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Evolving High Rate Filter and Use of Crushed Stone as Filter Media

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Considerable work has been done on multi-media filters, reverse flow filters and high rate filters. While the data available suggest good possibilities of adopting multi-media filters for high rate filtration, they have not become popular in India, the major cause being non-availability of desired quality of anthracite coal. A study to evolve a high rate filter was taken up. It was restricted to use of local materials such as sand and crushed stone as filter media. Pretreated water from an existing treatment plant was used as influent and models were operated for over a year. The study shows that conventional rapid sand filters can be overloaded to the extent of 100%, provided the pretreatment is adequate. Further, selected crushed stone can be used as filter media instead of sand and can easily be prepared from stone dust which is a waste product at quarries using stone crushers. In practice this can bring about savings at places where good quality sand has to be carted over long distances.

INTRODUCTION

A research study to develop high rate filter with the assistance of the Indian Council of Medical Research was approved during 1974-75. Considerable work has already been done on multi media filters, reverse flow filters and high rate filters in the laboratories. While the available data suggest good possibilities of adopting multi media filters for high rate filtration, they have not yet become popular in this country due to non-availability of desired quality of anthracite coal.

This study was, therefore, restricted to use of local materials and also to incorporate experiments using proper size of crushed stone as filter media.

OBJECTIVES

The objectives of the experiments were

(i) to examine the possibility of evolving a high rate filter using sand

(ii) to study the behaviour of crushed stone as filter media, and

(iii) to study the behaviour of crushed stone as filter media for high rate filtration.

OPERATIONAL PLANNING

To run at least two filter columns initially, one to contain sand and the other to contain crushed stone, were proposed to be operated simultaneously under similar conditions. Since for rapid gravity filters raw water has to be pre-conditioned in this experiment, it was decided to utilize settled water.

Normally is such experiments, the efficiency yardstick is taken as the turbidity. In this case, it was decided to observe also bacteriological test results for the determination of efficiency.

Since the grain size had to be increased for observing the behaviour at higher rates, it was thought proper to observe the depth upto which the filter was really effective. Hence, arrangements were made in the apparatus for tapping samples at different depths.

The experiment was conducted at the Laxmi Narain Giri Filtration Plant (22.5 mld) of the department at Bhopal. Therefore, it was possible to simulate conditions almost identical to that in a full-scale treatment plant for the model and to compare the behaviour of the model *vis-a-vis* that of the treatment plant.

APPARATUS

Filter columns of 100 mm diameter PVC pipes were used. Geometrical similarity with respect to height was maintained and the vertical scale of the model was the same as that of the full size filter. To observe the expansion due to back-wash, slits were cut in the pipes and covered with glass windows. For observing the head loss at different depths in the filter media, manometer tappings were taken at a number of points.

EXPERIMENTATION

Initially, for about a year the experiments were conducted and filter runs were taken simultaneously on crushed stone and sand filter columns, to assess the suitability of crushed stone as a filter media. Thereafter, the rate of filtration was increased keeping the effective size and the uniformity coefficient of the filter media, nearly the same, as in a conventional filter. The objective was to assess the higher filtration rate upto which such filters could be run.

After this test, the effective size of the media in both the filter columns were increased and trial runs taken simultaneously by increasing the filtration rate to the higher

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ranges. Rates of 6 120 lph/m², 7 340 lph/m² and 9 790 lph/m² were tried in this experiment. Since the filter runs at higher rates were of much longer duration, the number of observations had to be reduced.

Initially the turbidity and bacteriological test were conducted very frequently. Later, the frequency was reduced to one sample per day since hourly fluctuation in the behaviour was not observed in the initial runs.

It may be noted that normally, for such experiments, the practice is to test for turbidity and take the same as an index for the efficiency of the filter column. But, as the bacteriological efficiency is of paramount importance, particularly at low turbidity, bacteriological tests were also conducted. The importance of these tests was confirmed by the results so obtained.

OBSERVATIONS AND ANALYSIS

The models were run for more than a year and over 2 000 observations were recorded. Abstract of the observations and their analysis are given in Tables 1-4 and explained below for water settled with alum in settling tanks.

Particle Size

Effective size : 0.4 mm to 0.5 mm, 0.47 mm

Uniformity co-efficient : 1.30 to 1.40, 1.38

Rate of Flow 3 990 l/m²-hr

For a rate of flow of 3 990 l/m²-hr, the turbidity removal of the crushed stone filter model was better than that of the sand model. The mean value of turbidity of the crushed stone filtered water was 1.33 (JTU) whereas that for the sand model was 1.58 (JTU). The standard deviation for both the models were almost identical, being 0.45 and 0.41, respectively. Even though the turbidity of filtered water was greater in both the cases, the increments were only 0.33 in case of CS model and 0.58 in case of sand model. This little increase in the turbidity can be attribued to the PVC filter column having a very smooth surface. The chances of freak turbidity, trickling along the smooth surface of the filter bed cannot be ruled out. It is expected that on a regular bed with slightly coarser surface, this error can be rectified to filter out water with turbidity less than 1.0.

The low standard deviation indicates that the expected values will be close to the mean values. However, a definite conclusion can be that the turbidity removal efficiency of the crushed stone filter is better than that of the sand for this grain size.

Bacteriological test results of the filters indicate that the efficiency of the CS model is far better than that of the sand model, the mean MPN value of the CS filter being almost one-half of that of the sand filter, the mean values being 2.12 for CS model and 3.92 for the sand model.

A very low standard deviation for CS model, about 25% of that of the sand model, indicates that the expected value will not deviate much from the mean value which is already low. The high standard deviation in the sand model for the MPN value, the mean value of which is already about twice that of the CS model, indicates that the probability of getting much higher MPN values in the sand model cannot be ruled out.

Some error can be attributed to the filter columns of the PVC pipes permitting direct entry of organisms from the sides. In a regular filter with coarse side-walls, an expectation of mean MPN value being less than one in the case of CS filter can be considered normal.

For about 2 m head loss, the filter run in the CS model was for 73 hr whereas the same for the sand model was only 41 hr. The low standard deviation of 8 for CS filter model compared to that of 11 for the sand filter model indicates that the variation in the filter run in the case of CS filter will be much lower than that of the sand filter.

Particles Size

Effective Size : 0.7mm
Uniformity Coefficiency : 1.33

Rate of Filtration—3 900 l/m²-hr
(Back wash at 1.829 m head loss)

By increasing the grain size it was observed that the turbidity removal performances of the sand filter model was better than that of the crushed stone filter. The high standard deviation for the crushed stone filter indicates that the deviation in the expected values will be higher. Even the mean values were far above the tolerable limits, even after allowing for the error due to PVC filter columns stated earlier.

Surprisingly the bacteriological removal efficiency of the crushed stone model still remained slightly better than that of the sand model even though the results for both are far below the standards for filtered water *ie*, greater than 50 MPN.

The filter run efficiency of the crushed stone filter model was almost twice that of the sand model, However, standard deviation in the case of crushed stone model was almost twice that of the sand model. Therefore, the variation in the values from the mean for the crushed stone model can be expected to be considerable. Hence the high figure of about 92.33 hr cannot be taken as such while comparing the same with the sand model. Even though the turbidity of filterate for both the models was less than 5, the bacteriological removal efficiencies were very low. The increased filter run in the crushed stone filter model however is of interest.

Rate of Filtration 4 920 l/m²-hr

Whereas the mean values of the turbidity of the filtered water remained almost the same as that in the previous cases (for 3 900 l/m²-hr) the bacterial removal efficiency deteriorated. Similarly, the filter run for both the models reduced considerably. However, in all cases the performance of the crushed stone filter seems to be far better than that of the sand model.

Rate of Filtration 6 000 l/m²-hr

The turbidity of filtered water for both the models remained almost indentical with the filterate turbidity at about 4.0. The bacterial removal efficiency and the filter run both reduced further. However, the crushed stone model behaviour continued to be better than that of the sand model.

Rate of Filtration 7 200 l/m²-hr

For both the models the turbidity of the filtered water was again about 4.0. Turbidity removal efficiency and the filter run did not reduce very much compared to that when run at 6 000 l/m²-hr rate.

TABLE 1 ABSTRACT OF OBSERVATIONS

		Fine Grain		Coarse Grain
		Sand Media	Crushed Stone Media	
Filter Media	Effective Size Uniformity Co-efficient	D10 = 0.44 mm NU = 1.45	D10 = 0.47 mm NU = 1.50	D10 = 0.7 mm NU = 1.33 } Same for both media
Rate of Loading	(a) (b) (c)	4 700 l/m²-hr 7 050 l/m²-hr 9 160 l/m²-hr		6 120 l/m²-hr 7 340 l/m²-hr 9 790 l/m²-hr
Filters	A — Filter with Sand Media B — Filter with Crushed Stone Media			

Period of Observation	Type of Filter	Number of Filter Runs	Rate of Loading, l/m²-hr	Average Loss of Head, cm	Average Filter Run, hr	Turbidity, JTU: Influent Water	Turbidity, JTU: Effluent Water	MPN Coliform in 100 ml of Sample: Influent Water	MPN Coliform in 100 ml of Sample: Effluent Water	Reduction in Turbidity, %	Reduction in MPN Coliform, %	Backwash Water Consumed, %
FINE GRAIN												
Mar 15, '75 to	A	61	4 700	176	16.3	3.6	1.37	—	—	62	—	0.91
July 5, '75	B	61	4 700	170.8	19.4	3.6	1.20	—	—	67	—	0.69
July 10, '75 to	A	11	4 700	180	18.9	12.83	1.64	33	8	87.2	75.8	0.71
July 24, '75	B	11	4 700	178.8	19.81	12.83	1.30	33	6	90	82	0.68
July 25, '75 to	A	9	7 050	179.4	16.8	14.6	1.40	52	10	90.42	80.77	0.76
Aug 18, '75	B	9	7 050	178.8	16.8	14.6	1.36	52	9	90.69	82.70	0.76
Aug 26, '75 to	A	42	9 160	157	10.8	12.8	1.3	28	8	89.85	71.43	1.25
Nov 6, '75	B	42	9 160	112	10.4	12.8	1.18	28	4	90.79	85.73	1.3
Nov 7, '75 to	A	19	9 160	185	27	10.5	1.18	—	—	88.77	—	0.5
Dec 5, '75	B	13	9 160	168	41	10.5	0.87	—	—	91.72	—	0.34
Dec 8, '75 to	A	19	4 700	185	17	4.02	1.86	46	5	53.7	89.14	0.68
Dec 24, '75	B	16	4 700	167	22	4.02	1.56	46	2	61.16	95.5	0.65
Dec 25, '75 to	A	13	4 700	196	24	4.07	1.33	35	1.4	67.33	96	0.60
Jan 24, '76	B	10	4 700	185	39	4.07	0.81	35	1	80.10	97.15	0.38
Feb 10, '76 to	A	15	4 700	196	29	4.8	1.46	37	1.4	69.6	96.4	0.48
Mar 4, '76	B	13	4 700	186.5	32	4.8	0.75	37	0.1	84.4	97.3	0.44
COARSE GRAIN												
Sep 20, '76 to	A	5	6 120	180	99	7.33	1.46	—	—	80.1	82.5	2.2
Oct 19, '76	B	5	6 120	180	110	7.33	1.31	—	—	82.2	86.6	2.2
Oct 19, '76 to	A	6	9 790	180	56	5.9	1.25	—	—	78.82	84	2.4
Dec 2, '76	B	6	9 790	180	94	5.9	1.03	—	—	83	90.6	2.4
Dec 13, '76 to	A	2	7 340	180	94	6.5	1.3	—	—	80	—	—
Dec 31, '76	B	2	7 340	180	102	6.5%	1.1	—	—	83.5	—	—

TABLE 2 ANALYSIS OF SETTLED WATER

Rate of Flow, l/m²-hr	Test	Raw Water Mean	Raw Water SD	Filtered Water Crushed Stone Mean	Filtered Water Crushed Stone SD	Sand Mean	Sand SD	Filter Run, hr Crushed Stone Mean	Filter Run, hr Crushed Stone SD	Sand Mean	Sand SD
						C Stone	Sand				
	Effective Size					0.47 mm	0.45 mm				
	Uniformity Coefficient					1.38	1.33				
	Head Loss 2m										
3 990	Turbidity	6.8	0.26	1.33	0.45	1.58	0.41	—	—	—	—
	MPN	72.36	29.61	2.12	0.60	3.92	2.53	—	—	—	—
	Filter Run	—	—	—	—	—	—	73	8	41	11
9 776	Turbidity	7.1	0.24	0.88	0.15	1.62	0.98	—	—	—	—
	MPN	90.91	49.23	4.13	2.35	7.09	3.00	—	—	—	—
	Filter Run	—	—	—	—	—	—	96	23	74	—
						C Stone	Sand				
	Effective Size					0.7 mm	0.7 mm				
	Uniformity Coefficient					1.33	1.33				
3 900	Turbidity	23.62	2.43	4.25	0.64	3.87	0.25	—	—	—	—
	MPN	150	—	52	—	59	—	—	—	—	—
	Filter Run	—	—	—	—	—	—	92.33	16.44	51.00	9.89
4 920	Turbidity	17.8	5.92	4.04	0.95	4.38	2.38	—	—	—	—
	MPN	360	223.7	61.6	6.27	89	24.67	—	—	—	—
	Filter Run	—	—	—	—	—	—	60.63	16.1	25.72	5 32
7 200	Turbidity	13.12	1.61	3.95	0.47	3.95	0.31	—	—	—	—
	MPN	165	38	82.55	18.55	105.62	21.09	—	—	—	—
	Filter Run	—	—	—	—	—	—	49.33	11.84	27.71	7.27
						C Stone	Sand				
	Effective Size					0.4 mm	0.45 mm				
	Uniformity Coefficient					1.38	1.38				
	Filter Run Constant = 18 hr (Hf = Variable)										
3 990	Turbidity	6	3.88	1.83	0.316	1.43	0.37	—	—	—	—
	MPN	33.33	3.44	—	—	—	—	—	—	—	—
	Head Loss	—	—	—	—	—	—	137.27	12.87	137.88	12.88
6 000	Turbidity	14.44	3.49	1.45	0.31	1.46	0.31	—	—	—	—
	MPN	42.5	5.77	4.00	2.24	4.69	2.92	—	—	—	—
	Head Loss	—	—	—	—	—	—	133.60	7.64	130.3	5.56

Some experiments were also carried out by adding artificial turbidity to the settled water. The filters were run at 6 000 l/m²-hr and 7 200 l/m²-hr. The results obtained were almost identical to those when run without artificial turbidity. However, the bacterial removal efficiency deteriorated still further.

INFERENCES

In almost all cases, the performance of the crushed stone media filter model was better than that of the sand media filter model with respect to : (a) turbidity removal, (b) bacterial removal and (c) filter run.

The average percentage removal of turbidity and bacterial removal is given below

Percentage Removal	Rate of filtration, 80 lpm/m² Sand Media	Rate of filtration, 80 lpm/m² Crushed Stone Media	Rate of filtration, 160 lpm/m² Sand Media	Rate of filtration, 160 lpm/m² Crushed Stone Media
Turbidity	76.7%	80.44%	77.18%	87.60%
Bacterial	69.5%	97.07%	92.2 %	95.45%

These results show that a conventional filter could operate at double the normal rate filtration without the loss of efficiency.

Analysis of the results obtained from filter media of effective size 0.7 mm and uniformity co-efficient 1.33 indicates that the filtered water quality deteriorated both in terms of turbidity and bacterial removal.

CONCLUSION

Conventional rapid sand gravity filters have been constructed and operated at the rate of 80-100 lpm/m². These results show that selected crushed stone could be used as filter media without deterioration in the performance of filter.

Crushed stone filter media could be easily prepared out of the waste dust from stone quarries, where good quality sand has to be carted over long distances. In practice this could bring about savings in the cost of construction.

Conventional rapid sand filters which are normally designed for a rate of filtration of 80-100 lpm/m² could

TABLE 3 COMPARATIVE STATEMENT OF BACTERIOLOGICAL REMOVAL OF EXISTING 5 MGD TREATMENT PLANT AND FILTER MODELS

Loading Dates (1976)	MPN Coliform in 100 ml Sample from 22.5 MLD Water Treatment Plant			MPN Coliform in 100 ml Sample of Effluent Water from Filter Models (6 120 l/m²-hr)	
	Raw water	Settled water	Filtered water	Filter-A	Filter-B
Sep 17	920	139	Nil	49	52
Sep 19	540	119	Nil	21	28
Sep 20	350	31	Nil	2	Nil
Sep 21	220	19	Nil	3	2
Sep 22	443	43	3	11	13
Sep 23	649	71	4	13	10
Sep 27	920	131	Nil	4	2
Sep 28	649	64	Nil	7	4
Sep 29	350	39	Nil	3	Nil
Sep 30	220	29	Nil	1	1
Oct 1	1 600	162	5	47	51
Oct 5	920	139	Nil	17	7
Oct 8	350	71	Nil	3	2
Oct 11	540	139	2	19	11
Oct 12	540	71	Nil	17	13
Oct 13	350	61	3	11	7
Oct 14	480	59	Nil	12	8
Oct 15	350	37	Nil	4	1
Oct 16	726	49	Nil	9	4
Oct 18	540	61	Nil	10	3

Note : A — Filter Model filled with Sand Media.
B — Filter Model filled with Crushed Stone Media

TABLE 4 COMPARATIVE STATEMENT OF BACTERIOLOGICAL REMOVAL OF EXISTING 5 MGD TREATMENT PLANT AND FILTER MODELS

Loading Dates (1976)	MPN Coliform in 100 ml Sample from 22.5 MLD Water Treatment Plant			MPN Coliform in 100 ml Sample of Effluent Water from Filter Models (9 776 l/m²-hr)	
	Raw water	Settled water	Filtered water	Filter-A	Filter-B
Oct 26	540	131	4	23	17
Oct 27	643	189	3	27	11
Oct 29	920	81	3	21	9
Nov 1	540	64	Nil	13	6
Nov 2	920	71	Nil	11	5
Nov 4	643	109	Nil	14	4
Nov 5	1 600	84	2	19	7
Nov 8	920	49	Nil	11	2
Nov 9	540	29	Nil	9	4
Nov 15	1 600	162	7	7	Nil
Nov 16	2 400	189	4	43	29
Nov 17	920	151	Nil	49	33
Nov 19	930	137	Nil	Filter	Closed
Nov 20	540	79	1	-do-	
Nov 22	350	64	Nil	13	9
Nov 23	350	49	4	11	7
Nov 24	540	52	Nil	13	17
Nov 25	920	64	Nil	5	4
Nov 29	350	39	Nil	7	3
Nov 30	540	79	Nil	6	2

Note : A — Filter Model filled with Sand Media
B — Filter Model filled with crushed Stone Media

be overloaded to the extent of 100% without deterioration in the quality of filtered water provided the pretreatment of water is adequate and the turbidity of the inlet water is normally below 20 (JTU). Wherever augmentation is needed in stages pretreatment facilities can be added and existing filters can be overloaded upto a rate of filtration of 160 lpm/m² of the filter area by suitably modifying the inlet and outlet arrangements. Such modification of the existing units will cost only a small fraction of the cost of duplication of the filter beds.

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DISCUSSIONS

H A Sabannavar

1. What is the maximum turbidity of clarified water allowed before filtration.

2. What is the frequency of back washings.

Author

1. Set-I experiments: 12 JTU, Set-II: 20 ppm.

2. This is given in the paper.

A K Seth

Crusheds tone particles are usually of angular shape, whereas the river sand has rounded edges. With continuous use and friction during backwash, crushed stone particles may also get rounded, and may vary in size, *ie*, effective size and uniformity coefficient. Was any sand analysis was conducted after the experimentation and if so, was any difference in effective size and uniformity coefficient noted ?

Author

The filter was run for a period of 1 year and in that short period there was not much change. IIT, Kanpur has proposed to take up further studies on this.

S Bandyopadhyay

1. In crushed stone surface roughness and absorption characteristics may be better than water-rounded natural gravel and sand. There may be some flocculant obtained from leaching. Can these be the reason for higher efficiency ?

2. Could the coke breeze from coke ovens as replacement of anthracite and crushed slag, graded, in place of crushed stone/gravel be considered as filtration media ?

Author

1. Yes please.

2. May be used in dual media filters.