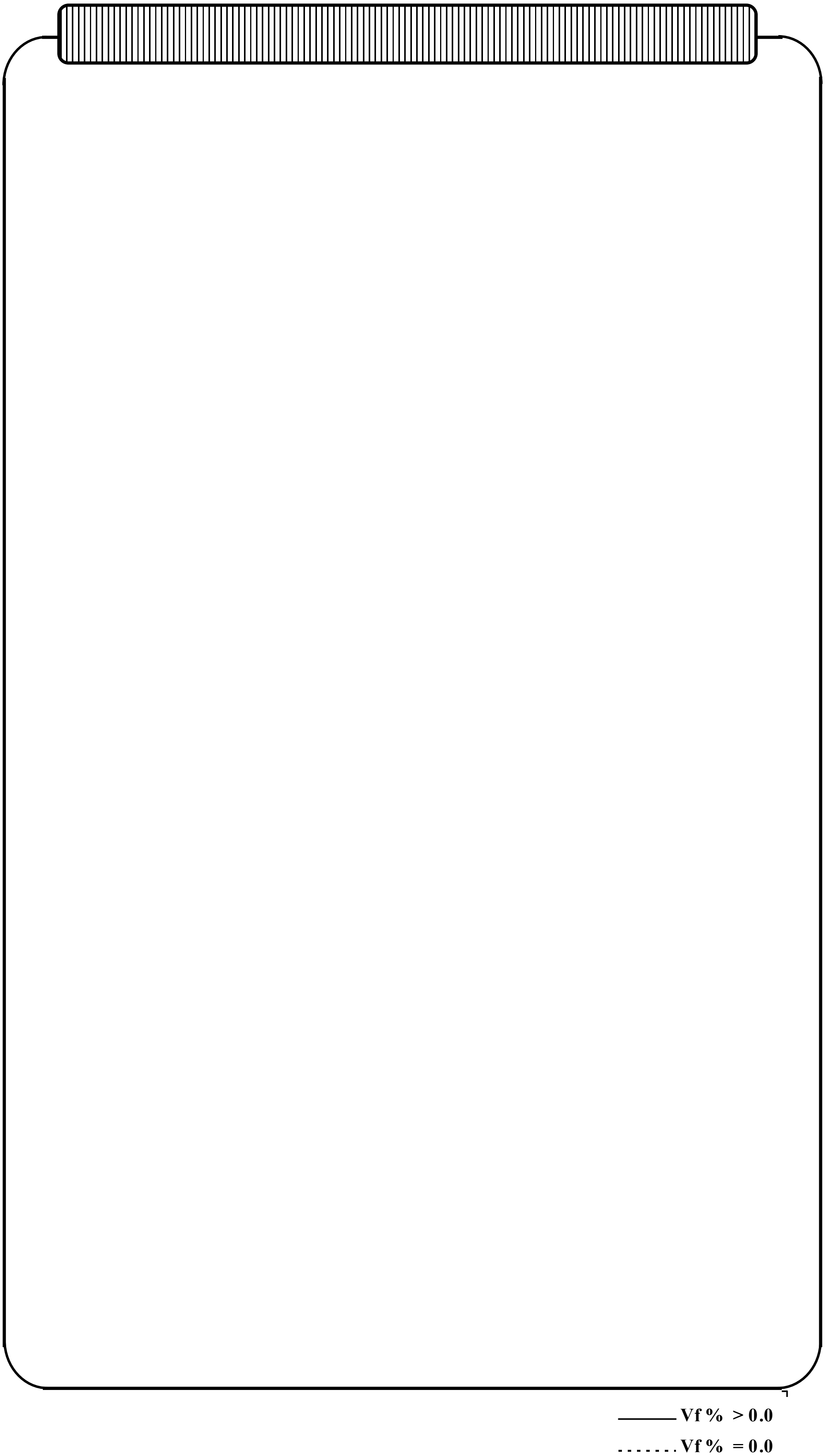

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