Treatment of Spent Filter Backwash Water Using the Leopold® Clari-DAF™ (Dissolved Air Flotation) System

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ABSTRACT

There is increasing interest in treating recovered spent filter backwash water in the drinking water industry. The Environmental Protection Agency (EPA) Filter Backwash Recycling Rule (FBRR) has come into effect, the purpose of which is to prevent concentrations of pathogens that may be present in filter backwash water from being returned to the head of the water treatment plant without some form of treatment or dilution. By treating this flow, the operating utility can better manage both public health and financial liability. Dissolved Air Flotation (DAF) employing the Leopold® Clari-DAF™ system was investigated as a possible technology alternative to simple or advanced sedimentation techniques. This application is not widespread, but sits somewhere in between the two normal applications of high-solids sludge thickening and low-turbidity clarification. Given this, a pilot plant program, supported by jar testing, was undertaken to determine the process capability and the design parameters for this application.

The Leopold Clari-DAF system proved very suitable for backwash water recovery. Effluent turbidities of <1.0 NTU were easily obtained when raw water turbidities were >50 NTU. Chemical requirements were low with only a single low dose of polymer required to bind the floc particles to form a solids matrix suitable for flotation. Flocculation contact times ranged from 0 to 10 minutes, depending on the nature of the raw water. Recycle rates as low as 5% performed satisfactorily with no significant improvement when increased to 20%. Sludge solids were 3.5% to 9.6% dry solids, and very low volumes of sludge (<0.1% of the incoming flow) made the solids handling system very compact.

KEY WORDS

Filter backwash water; DAF; flocculation; sludge; recycle; chemistry.

INTRODUCTION

The practice of recycling the spent filter backwash water from rapid gravity filters in a water treatment plant (WTP) has long been regarded as acceptable. Many different methods are employed in this practice. Some plants have state-of-the-art membrane units that treat the water to finished water quality. However, the general treatment step is simple storage in lagoons or ponds and then direct return to the head of the plant with only minimal or no treatment. Increasing awareness of the risks posed to the integrity of the WTP by recycling the filter backwash water without treatment to remove pathogens and their vectors, has resulted in many studies being undertaken and regulations developed to control this risk (USEPA, 2000) A complete technology study has been undertaken by the American Water Works Research Foundation (AWWARF) to evaluate various treatment options and technologies for this application along with estimated costs (AWWA Research Foundation, Project Paper). This study formed in part the evaluation of the DAF technology for filter backwash recovery, and the major experimental findings are presented from the Clari-DAF system pilot plant program, along with some back-up information from Clari-DAF jar testing studies.

METHODS

The pilot plant used in the program was the Leopold Clari-DAF system mobile pilot WTP. It includes variable coagulation chemistry, variable flocculation time/energy, variable DAF loading rate, a sludge removal system, and two gravity flow filter columns 10 ft (3m) tall with a 1 ft^2 ($0.1m^2$) cross section. On-line data is recorded every 5 minutes, 24 hours a day, creating a large data set from which the process performance can be understood. A schematic of the pilot plant is shown in Figure 1. Sludge samples were taken from a full desludge holding tank to get representative data on solids quality and quantity.

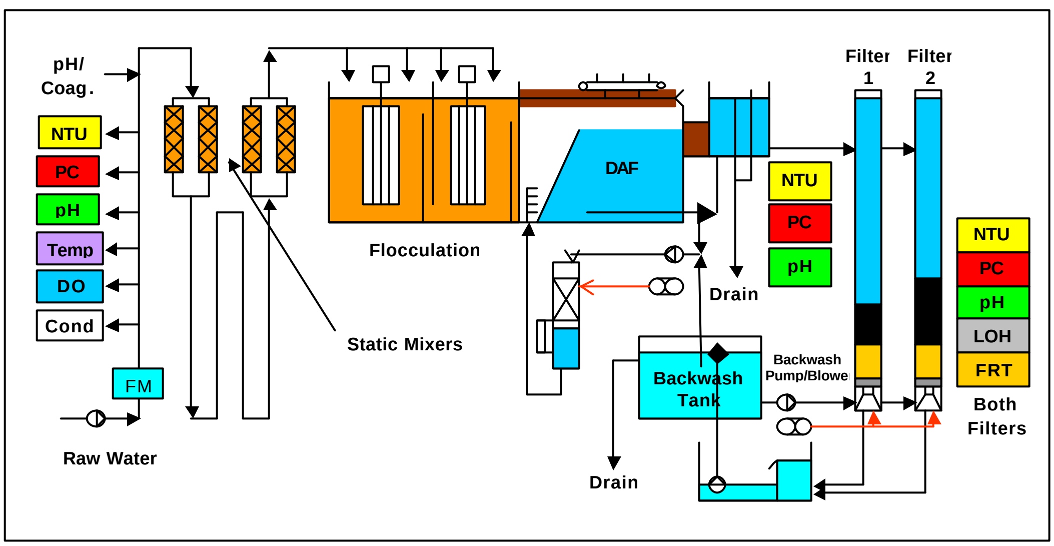

Figure 1. Schematic of the Clari-DAF System Mobile Pilot Water Treatment Plant Used in the Backwash Water Recovery Study Program.

On-line turbidity measurements were made using the HACH 1720C low-range turbidity meters, particle counts were made by HACH 1900WPC units, with constant supervision for correct operation. All instruments were calibrated in accordance with manufacturers' instructions or factory calibrated prior to commencement of the study. Electromagnetic flow meters were checked using a rise test where possible to verify rate of flow, and hence loading rates and recycle rates. Iron (Fe) and manganese (Mn) concentrations were determined on-board the pilot plant using the HACH 2010 Spectrophotometer and standard test kits. Suspended solids and sludge dry solids results were obtained using standard methods.

For high-range turbidities experienced in some of the pilot plant studies (>100 NTU), a HACH ratio turbidity meter was required. Specific volumetric dilutions were used on high iron and manganese waters to get meaningful data.

RESULTS

Filter Backwash Water Quality

When a rapid gravity filter is washed the quality of the water changes with time. The initial effluent quality is heavy in solids from the surface filtration load on the filter and the majority of the displaced turbidity in the depth of the filter. This gives a very large spike in a turbidity-vs.-time trace for a backwash water. However this tends to die off quickly to a background low level, depending on the type of filter wash regime. An example of a typical turbidity curve is given in Figure 2.

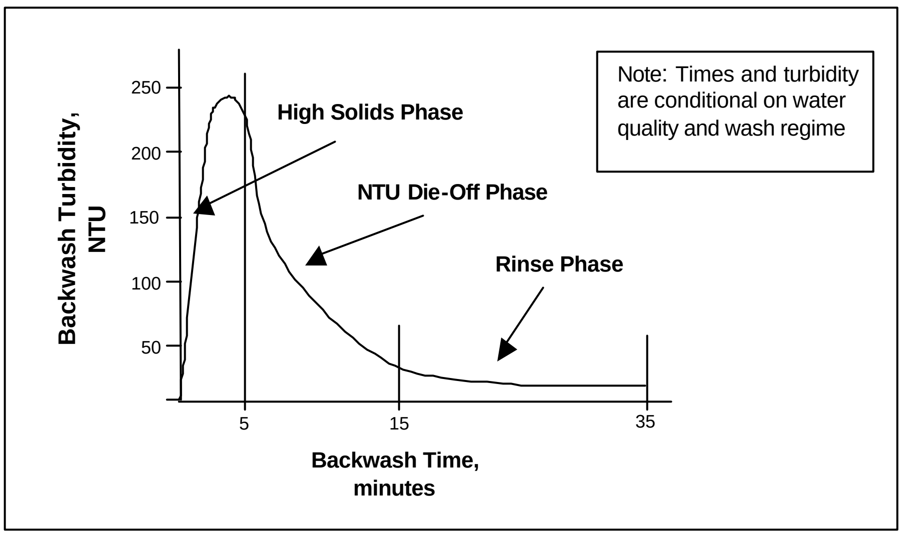

Figure 2. Typical Filter Backwash Turbidity Profile of a Rapid Gravity Filter.

The peak turbidity of backwash waters from pressure filters can be as high as 2,500 NTU and very long in duration, but with a die-off phase of only a few minutes.

High turbidity peaks are also often associated with high iron and manganese events. This must be carefully considered when returning the backwash untreated because the concentration effect of the filters may overload the WTP if the backwash is delivered as a slug. Table 1 gives data on turbidity, iron, and manganese concentrations from the five Clari-DAF system studies.

Table 1
Backwash Water Quality Results of Clari-DAF System Studies

Location	Study Type	Minimum mg/l			Average mg/l			Maximum mg/l		
	JT/PP	***NTU***	***Fe***	***Mn***	***NTU***	***Fe***	***Mn***	***NTU***	***Fe***	***Mn***
Camden, N.J.	JT	145	35	40	1540	373	70	2880	951	120
Wanaque, N.J.	JT	2.1	—	—	11.9	—	—	91	—	—
Durham, N.C.	PP	34	1.20	0.15	188	2.50	0.18	730*	3.10	0.20
Betasso, Colo.	PP	8	0.30	0.02	30	1.90	0.07	+100	2.40	0.08
Cleveland, Oh.	PP	15	0.02	0.14	30	0.15	0.25	75	0.24	0.40

PP = Pilot Plant; JT = Jar Testing
*Suspected back-mixing of settled sludge in line causing high turbidity.

The pH of the backwash water tended to be stable at 7.0, in the range of the treated finished water. Washing with chlorinated backwash did change the pH, but not significantly.

Turbidity Removal by the Clari-DAF System

The industry standard for monitoring clarification process performance is turbidity measurement. Figure 3 charts the data for the turbidity removal by a Clari-DAF system pilot plant study conducted in Cleveland, Ohio. Of note is the stability of the Clari-DAF system effluent turbidity in relation to the changes in raw water turbidity. The percentage removal values were excellent, with an average 95% removal of turbidity and a peak of 98.9%. Turbidity removal results for all five studies are provided in Table 2.

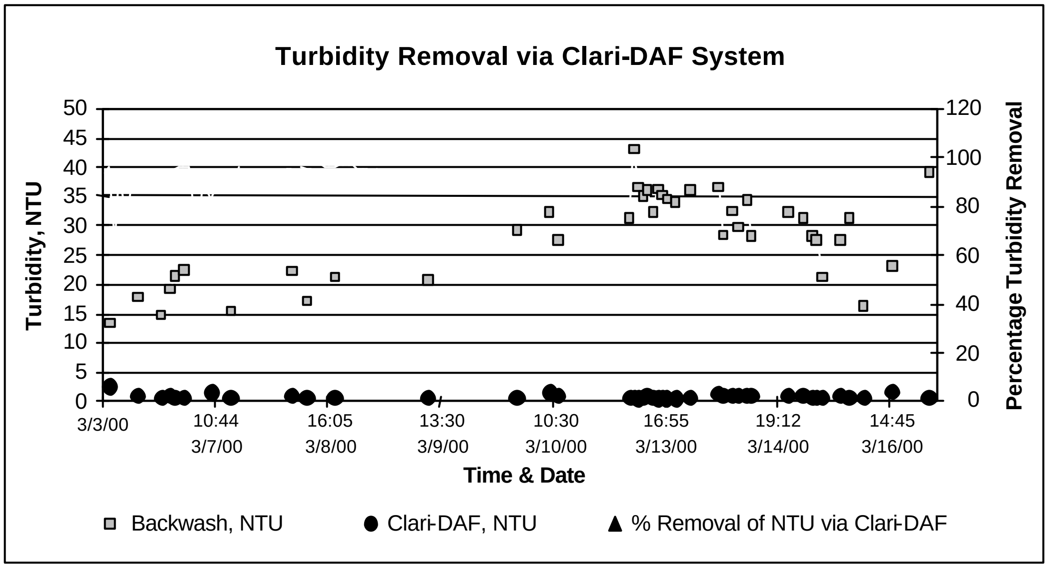

Figure 3. Turbidity Removal Results Cleveland, Ohio Clari-DAF System Pilot Plant Study.

Table 2
Percentage Turbidity Removal by the Clari-DAF System

Location	Raw Water Turbidity, Avg NTU	Clari-DAF Effluent Turbidity, Avg NTU	Turbidity Removal, Percentage NTU
Camden. N.J.	2,880	16	99.4
Wanaque, N.J.	11.9	0.52	95.6
Durham, N.C.	149	6.7	95.5
Betasso, Colo.	60	2.8	95.3
Cleveland, Oh.	25.2	1.13	95.5

*Specific to a test run and not full study data.

Effect of Polymer Dose

Table 3 provides data from four of the studies showing the effect of increasing the polymer dose on Clari-DAF system performance. No primary coagulants were used in any of the studies because they were not necessary to build the floc structure. Figure 4 presents data from the Durham, North Carolina study of the direct affect of polymer dose on removal of turbidity by the Clari-DAF system.

Table 3
Effect of Polymer Dose on Clari-DAF System Performance

Polymer Dose, ppm	Wanaque, N.J., NTU	Durham, N.C., NTU	Betasso, Colo., NTU	Cleveland, Oh., NTU
Raw Water	**35**	**672**	**60**	**35**
0	3.5	143	30	4.5
0.1	0.25	8.5	0.9	1.8
0.2	0.10	9.8	0.5	1.3
0.3	0.15	2.1	0.5	1.0
0.4	0.15	2.4	—	0.9

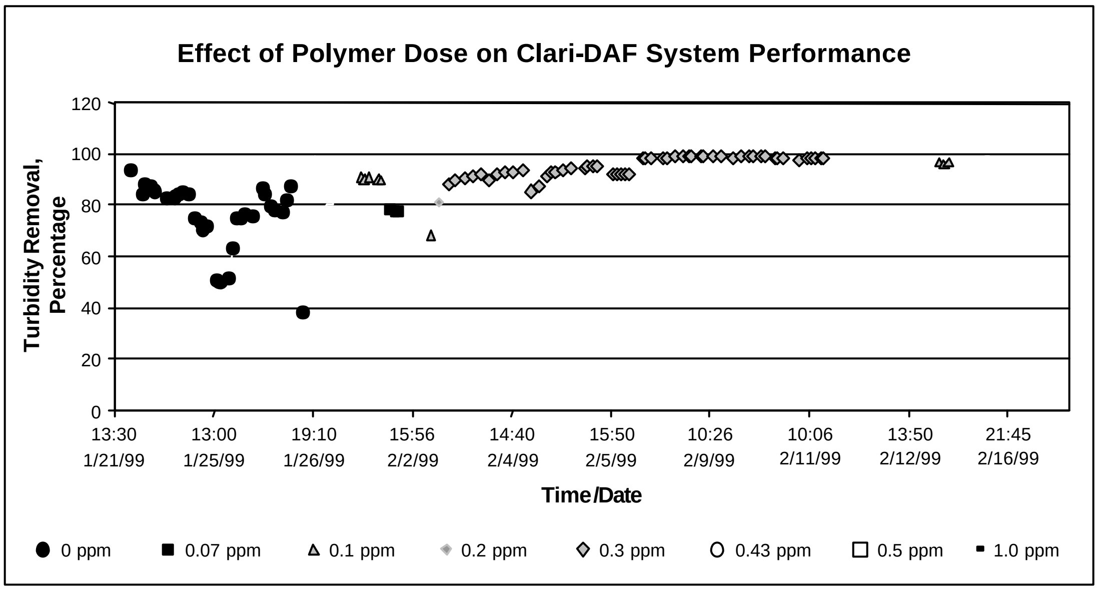

Figure 4. Effect of Polymer Dose on Clari-DAF System Turbidity Removal, Durham, N.C.

Iron Removal

Post-filtration iron is almost 100% oxidized and is in particulate form, enabling the Clari-DAF system to remove high percentages, as shown by the data in Table 4. Iron residuals in Clari-DAF system effluent are typically less than the 0.3 mg/l MAC (maximum acceptable concentration) for finished water, imposing no load on the main WTP.

Table 4
Iron Removal by the Clari-DAF System

	Raw Water Fe Residual, mg/l (Total)			Clari-DAF Effluent Fe Residual, mg/l (Total)			Fe Residual Removal, Percentage
	Min	***Avg***	***Max***	***Min***	***Avg***	***Max***	***Avg***
Cleveland, Oh.	0.02	0.14	0.24	N/D	0.009	0.04	93
Camden, N.J.	—	—	951	1.35	1.56	1.71	99
Durham, N.C.	—	3.1	0.2	0.23	023	0.28	93
Betasso, Colo.	0.27	1.53	0.11	0.11	0.11	0.12	95

N/D = None Detected

Manganese Removal

Because there is no appreciable additional oxidation in the Clari-DAF system process, any observed manganese removal is particulate manganese only. This can be seen in the Betasso, Colorado study data in Table 5. The Clari-DAF system removed the majority of the particulate manganese from the backwash water. The filters removed little thereafter, leaving dissolved manganese in place.

Table 5
Clari-DAF System and Filter Manganese Removal, Betasso, Colorado Study

Sample No.	Raw Water Mn, mg/l	Clari-DAF Effluent Mn, mg/l	Percentage Mn Removal, Raw/DAF	Filter Mn, mg/l	Percentage Removal, Raw/Filter	Additional Percentage Removal by Filter
S1	0.018	0.015	17	0.011	39	22
S2	0.082	0.021	74	—	—	—
S3	0.078	0.018	77	0.012	85	8

In most studies the Clari-DAF system kept Mn levels below the 0.05 mg/l MAC for finished water.

Effect of Recycle Rate on Clari-DAF System Performance

Studies were undertaken to determine the amount of recycle required to achieve acceptable performance. The recycle system used was a packed-tower-type saturator with constant-flow and actuated air feed operating at a pressure of 85 psig (5.8 Bar). Clarified effluent was used in all pilot plant studies after suitable treatment had been achieved. Figure 5 illustrates data from the Durham, North Carolina study, which was mirrored by results of the Cleveland, Ohio and Betasso, Colorado studies.

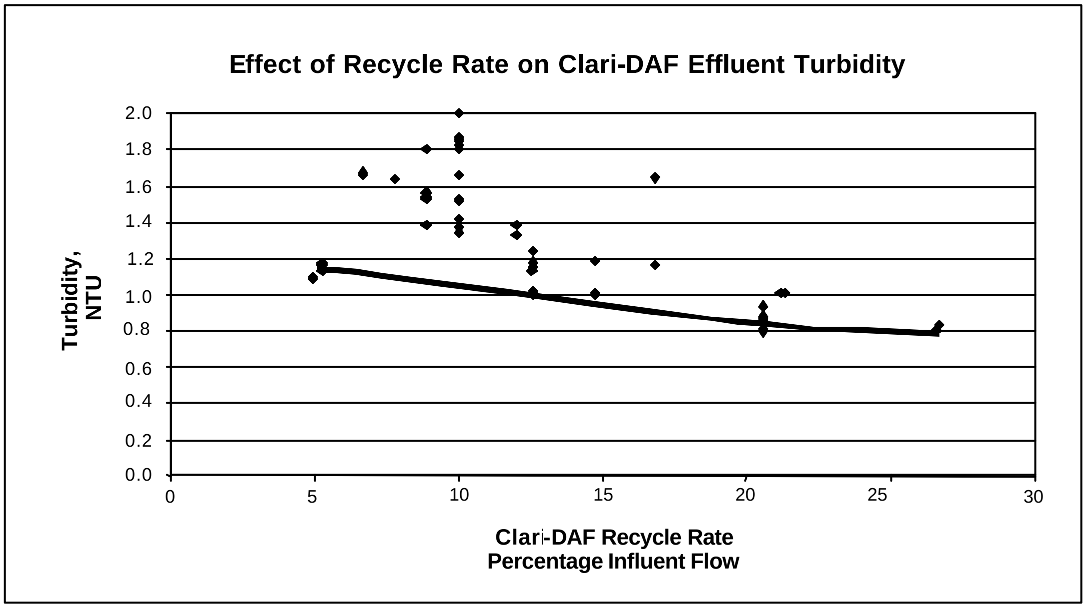

Figure 5. Effect of Recycle Rate on Clari-DAF Performance, Durham, N.C.

Clearly, the recycle rate has an affect on Clari-DAF system performance. However it is only marginal compared to the raw water turbidity. A study range of 5% to 25% yielded very similar results, giving rise to the possibility of a low-cost recycle operation for the Clari-DAF system in this application.

Effect of Flocculation Contact Time on Clari-DAF System Performance

Pre-filtered floc particles in the backwash water retain their initial structure. In the studies, only polymer was required to build suitable floc, indicating that long flocculation times might not be necessary. The data in Table 6 confirms this.

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Table 6
Effect of Flocculation Contact Time on Clari-DAF System Performance.

Flocculation Contact Time, Minutes	No. of Stages	Percentage Removal of Turbidity			
		Betasso, Colo.	Durham, N.C.	Cleveland, Oh.	Wanaque, N.J.
0	0	97	—	96	99
5	1	—	—	97	98
10	1	98	94	—	—
15	2	99	95	—	—
20	2	99	99	98	—
25	2	—	99	—	—
30	2	—	99	—	—

Flocculation time does not appear to be a dominant factor in Clari-DAF system performance.

Effect of Loading Rate on Clari-DAF System Performance

The Clari-DAF system was found to be unaffected by loading rate. Figure 6 illustrates data from the Betasso, Colorado study, showing little significant change in Clari-DAF system effluent turbidity as loading rate increases. Lower percentage removal at low loading rates is due to low influent turbidity.

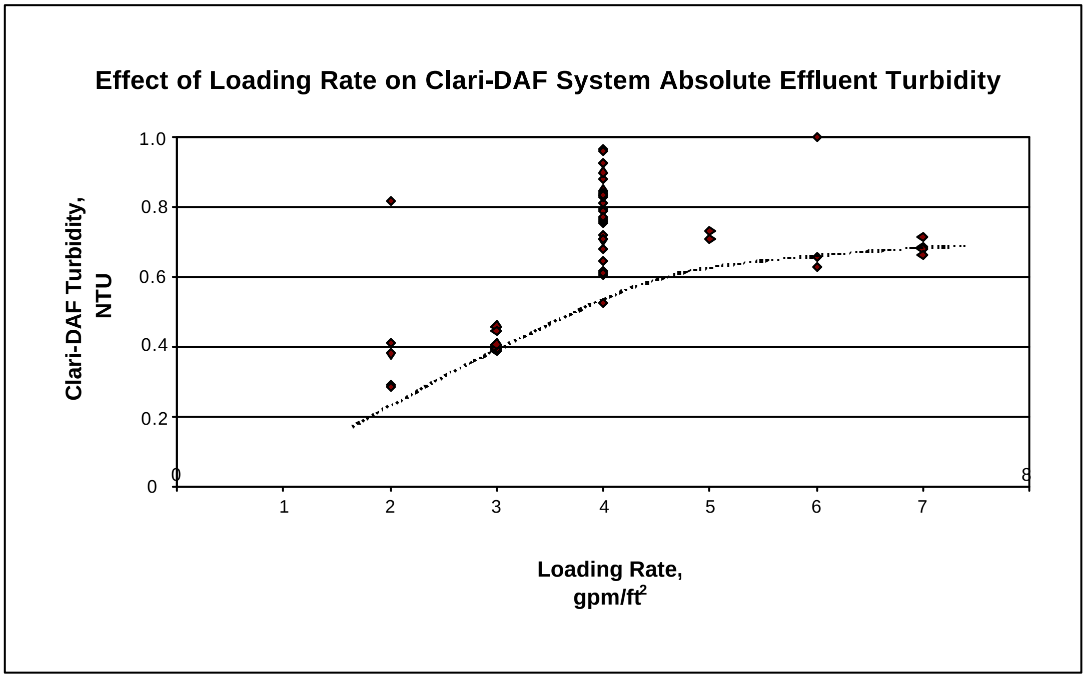

Figure 6. Effect of Loading Rate on Clari-DAF System Performance

Sludge Solids Quality and Quantity

All clarifiers are solid/liquid separators, and as such, studies on sludge quality and quantity must be undertaken in conjunction with clarifier turbidity removal. Table 7 shows the ability of the Clari-DAF system to produce a low volume of high-solids sludge, which maximizes the recycle flow to the head of the plant and minimizes the amount of residuals that need subsequent treatment and disposal.

Table 7
Clari-DAF System Sludge Production

Location	Dry Solids, Percentage			Inlet Volume, Percentage		
	Min	*Max*	*Avg*	*Min*	*Max*	*Avg*
Betasso, Colo.	1.57	3.57	2.56	0.04	0.49	0.16
Cleveland, Oh.	1.79	6.22	2.85	0.09	0.17	0.11
Durham, N.C.	3.1	4.8	5.1	0.12	0.17	0.15
Surface Samples	6.9	7.1	7.0	—	—	—

DISCUSSION

It is evident from the data obtained by the Clari-DAF system pilot studies that the Clari-DAF system is capable of treating the spent filter backwash water to a high degree. The level of required treatment is always site-specific; however, there are two water qualities that are operationally acceptable: raw water quality and clarified water quality. The latter is preferred because it allows for a high-quality return to the head of the plant, and in the event of a non-optimized unit process, a built-in safety factor. Raw water quality is acceptable, and in some ways is more appropriate, because the WTP chemistry then only needs to be flow-paced to maintain good performance without managing backwash flow quality. However, if the target is raw water quality in terms of turbidity, then data needs to be collected on the removal of the pathogens in addition to turbidity because one does not evidence the other. Also, should the unit process go out of optimized operation, what is the effect on the main plant? In addition to water quality, the advantages of using a Clari-DAF system in the filter backwash recycle mode affect overall system footprint. The footprint of the Clari-DAF system itself is small because it can handle high loading rates (5 to 7 gpm/ft^2). Moreover, in terms of full-system design, little space is required for sludge management and disposal. This is unique to DAF and the Clari-DAF system, which produces very low volumes of sludge and high dry solids that can be dewatered directly without additional thickening systems. The cost of operation of the Clari-DAF system is largely associated with the recycle system and polymer usage. At 5% to 10% required recycle for a specific water quality, and only <0.3 mg/l polymer required, the Clari-DAF system can be very cost effective for backwash water recovery.

CONCLUSIONS

- The Clari-DAF system is capable of treating a wide range of spent filter backwash water qualities to clarified or raw water quality in the range of 1 to 3 NTU.
- Typical loading rates for design are 5 to 7 gpm/ft^2.
- Typical polymer dose required is 0.1 to 0.5 mg/l, the polymer type being site-specific.
- Flocculation contact time required is in the range 0 to 10 minutes with low to medium energy required to build floc.

- Sludge solids were found to be site-specific but in the range of 3% to 7% dry solids and consequently very low volumes in the order of <0.1% of the incoming flow to the Clari-DAF system.
- Recycle rate in the range of 5% to 25% did not significantly affect the Clari-DAF system performance.
- The Clari-DAF system can be cost effective in operation when recovering spent filter backwash water.

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