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The Trickling Filter/Solids Contact Process: Application to Army Wastewater Plants

by
Richard J. Scholze

More than half of the Army's wastewater treatment plants use trickling filter technology to provide secondary treatment. With the growth in regional population at many installations, there is concern that trickling filters alone may not be able to handle the additional loads generated. Moreover, this form of secondary treatment will need to be enhanced in order to produce an effluent meeting stricter environmental regulations.

Several add-on and replacement techniques recently have emerged for trickling filter systems. These methods have reinforced the role of trickling filters in providing effective, economical secondary treatment. Of particular interest to the Army is the trickling filter/solids contact (TF/SC) process. This method has some advantages over competing technologies, offering improved effluent quality, simple, reliable operation, low maintenance, and cost-effective treatment.

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Several add-on and replacement techniques recently have emerged for trickling filter systems. These methods have reinforced the role of trickling filters in providing effective, economical secondary treatment. Of particular interest to the Army is the trickling filter/solids contact (TF/SC) process. This method has some advantages over competing technologies, offering improved effluent quality, simple, reliable operation, low maintenance, and cost-effective treatment.

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FOREWORD

This work was performed by the U. S. Army Construction Engineering Research Laboratory (USA-CERL) for the U.S. Army Engineering and Housing Support Agency (USAEHSC). The project was part of the FY87 Facilities Technology Applications Test (FTAT) program. T. Wash, CEHSC-FU-S, was the USAEHSC Technical Monitor.

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COL Carl O. Magnell is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

U.S. Army installations own and operate more than 100 wastewater plants that provide both primary and secondary treatment. Of this number, over half use trickling filters to supply secondary treatment. Trickling filter systems are easy to operate and reliable, consume little energy, and represent a large capital investment. In addition, they can usually treat wastewater to a quality meeting National Pollutant Discharge Elimination System (NPDES) permit standards and are well suited for use at military installations. For these reasons, trickling filter technology most likely will continue to be the Army's dominant form of secondary treatment.

As regional populations have increased at some installations, there has been growing concern that trickling filter systems alone may be incapable of handling the additional loads generated. Also, stricter environmental regulations are expected to demand a higher effluent quality than is now possible using only trickling filters. These issues, coupled with the increasing age and physical deterioration of many plants, have led the Army to seek ways of upgrading its treatment systems.

Several add-on and replacement methods have emerged in recent years to supplement trickling filters. These systems, which can be retrofitted to existing plants, have proven effective and reliable in actual use at several treatment facilities. The high level of success with these methods has reinforced the role of trickling filter technology in providing effective, economical secondary treatment.

Examples of these enhancement methods are synthetic filter media (primarily cross-flow in recent applications), flocculator-clarifiers, and the trickling filter/solids contact (TF/SC) process. These methods have permitted treatment plants to achieve effluent concentrations of 10 mg/L for both biochemical oxygen demand (BOD_5) and suspended solids (SS), making trickling filters capable of meeting advanced levels of effluent quality.

An earlier study[1] by the U.S. Army Construction Engineering Research Laboratory (USA-CERL) presented an in-depth review of trickling filters with synthetic media. Subsequent work at USA-CERL in this area has suggested that the TF/SC process may be especially attractive for implementation at Army treatment plants. TF/SC technology has been emerging at a rapid pace, with several municipal plants now operational, under construction, or in the design stages. This technology should be explored further for potential application to the Army in both retrofit and new construction.

[1]C. P. C. Poon, R. Scholze, J. Bandy, and E. Smith, *Upgrading Army Sewage Treatment Plant Trickling Filters With Synthetic Media*, Technical Report N-182/ADA145648 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], June 1984).

Objective

The objective of this work was to evaluate the TF/SC process for use in upgrading Army wastewater treatment plants as well as for possible application to new construction.

Approach

Information from a literature review, surveys of the field, and site visits was compiled and analyzed in terms of application to Army wastewater treatment facilities.

Mode of Technology Transfer

It is recommended that information from this investigation be incorporated into the appropriate manuals as they are revised: Technical Manual (TM) 5-665, *Operation and Maintenance of Wastewater Treatment Facilities*; TM 5-814-3, *Domestic Wastewater Treatment*; and Engineering Manual (EM) 1110-2-501, *Design of Wastewater Treatment Facilities Major Systems*. An Engineer Technical Note (ETN) will be prepared to provide advance information to the field.

2 TECHNOLOGY OVERVIEW

History

Trickling filters have been used to treat wastewater for more than a century and, as recently as the early 1970s, were the most common form of wastewater treatment in the United States. The main reasons for the popularity of trickling filters were simplicity, reliability, stability, economy, ease of operation and energy-saving features.

Following adoption of uniform national treatment standards by the U.S. Environmental Protection Agency (USEPA) in 1973 and the 30-mg/L limit imposed for BOD_5 and SS levels in secondary treatment, the trickling filter process became less popular. Effluent concentrations of BOD_5 and SS from trickling filter plants often were in the 20- to 40-mg/L range. When this level was considered inadequate, engineers typically added tertiary treatment in the form of chemical addition or filtration, or replaced the trickling filters with other processes, such as activated sludge. However, it is recognized that the performance problems of trickling filters were largely due to poor efficiency of the secondary sedimentation process, and not the trickling filters themselves.[2]

Many existing trickling filter plants had to upgrade their performance to meet new discharge requirements for secondary or advanced treatment (SS and BOD_5 limits of 10 mg/L). For one such plant located at Corvallis, OR, the new effluent requirements were to be 10/10 mg/L for 5-day BOD_5 and SS. The plant was converted to a coupled trickling filter/activated sludge (TF/AS) plant with flocculator center wells in the secondary clarifiers. The design engineers believed this system would be able to provide the 10/10 levels necessary without needing tertiary filtration.

During 1978-79, the plant was operated with and without the activated sludge aeration tanks. When these tanks were out of service, secondary sludge had to be delivered to an aerated return sludge channel along the side of the activated sludge aeration tanks. This return sludge was aerated for approximately 10 min and then combined with trickling filter effluent to form the mixed liquor entering the secondary clarifiers. The surprising results were that the plant continued to produce an effluent that met the 10/10 discharge requirements even though the return sludge aeration and aerated contact times were relatively short. In this operating mode, the only modifications to the original plant were the new secondary clarifiers and the recirculation of sludge to the aerated return sludge channel. This new system was christened the "trickling filter/solids contact (TF/SC)" process.[3] Operating results since that initial start have consistently produced a high-quality effluent.[4]

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[2]D. P. Norris, D. S. Parker, M. L. Daniels, and E. L. Owens, "High Quality Trickling Filter Effluent Without Tertiary Treatment," *Journal of the Water Pollution Control Federation (JWPCF)*, Vol 54 (1982), pp 1087-1098.

[3]D. P. Norris, et al.; R. N. Matasci, A. H. Benedict, D. S. Parker, and C. Kaempfer, *Trickling Filter/Solids Contact Process: Full-Scale Studies*, NTIS PB 86-183 100/AS (U.S. Environmental Protection Agency [USEPA], April 1986).

[4]K. Brough, C. Onstad, L. Lamperti, and B. Curtis, "Operation of the Trickling Filter/Solids Contact Process at Corvallis, Oregon," paper presented at the 51st Annual Pacific Northwest Pollution Control Association Conference, Eugene, OR (1984).

As an indication of the success of this development since 1979, at least 50 TF/SC projects have reached the final design stage or beyond, with many of these operational.[5] Table 1 lists several sites using TF/SC.

Process Description

TF/SC is a physical and biological process that includes (1) a trickling filter, (2) an aerobic solids contact period, (3) a flocculation period, and (4) secondary clarification. Two operating features have also been identified as critical: (1) solids must be maintained in an aerobic, flocculant state and (2) solids must be recycled from the secondary clarifier to combine with trickling filter effluent as a mixed liquor.[6]

Figure 1 shows the various components of the process. The main function of the first process element, the trickling filter, is to reduce soluble BOD_5 in the wastewater. The aerated solids contact period then provides contact between finely divided solids in the trickling filter effluent and recycled biological solids to remove additional soluble BOD_5 if necessary. The contact period allows for initial flocculation of dispersed solids into floc.

There are three variations of the TF/SC process as shown in Figure 1. The appropriate mode is determined by requirements for particulate or soluble BOD_5 removal.[7] Returned sludge must be kept in an aerobic state to maintain its flocculating qualities; this condition is achieved by using either a return sludge aeration tank or an aerated contact tank. If a major fraction of the soluble BOD_5 in the trickling filter effluent must be removed in addition to particulate matter to meet discharge standards, an aerated solids contact tank is necessary. This arrangement is shown as Mode I in Figure 1. The residence time required to reduce the soluble BOD_5 is greater than the time required to maintain the sludge in an aerobic, flocculating condition, which eliminates the need for a sludge reaeration tank. Typical residence times in the aerated contact tank run 15 min to 2 hr, depending on the degree of soluble BOD_5 removal required. Aerated solids contact tanks are always smaller than activated sludge tanks because their residence times vary from 3 to 60 min rather than the 120 to 480 min or longer required by activated sludge.

If particulate removal is the primary concern (low soluble BOD_5 and high levels of SS), only a return sludge aeration tank is needed (Mode II). This tank is sized to maintain the sludge in an aerobic, flocculating state to allow the clarifier to function optimally. A return sludge aeration tank provides the most economical form of aerobic residence time because the sludge is more concentrated in the return sludge line than it would be in an aerated contact tank.

A combination of the two aerated tanks (Mode III) is required if a modest amount of soluble BOD_5 removal is necessary as well as particulate removal. For this case, a short residence time in an aerobic contact tank reduces soluble BOD_5 a small amount. Distributing residence time between an aerated contact tank and a return sludge tank provides the best economy.

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[5] D. S. Parker, "The TF/SC Process at Eight Years Old: Past, Present, and Future," paper presented at the 59th Annual Conference of the California Water Pollution Control Association (1987).

[6] R. N. Matasci, et al.

[7] R. C. Fedotoff, "The Trickling Filter Finds a New Partner," *WATER/Engineer and Management* (June 1983).

Table 1

One Firm's Summary of TF/SC Projects*

Location	ADWF Plant Design Flow, m^3/sec	(mgd)	Monthly Average Effluent Requirements, mg/L BOD$_5$	SS	TF/SC Mode	Status[a]	TF Media Type[b]
Corvallis, OR	0.44	(10)	10	10	III	O	R
Tolleson, AZ	0.35	(8)[c]	30	30	I	O	P/R
Morro Bay, CA	0.11	(2.4)[d]	None	70[e]	III	O	R
Springfield, OR	0.26	(6)	30	30	II	O,P	R
Garland, TX	1.31	(30)	10	15	I, III	O	P
South Salt Lake City, UT	2.74	(62.5)	10	15	I	O	P
Eureka, CA	0.26	(6)	30	30	I	O	P
Medford, OR	0.79	(18)	20	20	I	O	P
Coeur D'Alene, ID	0.18	(4)	30	30	I	O	R
Goleta, CA	0.43	(10)[d]	None	62[e]	III	C	P
Guayama, PR	0.44	(10)	30	30	I	C	P
Price River, UT	0.18	(4)	10	20	III	S	R
Omaha, NE	3.06	(70)	45	45	III	C	P
Fort Smith, AR	0.26	(6)	30	30	II	C	R
Monterey, CA	1.31	(30)[f]	30	30	III	D	P
Burney, CA	0.044	(1.0)	40	None	III	D[g]	P
Everett, WA	0.70	(16)	30	30	III	D	P
Salem, OR	1.0	(23)[h]	30	30	I	D	R
Boulder, CO	0.70	(16)	30	30	III	D	R
Mesa (Turner Ranch), AZ	0.18	(4)	10[i]	10[i]	III	C	P
Colorado Springs, CO	0.43	(10)	30	30	I	D	R

*Source: D. S. Parker, "The TF/SC Process at Eight Years Old: Past, Present, and Future," paper presented at the 59th Annual Conference of the California Water Pollution Control (WPC) Association (1987). Used with permission.

[a] O = operation; C = construction; P = operation phased out; D = design; S = start-up;

[b] P = plastic; R = rock.

[c] Expansion now under construction will double the listed flow.

[d] Total flows; these plants provide secondary treatment for only part of total flow because of ocean discharge waivers.

[e] Only 75 percent removal required because of ocean discharge waiver.

[f] Expansion of existing plant now under construction.

[g] Phased program, trickling filter to be constructed first.

[h] Wet season average flow; TF/SC is not used during canning season.

[i] Design objective to meet a turbidity requirement of 1 NTU; includes tertiary filtration.

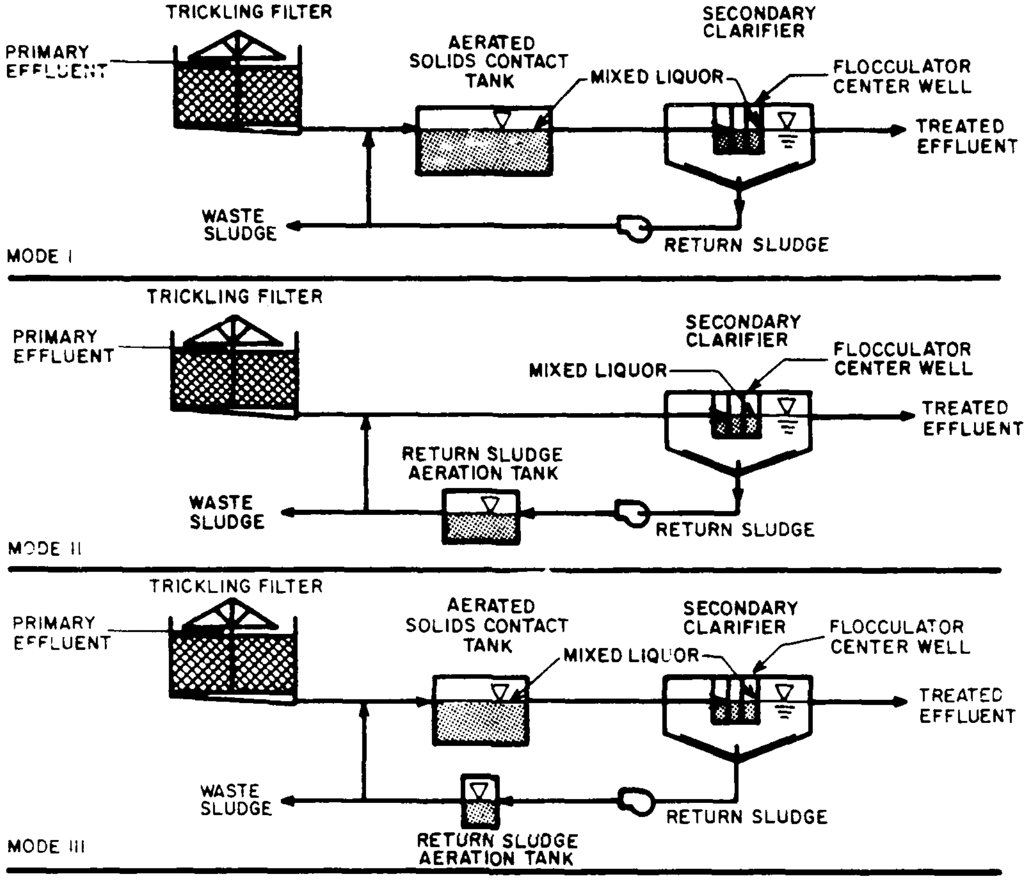

Figure 1. Variations of the TF/SC process.

The third element in the TF/SC process is the flocculation period. Flocculation begins in the contact tank and continues in the clarifier. Flocculator-clarifiers (Figure 2) with a large center well and a mildly stirred environment are the preferred alternative when it is necessary to produce effluent meeting permit requirements of 10/10 BOD_5 and SS. The flocculation step promotes clear effluent and growth of large, settleable floc, which are removed in secondary clarification.

Fine-bubble aeration is used to minimize turbulence in the activated solids contact tank while maintaining adequate dissolved oxygen levels.[8] Even with reduced turbulence, the effluent contains a fairly high level of dispersed solids when it enters the clarifier. The transfer process itself produces a degree of floc breakup. To provide additional flocculation in the clarifier, mild stirring occurs in the specially designed center well. There, large floc are formed that settle out in the secondary clarifier. Because of the enlarged center well, the unit is called a flocculator-clarifier.

Appendix A illustrates the TF/SC process using photographs from operational plants.

[8]D. S. Parker.

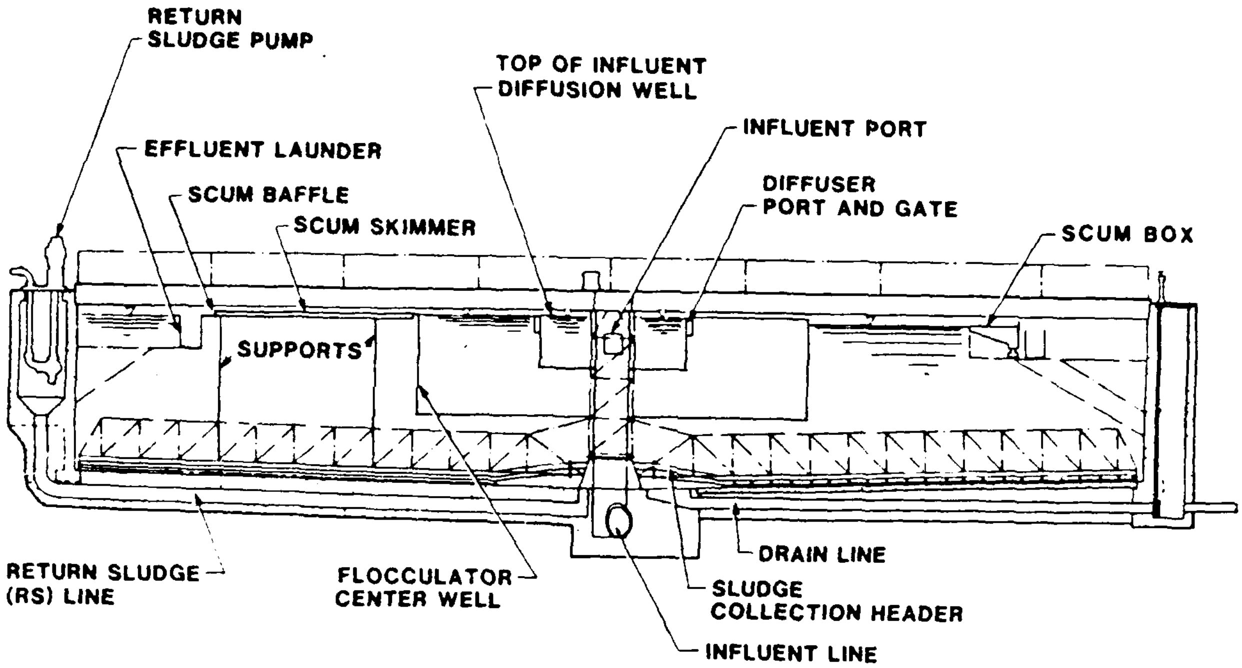

Figure 2. **Cross section of flocculator-clarifier.** (Source: D. S. Parker, "The TF/SC Process at Eight Years Old: Past, Present, and Future," paper presented at the 59th Annual Conference of the California WPC Association [1987]. Used with permission.)

TF/SC Compared With Other Processes

The TF/SC process is related to several conventional treatment systems, but there are some important differences between the systems as noted by Matasci, et al.[9] Figure 3 depicts these competing systems for comparison. The main differences are in terms of function and the loading on each unit. The primary organic removal unit in the TF/SC process is the trickling filter. BOD_5 loadings are maintained at low levels. The aerated solids contact tank has a low residence time and is used as a polishing unit only to reduce BOD_5 and SS. The clarifier is usually designed with flocculation features to produce the highest effluent quality possible and eliminate the need for tertiary filtration.

The TF/AS process is often used when nitrification is desired. Functions of organic removal are more evenly split between the aeration tank and the trickling filter. The trickling filter acts as a roughing filter since it removes only some of the organics. The aeration tank not only removes a large part of the organics, but also provides nitrification. In contrast to the TF/SC process, there is no deliberate effort to cause flocculation of finely divided solids in the aeration basin. A conventional secondary clarifier is usually employed.

The activated biofilter (ABF) process resembles the TF/AS process more than it does the TF/SC, because BOD_5 loadings on the trickling filter are often higher and the

[9]R. N. Matasci, et al.

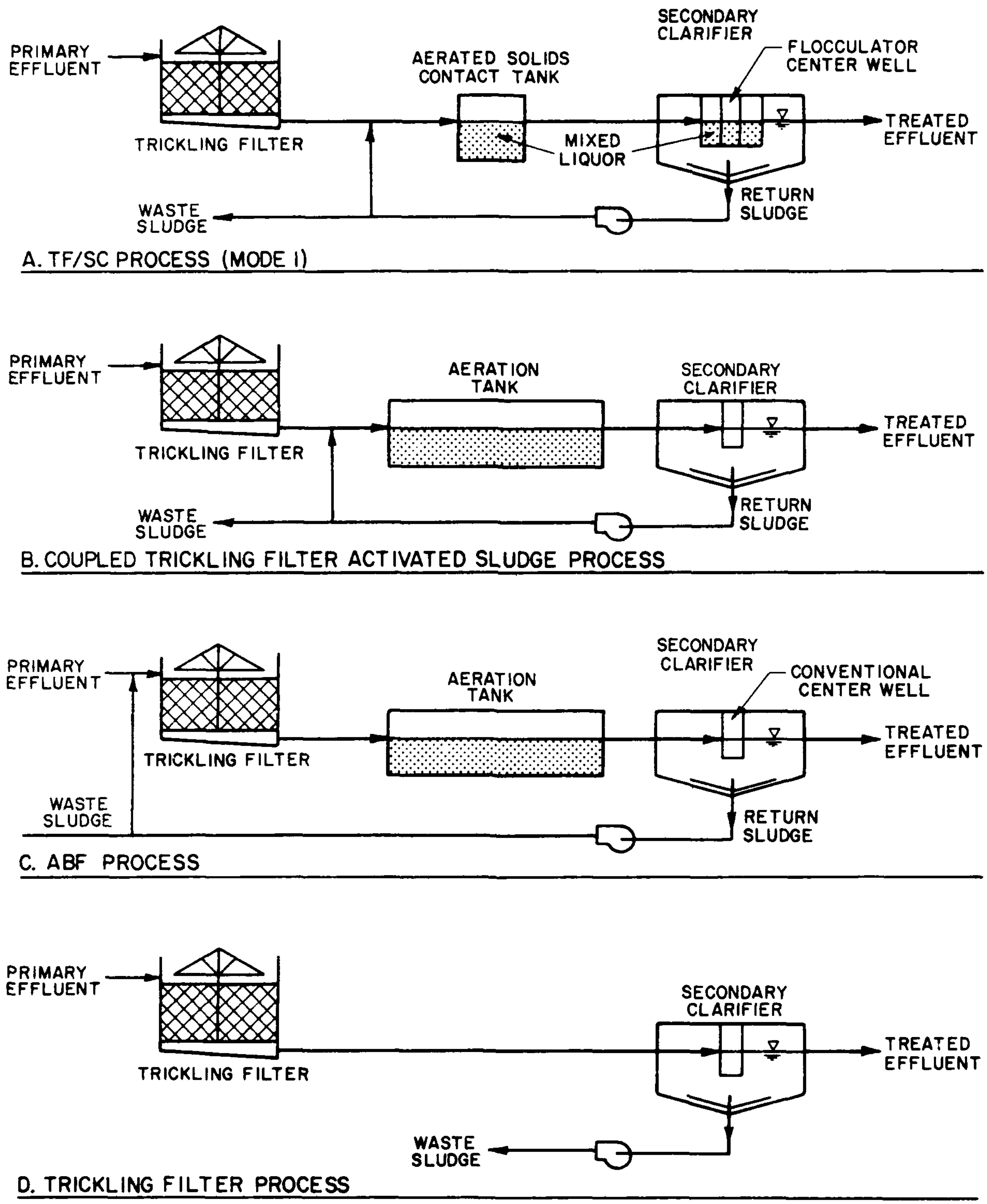

Figure 3. Comparison of TF/SC process and conventional processes.

aeration tank is designed to do more of the organics removal task than with TF/SC. Some ABF designs have eliminated the aeration tank and reduced the trickling filter loading compared with conventional trickling filters. Another design feature of the ABF process is sludge recycle over the media, which enhances organics removal.

The conventional trickling filter features organic loadings in the same range as the TF/SC process. There is no solids contact tank to promote flocculation of dispersed solids. Effluent is typically near the 30/30 monthly average BOD_5 and SS values. A conventional clarifier is used.

To summarize, features distinguishing TF/SC from these other processes are:[10]

1. The primary functions of the contact tank and clarifier flocculation are to increase flocculation and solids capture and reduce particulate BOD_5.

2. Most soluble BOD_5 is removed in the trickling filter.

3. Return sludge solids are mixed with trickling filter effluent rather than with primary effluent as in the ABF process.

4. The aerated solids contact tank is not designed to nitrify, although nitrification may occur in the trickling filter.

5. The aerated solids contact time is 1 hr or less based on total flow, including the recycle.

6. The solids retention time in the aerated solids contact tank is less than 2 days. Most TF/SC designs range considerably less than this time, 0.2 to 1.0 days, depending on bioflocculation objectives.

Applicability

The TF/SC process has been operating effectively under a variety of conditions: large and small treatment plants, cold and temperate climates, and wide-ranging effluent requirements. The process can be useful where there are existing rock-media trickling filters. Service life of these plants can be extended, as can capacity, by adding new aerated solids contact tanks. Flocculator-clarifiers can also be added to meet more stringent discharge permits and/or handle higher flows.

TF/SC also has been used in new construction and has proven to be an economical choice. A type of plastic medium has been used in all known new plant construction projects for the trickling filter. This new plastic medium, a cross-flow corrugated sheet (Figure 4), has emerged as the industry standard. It has been shown to be significantly more efficient in soluble BOD_5 removal than the original vertical sheet medium.[11] Several vendors currently supply this type of plastic medium: Munters Corp., American Surfpac Co., B.F. Goodrich Co., and the Statiflo Corp.

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[10] R. N. Matasci, et al.

[11] T. Richards and D. Reinhart, "Evaluation of Plastic Media in Trickling Filters," *JWPCF*, Vol 58 (1986); D. S. Parker and D. T. Merrill, "Effects of Plastic Media Configuration on Trickling Filter Performance," *JWPCF*, Vol 56 (1984), p 955.

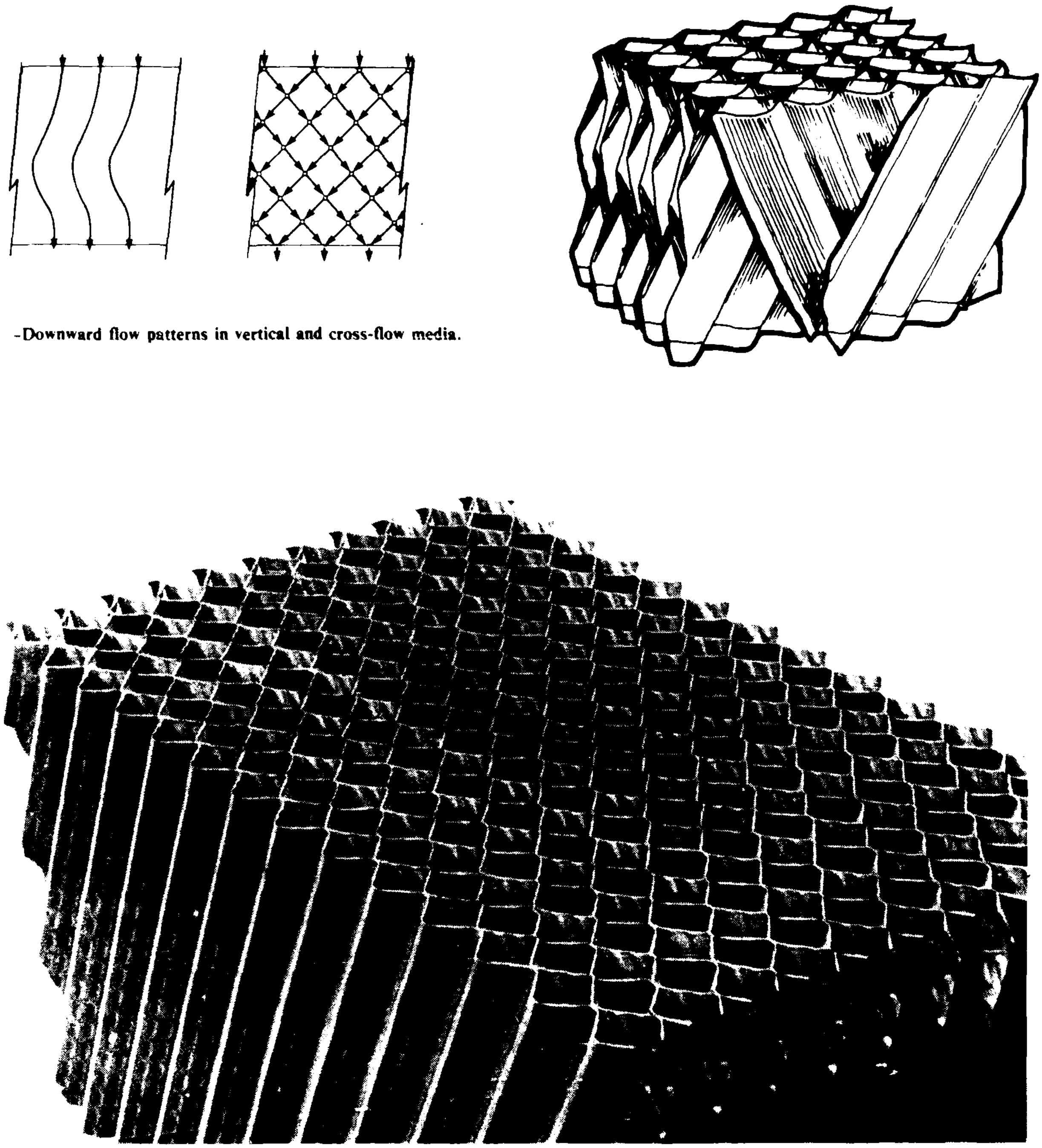

Figure 4. Cross-flow media. (Source: *BIOdek® Biological Wastewater Treatment Media* [The Munters Corporation, Fort Myers, FL]. Used with permission.)

3 OPERATION AND MAINTENANCE

TF/SC is an emerging technology. As such, it is not possible to make sweeping statements about operation and maintenance (O&M) for these systems due to the lack of a suitably sized data base. Existing TF/SC facilities vary tremendously in specific O&M, depending on factors such as permit requirements, purpose of upgrade or new construction, economics, and design features. Data such as those on activated sludge plants and conventional trickling filter plants are not available for TF/SC and it would not be valid to lump together data from the few existing plants. However, information provided by several treatment plants is of interest for comparing the different O&M features.

A USEPA study examined several operating TF/SC plants and compiled various operational attributes for the TF/SC process.[12] It must be pointed out that these results were obtained from a very few plants and that generalizations may not be appropriate.

Parker has collected operating data from five plants for a 1-year period.[13] The author did a follow-up survey of the same plants to confirm that the TF/SC process was continuing to perform effectively. Tables 2 through 6 list the results along with design data for these plants.

Cosettling

Cosettling raw sewage solids and waste TF/SC solids in the primary sedimentation tank is a common practice in trickling filter and TF/SC designs. This step simplifies solids thickening and eliminates the need for separate sludge thickening, which is an economic benefit. However, Matasci, et al. have suggested that cosettling may increase sludge disposal costs.[14] They found that primary treatment SS removal averaged between 53 and 62 percent at three TF/SC plants that cosettle and 74 percent, an exceptional result, at one plant that does not use cosettling. Primary sludge concentrations were typically between 3.7 and 5.3 percent when cosettling was practiced. Concentrations of 5 to 7 percent are common when primary solids are thickened in primary sedimentation tanks and cosettling is not practiced. Thus, cosettling may reduce SS removal.

Trickling Filter Soluble BOD_5 Removal

The primary function of the trickling filter in the TF/SC process is to remove most of the soluble BOD_5 present in the primary effluent. Previous investigators have found many factors to be correlated with trickling filter effluent soluble BOD_5, including the influent concentration, trickling filter depth, hydraulic loading rate, temperature, and media-specific surface. The modified Velz equation often is used to model the effects of these variables on effluent soluble BOD_5; this equation is discussed in detail in Chapter 4 (Eq 3).

[12] R. N. Matasci, et al.
[13] D. S. Parker.
[14] R. N. Matasci, et al.

Table 2

Medford Performance*

Date	Flow, m^3/sec (mgd)	Effluent Quality, mg/L		
		BOD_5	$cBOD_5$	SS
April 1984	0.43 (9.9)	14	6	7
May	0.36 (8.2)	22	8	7
June	0.36 (8.3)	23	11	9
July	0.39 (9.0)	16	6	6
August	0.37 (8.4)	24	7	8
September	0.35 (7.9)	28	7	8
October	0.34 (7.7)	24	5	7
November	0.57 (13.1)	20	5	6
December	0.55 (12.6)	15	4	4
January 1985	0.38 (8.6)	18	4	5
February	0.43 (9.7)	20	5	4
March	0.36 (8.2)	27	5	5
Average	0.41 (9.3)	21	6	6

*Source: D. S. Parker, "The TF/SC Process at Eight Years Old: Past, Present, and Future," paper presented at the 59th Annual Conference of the California WPC Association (1987). Used with permission. Mr. Marvin Kennedy, engineer at the Medford, confirmed in a 1987 telephone interview that results have been about the same through the intervening time period.

Table 3

Eureka Performance*

Date	**Flow, m^3/sec (mgd)**	**Effluent Quality, mg/L** Secondary BOD_5	Secondary SS	Final $cBOD_5$	Final SS
November 1984	0.42 (9.5)	8	8	10	14
December	0.34 (7.8)	9	7	5	5
January 1985	0.24 (5.4)	9	6	8	4
February	0.21 (4.9)	11	5	8	3
March	0.27 (6.1)	9	6	9	6
April	0.30 (6.9)	11	11	9	6
May	0.22 (5.0)	9	10	13	10
June	0.23 (5.2)	7	8	8	10
July	0.22 (5.1)	9	21	6	10
August	0.22 (5.0)	9	21	6	12
September	0.16 (3.7)	11	18	8	9
October	0.17 (3.9)	11	9	12	6
Average	0.25 (5.7)	9	10	8	8

*Source: D. S. Parker, "The TF/SC Process at Eight Years Old: Past, Present, and Future," paper presented at the 59th Annual Conference of the California WPC Association (1987). Used with permission. Mr. Clay Yerby, engineer at Eureka, confirmed in a 1987 telephone interview that results have been about the same throughout the intervening time period.

Table 4

Tolleson Performance

Date	Flow, m^3/sec (mgd)	Effluent Quality, mg/L	
		BOD_5	SS
July 1983	0.22 (5.0)	6	6
August	0.23 (5.3)	5	5
September	0.25 (5.7)	4	4
October	0.27 (6.2)	5	5
November	0.28 (6.4)	9	20
December	0.27 (6.2)	6	7
January 1984	0.29 (6.7)	10	11
February	0.28 (6.5)	9	9
March	0.28 (6.3)	5	11
April	0.28 (6.3)	7	15
May	0.34 (7.8)	11	21
June	0.25 (5.8)	9	16
Average	0.27 (6.2)	21	10.83

*Source: D. S. Parker, "The TF/SC Process at Eight Years Old: Past, Present, and Future," paper presented at the 59th Annual Conference of the California WPC Association (1987). Used with permission.

Table 5

Oconto Falls Performance

Date	Flow, m^3/sec (mgd)	Effluent Quality, mg/L BOD$_5$	Effluent Quality, mg/L SS
April 1983	0.019 (0.43)	21	16
May	0.020 (0.46)	19	18
June	0.016 (0.37)	17	12
July	0.013 (0.30)	17	9
August	0.012 (0.28)	14	8
September	0.014 (0.33)	17	8
October	0.016 (0.37)	16	9
November	0.014 (0.33)	19	10
December	0.015 (0.32)	25	13
January 1984	0.014 (0.31)	31	16
February	0.018 (0.41)	23	14
March	0.017 (0.39)	31	23
Average	0.016 (0.36)	21	13

*Source: D. S. Parker, "The TF/SC Process at Eight Years Old: Past, Present, and Future," paper presented at the 59th Annual Conference of the California WPC Association (1987). Used with permission.

Table 6

Corvallis Performance

Date	Flow, m^3/sec (mgd)	Effluent Quality, mg/L			
		Secondary		Final	
		BOD_5	SS	$cBOD_5$	SS
April 1983	0.53 (12.2)	10	5	4	9
May	0.32 (7.4)	12	8	6	10
June	0.32 (7.3)	10	7	5	9
July	0.27 (6.2)	11	7	5	9
August	0.27 (6.2)	10	5	5	7
September	0.25 (5.7)	13	9	7	10
October	0.25 (5.6)	12	8	6	10
November	0.67 (15.2)	10	7	5	9
December	0.78 (17.9)	10	6	5	9
January 1984	0.59 (13.4)	9	7	5	5
February	0.73 (16.6)	13	6	4	13
March	0.56 (12.7)	9	6	4	9
Average	0.46 (10.5)	11	7	5	9

*Source: D. S. Parker, "The TF/SC Process at Eight Years Old: Past, Present, and Future," paper presented at the 59th Annual Conference of the California WPC Association (1987). Used with permission.

Matasci, et al. used the modified Velz equation to successfully model soluble carbonaceous BOD_5 removal for one TF/SC plant.[15] They found higher removal rate coefficients for rock media (one site) than for plastic media (also one site). This result may have been due to differences in hydraulic residence time or in oxygen transferred per unit of media surface area. "Soluble" BOD_5 for this project was defined operationally as the BOD_5 remaining in the filtrate after filtration through a Whatman 934AH filter (1.5 nm retention).

Trickling Filter Loading

For the range of average trickling filter BOD_5 loadings studied at four plants (5.8 to 29 lb/day/1000 cu ft), Matasci, et al. found BOD_5 loading to have a weak influence on final effluent SS.[16] They showed that the final effluent SS is correlated with trickling filter effluent SS, which are in turn most sensitive to primary effluent SS concentration. These results highlight the importance of reliable primary treatment.

Media Type

For five TF/SC plants, microscopic examinations were performed on the trickling filter effluents and mixed liquors.[17] Results suggested that the floc formed in rock media are more compact and less diffuse than those formed in plastic media. A diverse range of environments was found to be present in trickling filters.

Solids Contact Operating Parameters

Three operating parameters for TF/SC were examined for their effects on process performance: solid retention time (SRT), mixed liquor suspended solids (MLSS), and sludge volume index (SVI).[18] SS concentration in the final effluent was used as the measure of TF/SC performance because the TF/SC process improves effluent quality mainly by lowering final effluent SS and its related BOD_5.

Solids Retention Time

SRT, also called "sludge age" and "mean cell residence time," has been used as a primary process control parameter for other treatment systems. Biological SRT has been defined as the average time a unit of biomass remains in the treatment system:[19]

$$SRT = \frac{X_T}{(\Delta x/\Delta t)_T} \qquad \text{[Eq 1]}$$

where X_T = total active microbial biomass in the treatment system (mass) and $(\Delta X/\Delta t)_T$ = total amount of active microbial mass withdrawn daily, including those solids purposely wasted as well as those lost in the effluent (mass/time).

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[15] R. N. Matasci, et al.
[16] R. N. Matasci, et al.
[17] R. N. Matasci, et al.
[18] R. N. Matasci, et al.
[19] A. W. Lawrence and P. O. McCarty, "Unified Basis for Biological Treatment Design and Operation," *J. Sanitary Eng. Div. Am. Soc. Civil Engrs. (ASCE)*, Vol 96, SA3 (1970), p 757.

Matasci, et al. followed the above definition for TF/SC but defined X_T as the amount of SS in the aerated solids contact tank, excluding the mass of solids in the flocculator center well and the secondary clarifier sludge blanket.[20] They found that solids spend most of their time in the secondary clarifier and sometimes very little time in the aerated solids contact tank. It was concluded that correlations between SRT in the aerated solids contact tank and final effluent were not statistically significant at two plants and showed only a weak correlation at another plant.

Mixed Liquor Suspended Solids (MLSS)

Matasci, et al. found that MLSS concentrations between 900 and 2300 mg/L at two plants did not affect effluent SS significantly.[21] At a third plant, an increase from 1500 to 7000 mg/L raised the final effluent SS concentration 2 mg/L. This insensitivity implies that plant operation is simplified because little attention is required for sludge inventory management.

Sludge Volume Index (SVI)[22]

Matasci, et al. found that two TF/SC plants with large center-well flocculators had no correlation between SVI and final effluent SS. A third site with a smaller center well showed a correlation of increased SVI values with reduced final effluent SS values.

Contact Tank Soluble BOD_5 Removal[23]

The Matasci, et al. study showed that soluble BOD_5 removal in the aerated solids contact tank can be modeled effectively with first-order reaction kinetics. Significant soluble BOD_5 removal will occur in the aerated solids contact tank only if trickling filter effluent soluble BOD_5 concentrations are above 5 mg/L and if enough contact time is provided.

Solids Flocculation[24]

Matasci, et al. also demonstrated that most flocculation in the aerated solids contact tank occurs in the beginning of the channel during the first 10 min of aerated solids contact time. Thus, high turbulence should be minimized in that channel. It was concluded that, for two sites, only about 12 min of aerated solids contact time are needed for efficient SS removal. Additional SS are removed in the flocculator center well.

Secondary Clarifier Overflow Rate

Matasci, et al. examined the secondary clarifier overflow rate for some TF/SC plants. They found a low final effluent SS over a wide range of overflow rates. This result suggests that, because of its insensitivity to overflow rates, this type of clarifier

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[20] R. N. Matasci, et al.
[21] R. N. Matasci, et al.
[22] R. N. Matasci, et al.
[23] R. N. Matasci, et al.
[24] R. N. Matasci, et al.

can be designed and operated at higher overflow rates than previously believed. The secondary clarifiers used had in-board launders, high sidewater depths, suction tube or header sludge removal systems, and flocculator center wells.

The Matasci study offered further explanation of the clarifiers' insensitivity to overflow rate. This insensitivity may be due in part to conditioning of the mixed liquor solids in the aerated solids contact tank as well as in the flocculator center wells. In-board launders avoid the carryover of solids from density currents along the clarifier walls. Suction header sludge removal systems quickly remove settled solids, minimizing their carryover from denitrification and quickly returning settled solids to an aerobic environment. The high sidewater depths increase clarifier detention time and provide a larger distance between effluent launders and the sludge blanket; also, deeper clarifiers are less sensitive to changes in overflow than are shallow clarifiers.

Coagulant Addition

Matasci, et al. found that ferric chloride addition in the aerated solids contact tank for phosphorus removal does not impair TF/SC operation.[25]

Summary

Information available on TF/SC operation indicates that this process can produce a reliable, steady effluent more easily than competing processes. The operating parameters are still undergoing change and optimization which will continue to expand the data base for future improvements.

[25] R. N. Matasci, et al.

4 DESIGN CONSIDERATIONS

Poon, et al. have proposed a design for a TF/SC system.[26] Much of the design information from their report is repeated here for the reader's convenience.

Appendix B shows example design calculations for an Army facility. To determine the system size, the designer needs to know: (1) filter media volume, (2) solids contact channel size and aeration rate, and (3) size of the secondary clarifiers. The trickling filter media volume requirements can be estimated using the Schulze equation:

$$\frac{L_e}{L_o} = e^{\frac{-K_{20}\,\theta D}{Q^{0.5}}} \qquad \text{[Eq 2]}$$

or:

$$\ln \frac{L_e}{L_o} = \frac{-K_{20}\theta D}{Q^{0.5}}$$

where:

L_e = BOD_5 of secondary clarified effluent (mg/L)

L_o = BOD_5 of biooxidation influent (mg/L)

K_{20} = Wastewater treatability factor at 20°C

θ = Wastewater temperature correction factor

D = Media depth in feet

Q = Raw hydraulic flow rate (gal/min/sq ft).

Using Equation 2, the values of D, L_e, L_o, K_{20}, and θ are set and the equation is solved for Q. Plant raw influent flow rate is then divided by Q to establish the media top surface area, and then is multiplied by D to calculate media volume. The trickling filter can be designed with L_e at 30 to 35 mg/L.

Sizing the solids contact channel requires estimation of the filter effluent soluble BOD_5. The channel volume is then established to provide a long enough contact time to reduce the soluble BOD_5 to the level desired in the final effluent.

This trickling filter effluent soluble BOD_5 calculation is based on the Velz equation and requires assumptions as to: (1) the soluble BOD_5 concentration (S_i) in the trickling filter feed prior to dilution with recycle, (2) the recycle ratio (R), defined as the recycle flow rate divided by the feed flow rate, (3) the wastewater temperature (T), and (4) the

[26] C. P. C. Poon, R. Scholze, J. Bandy, and E. Smith.

trickling filter hydraulic feed flux (Q_i), defined as the flow from primary sedimentation divided by the cross sectional area of the trickling filter. The modified Velz equation is:

$$S_e = \frac{S_i}{\left([R+1]\, e\right)\left(\dfrac{K_{20}\, A_s D\theta^{(T-20)}}{[Q_i\ (R+1)]^n} - R\right)} \qquad \text{[Eq 3]}$$

where:

S_e = Soluble BOD_5 concentration in the trickling filter underflow (mg/L)

S_i = Soluble BOD_5 concentration in the trickling filter feed (mg/L)

R = Recycle ratio (gpm/gpm)

A_s = Average media-specific surface (sq ft/cu ft)

T = Wastewater temperature (°C)

Q_i = Trickling filter hydraulic feed flux (gal/min/sq ft)

n = Flow exponent.

Key assumptions in establishing the contact channel size, in addition to the filter effluent soluble BOD_5 and the plant ADWF, are: (1) the desired final effluent soluble BOD_5, (2) the mixed liquor volatile SS concentrations, and (3) the BOD_5 removal rate in the aerated channel, expressed as grams of BOD_5 removed per gram of mixed liquor volatile SS per day.

An example of the air supply for a solids contact channel aeration system is a coarse-bubble system sized to provide enough dissolved oxygen in the channel to maintain an aerobic condition in the mixed liquor, but simultaneously limiting air input to produce only gentle mixing and avoid breakup of the settleable floc. The main assumptions in sizing the channel aeration system are: (1) oxygen uptake of the mixed liquor and (2) oxygen transfer efficiency. Testing of the TF/SC process at Corvallis provided the basis for the oxygen uptake rate used in sizing the aeration system. The oxygen transfer efficiency was assumed to be 6 percent. Recent designs have used fine-bubble diffusers such as Wyss diffusers.

The trickling filter biological floc produced by the TF/SC process are separated by secondary flocculator clarifiers. Flocculation chamber size is based on a 20-min hydraulic detention time. Sludge collection equipment should be the submerged rapid sludge withdrawal type when possible. An updated view of TF/SC design has been published elsewhere.[27]

The modified Velz equation (Eq 3 above) has been used for predicting soluble BOD removal in trickling filters and for sizing the units when corrugated plastic media are used. However, site-to-site variability in the treatability coefficient for the same media type can lead to estimates of filter sizes that vary by 100 percent.[28] This variability led to a recent investigation into trickling filter soluble BOD removal mechanisms and the

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[27] D. S. Parker.
[28] D. S. Parker.

development of a trickling filter model.[29] The model accounts for the mass transfer resistance in the laminar liquid film flowing over the media as well as the diffusion and removal of soluble BOD components within the biofilm. Also, the model permits rational decision-making on factors such as tower depth and recycle level. This model has been applied successfully at several sites and permits accurate sizing of trickling filters--usually without a pilot study--for treating municipal wastewaters.[30]

An example can help explain the model.[31] In Mode I TF/SC plants, a significant level of soluble BOD can be removed in the aerated solids contact (ASC) tank. First-order removal kinetics in a plug-flow ASC configuration can be used to estimate soluble BOD_5 removal according to the following equation:

$$\ln \frac{C}{C_o} = -K_{20}\theta^{(T-20)}X_v t \qquad \text{[Eq 4]}$$

where:

- C = Soluble carbonaceous BOD_5 after time t (mg/L)
- C_o = Soluble carbonaceous BOD_5 of the mixed liquor at the beginning of the channel (mg/L)
- K_{20} = First-order reaction rate coefficient at 20°C (1/mg-min)
- θ = Temperature correction coefficient (assume $\theta = 1.035$)
- T = Wastewater temperature (°C)
- X_v = Mixed liquor volatile SS (mg/L)
- t = Contact time based on total flow in the channel (min).

Studies of soluble BOD reduction along an ASC channel at Medford, OR, showed that K_{20} values ranged from 2.0 to 3.3 x 10^{-5} L/mg-min.[32] Other sites, however, have shown both lower and higher values. Information from additional sites is needed for making accurate predictions of rate coefficients to be used in designing new facilities.

C_o at the head-end of the channel can be related to the soluble effluent BOD_5 in the TF effluent (S_1) by a simple mass balance:

$$(1 + R)C_o = RC_1 + S_1 \qquad \text{[Eq 5]}$$

where:

- R = return sludge recycle ratio
- C_1 = ASC tank effluent soluble BOD_5
- S_1 = TF effluent soluble BOD_5.

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[29] B. E. Logan, et al., "A Fundamental Model for Trickling Filter Process Design," paper presented at the 59th Annual Conference of the Water Pollution Control Federation, Los Angeles, CA (1986).
[30] D. S. Parker.
[31] D. S. Parker.
[32] R. N. Matasci, et al.

Using Equations 4 and 5, engineers can calculate the efficiency of soluble BOD_5 removal across the contact tank.[33] Figure 5 shows an example calculation. For the conditions shown in Figure 5, most of the soluble BOD_5 removal occurs rapidly, with 80 percent removed within 20 min of contact time.

To complete the example, Parker presents Figure 6 for the trickling filter and Figure 5 for the ASC tank, which together demonstrate optimal soluble BOD_5 removal between the two process units.[34] For example, consider a waste with a temperature of 15°C and a primary effluent soluble BOD_5 of 75 mg/L. To meet discharge requirements, the process must produce a soluble BOD_5 level of 10 mg/L. With an eight-module tower, the following two cases from Parker satisfy the design constraint:

	Case A	Case B
TF hydraulic load (m/hr)	1.3	2.0
ASC contact time (min)	4	10
Removal in TF (percent)	80	67
Removal in ASC (percent)	33	60

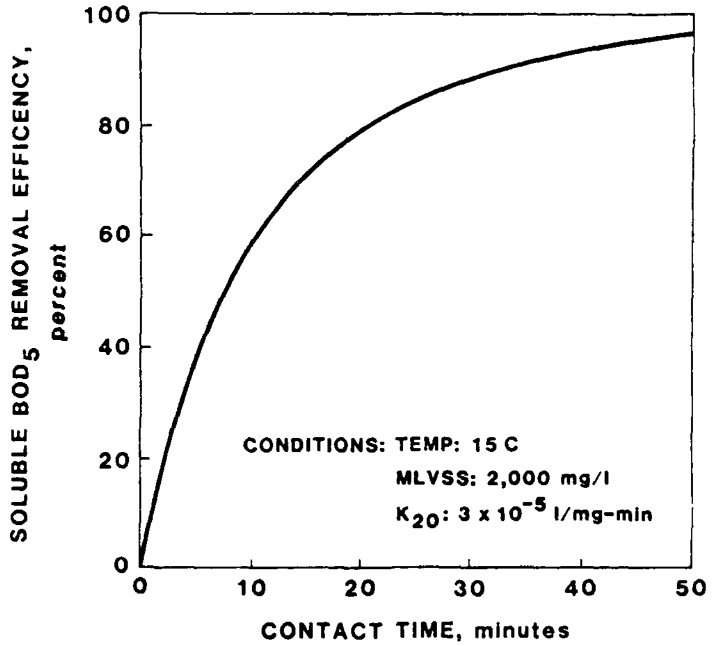

Figure 5. Predicted soluble BOD_5 removal in solids contact tank. (Source: D. S. Parker, "The TF/SC Process at Eight Years Old: Past, Present, and Future," paper presented at the 59th Annual Conference of the California WPC Association [1987]. Used with permission.)

[33] D. S. Parker.
[34] D. S. Parker.

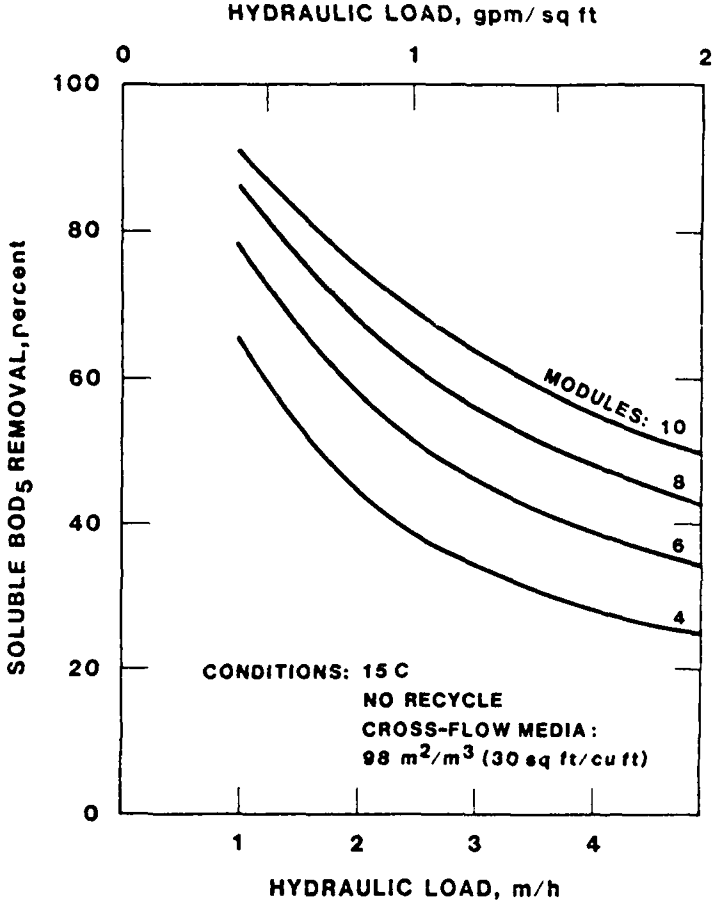

Figure 6. Effects of hydraulic loading and number of modules on trickling filter efficiency. (Source: D. S. Parker, "The TF/SC Process at Eight Years Old: Past, Present, and Future," paper presented at the 59th Annual Conference of the California WPC Association [1987]. Used with permission.)

Case B requires 32 percent less media, but needs only an extra 6 min contact time. Both examples would require a return sludge aeration tank to ensure good bioflocculation properties for the sludge. Parker concluded that, with the relative costs of trickling filters and ASC tanks, case B is favored.

An expanding data base for TF/SC plants indicates that successful bioflocculation requires physical contact of the trickling filter underflow with the return biological solids and a long enough aerated retention time for those biological solids to maintain them in an active biological state. TF/SC plants with rock media have an advantage over plants with plastic media in that the underflow solids are already fairly well flocculated and therefore require shorter aerated retention to maintain bioflocculation than do solids generated on the plastic media.[35]

[35] D. S. Parker.

The time for physical flocculation is relatively short compared with the detention times required to maintain solids in an aerobic state. Two studies have indicated that most flocculation occurs in the first 12 min at several TF/SC plants.[36]

The Parker paper also observed that the process is less costly when the trickling filters are operated at relatively high BOD_5 loadings (up to 2 kg/m^3 or 125 lb/1000 cu ft/day) because the aerated solids contact tank is very efficient at soluble BOD_5 removal. That study noted a trend to decrease the size of trickling filters in favor of somewhat larger aerated solids contact tanks.

[36]R. N. Matasci, et al.; D. S. Parker.

5 ECONOMICS

Overview

Available capital and O&M costs must be determined on a case-by-case basis since not enough plants are online to derive valid averages. At one plant treating about 6 mgd, the average O&M cost per 1000 gal treated is $0.19. Using the TF/SC process and flocculating clarifiers, the process treats influent BOD_5 averaging 268 mg/L to a final effluent level of 7.0 mg/L, and influent SS from 240 to 11.0 mg/L. The TF/SC plant at Corvallis has estimated a savings of $30,000/year, or 20 percent of plant electrical costs. The Corvallis plant also showed about a 24 percent reduction in sludge volume produced.

Economic evaluation of alternative treatment systems requires consideration of annual costs as well as capital expenditures (project costs). Annual costs include O&M, depreciation, and interest rates on capital expenditures.

O&M expenses include all costs for labor, energy, materials and supplies, and chemicals chargeable to various system components. The interest on capital and depreciation of structures and equipment is commonly referred to as "fixed cost." Part of the annual costs of a facility includes the capital cost amortized over its economic life.

Retrofit conversions at some facilities have been as low as $15,000, but are usually several hundred thousand dollars, depending on site-specific factors and the degree of treatment desired. The current costs of fines for NPDES violations also must be included in a cost study if poor performance of the existing system is an ongoing problem.

Example

Under a contract with B. F. Goodrich, Brown and Caldwell Consulting Engineers did a complete engineering-economic study of the TF/SC process compared with conventional technology (activated sludge and rotating biological contactors [RBC]).[37]

For the study, the plant was to be sized at 10 mgd. Electricity purchased from the local public utility was assumed to cost $0.05/kWh; chemicals were priced at $250/ton for chlorine delivered and $2/lb for polymer delivered. For fixed costs, the economic lives of land, pipelines, structures, and equipment were set in accordance with USEPA guidelines as:

Item	Life
Land	Permanent
Pipelines	50 years
Structure	40 years
Equipment	20 years

Table 7 compares total project costs for the three alternative treatment systems. Based on these data, the TF/SC is shown clearly to be the least costly alternative,

[37] *Engineering-Economic Comparison of the Trickling Filter/Solids Contact Process to Conventional Technology* (Brown and Caldwell Consulting Engineeers, April 1981).

Table 7

Economic Comparison of Total Project Costs*

Item	Estimated Cost** ($K)		
	Trickling Filter/Solids Contact	Activated Sludge	Rotating Biological Contactor
Preliminary treatment	1100	1100	1100
Primary treatment	2330	2330	2330
Trickling filter circulation pumping station	420	-	-
Trickling filters	2100	-	-
Solids contact channel	520	-	-
Aeration basins	-	4500	-
Rotating biological contactor reactors	-	-	4520
Flocculator clarifiers	2000	-	-
Conventional secondary clarifiers	-	1770	1500
Dual-media filtration	-	1500	1500
Disinfection	2040	2040	2040
Dissolved air flotation thickeners	-	390	-
Gravity thickeners	-	-	500
Anaerobic digesters	2220	2220	2220
Facultative sludge lagoons and land application of sludge	830	830	830
Energy recovery facilities (including sludge gas engine generator and waste heat equipment)	320	320	320
Site work	300	300	300
Administration, operations, and maintenance buildings	2800	2800	2800
Outside piping	1900	1900	1900
Subtotal, construction cost	18880	22000	21860
Engineering, administration, legal, fiscal, and contingencies at 35 percent	6580	7700	7650
Subtotal, project cost exclusive of land	25460	29700	29510
Land	260	265	255
Total project cost	25720	29965	29765

*Source: *Engineering-Economic Comparison of the Trickling Filter/Solids Contact Process to Conventional Technology* (Brown and Caldwell Consulting Engineers, April 1981). Used with permission.

**Costs based on ENR-CCI value of 3500. Updating to July 1987 would use an ENR-CCI value of 4400.

followed by the RBC and activated sludge processes. Table 8 is an energy comparison showing that the TF/SC also uses the least energy of the three.

Table 9 compares the estimated present worth of O&M costs for the three alternatives. The energy cost shown is the net requirement for purchased power in terms of electricity and waste heat. The TF/SC process was found to have a substantially lower total annual O&M cost compared with the other alternatives. The TF/SC process provides 61 and 33 percent reductions in total annual cost compared with the activated sludge and RBC processes, respectively. This is a key benefit of the TF/SC process, especially for operating agencies hard-pressed to meet increasing O&M budgets.

Table 8

Energy Comparison of Alternatives—Total Plant Basis

	Estimated Energy Requirements (1000 kWh/yr)		
Item	**Trickling Filter/Solids Contact Process**	**Activated Sludge Process**	**Rotating Biological Contactor Process**
Preliminary treatment	70	70	70
Primary treatment	25	25	25
Secondary biological process	1080	1650	1940
Dual-media filtration	*	550	550
Effluent disinfection	55	55	55
Sludge thickening	**	280	10
Anaerobic digestion	1500	1550	1550
Facultative sludge lagoons and land application of sludge	55	55	55
Energy recovery	125	125	125
Building and digestion heating and cooling+,++	300	550	200
Subtotal	3210	4910	4580
Estimated equivalent energy available from energy recovery facilities	-1450	-1450	-1450
New total estimated energy usage	1760	3460	3130

*Not required.
**Waste sludge thickening in primary clarifiers.
+For northern United States locations.
++Net demand.

Table 9

Economic Comparison of Estimated Present Worth of O&M Costs*

Item	Estimated Annual Costs ($K) Trickling Filter/Solids Contact	Activated Sludge	Rotating Biological Contactor
Labor	257	381	332
Energy	88	173	157
Materials and supplies	26	38	33
Chemicals	47	62	47
Total operation and maintenance cost	418	654	569
Total present worth cost**	4386	6862	5971

*Source: *Engineering-Economic Comparison of the Trickling Filter/Solids Contact Process to Conventional Technology* (Brown and Caldwell Consulting Engineers, April 1981). Used with permission.
**Based on an ENR-CCI value of 3500; 20-year analysis at 7-1/8 percent interest.

Since the varying relationships between annual costs, capital expenditures, and project staging often result in one plan being considered economically more attractive than another, the true economic value of a project can best be expressed in terms of present worth. The present worth of an alternative plan represents the long-term financial requirements of time-related projects and is the sum of the present worth capital expenditures and annual O&M costs over the planning period. It represents the cost savings realized from delaying the construction and operation of a project and, hence, capital expenditures.

Table 10 compares the cost-effectiveness of all three alternatives in terms of total present worth from Table 9. It is evident that the TF/SC process has the lowest total present worth cost for a 20-year planning analysis at 7-1/8 percent interest for a 10-mgd treatment plant. The TF/SC plant shows a 16 percent cost savings over the other two systems.

The primary reasons for the better cost-effectiveness of TF/SC are:

1. Monthly average BOD_5 and SS of 10 mg/L or less are attainable without effluent filtration.

2. Soluble BOD_5 reduction in the solids contact channel, beyond that normally expected from the trickling filters, provides a cost-effective method of producing effluent that meets requirements.

Table 10

Cost-Effectiveness Comparison of Alternatives*

Item	Estimated Annual Costs ($K)		
	Trickling Filter/Solids Contact	Activated Sludge	Rotating Biological Contactor
Total present worth project cost	25720	29965	29765
Total present worth of operation and maintenance costs**	4386	6862	5971
Total present worth cost	30106	36827	35736

*Source: *Engineering-Economic Comparison of the Trickling Filter/Solids Contact Process to Conventional Technology* (Brown and Caldwell Consulting Engineers, April 1981). Used with permission.

**Based on an ENR-CCI value of 3500; July 1987 has an ENR-CCI value of 4400. This was a 20-year analysis at 7-1/8 percent interest.

3. Waste biological sludge from the TF/SC process is dense enough for efficient wasting directly to the primary clarifiers for cosettling with the primary sludge. This eliminates the need for a separate sludge-thickening step in the treatment train.

4. Sludge yields in the TF/SC process are comparable to those of competing technologies; thus, associated sludge-handling and treatment costs are comparable.

5. The TF/SC process is a stable, relatively simple system requiring far less equipment, electrical control, and operator attention than other technologies, so the total O&M costs are substantially lower.

6. The TF/SC process consumes less than half the estimated annual energy demand of conventional technology because of its lower overall horsepower requirements. Reduced sludge recycle compared to the activated-sludge process is significant.

6 RECENT DEVELOPMENTS

Parker, one of the leading proponents of TF/SC technology, has summarized recent evolution of the process as follows:[38]

1. Flocculator-clarifier design overflow rates have changed for a significant cost savings. Plant-scale tests have shown that overflow rates at peak wet weather conditions can be set as high as 3.2 m/hr (1900 gpd/sq ft), whereas previous designs had been in the 1.9 to 2.5 m/hr (1100 to 1500 gpd/sq ft) range.

2. Aerated solids contact tanks have changed in size. Early aerated solids contact tanks were at plants where the preceding trickling filters removed a high percentage of soluble BOD_5. This was evident with short contact times and relatively small tank size because only bioflocculation was needed. Aerated solids contact tanks can also provide a high degree of soluble BOD_5 removal with somewhat longer contact times, but still less than 60 min.

3. Cross-flow media have permitted a 40 percent reduction in trickling filter size.

4. A better understanding of soluble BOD_5 removal in both the solids contact tank and the trickling filter has permitted increases in trickling filter loadings from the 0.5 to 0.8 kg/m^3/day (30 to 50 lb BOD_5/1000 cu ft/day) range to as much as 2 kg/m^3/day (125 lb BOD_5/1000 cu ft/day).

5. Organic loading on rock trickling filters can be extended to levels higher than those previously assumed. Loading capabilities of existing trickling filters often can be tested by taking some units out of service to place a higher loading on the remaining units. Soluble BOD_5 removal and odor assessment can be used to determine the unit's ultimate capacity.

[38] D. S. Parker.

7 CONCLUSIONS AND RECOMMENDATIONS

The TF/SC process represents a valuable technology for upgrading existing Army trickling filter wastewater treatment plants as well as for incorporation in new construction. Based on a literature review, site visits, and telephone surveys, TF/SC can produce high-quality effluent and is simple to operate, reliable, and cost-effective. The process has several advantages over competing methods, including:

1. Monthly average BOD_5 and SS of 10 mg/L or less are attainable without effluent filtration.

2. Soluble BOD_5 reduction in the solids channel, beyond that normally expected from the trickling filters, provides a cost-effective method of producing an effluent meeting requirements.

3. Waste biological sludge from the TF/SC process is dense enough for efficient wasting directly to the primary clarifiers for cosettling with the primary sludge. This feature eliminates the need for a separate sludge-thickening step in the treatment system.

4. Sludge yields in the TF/SC process are comparable to those of competing technologies; thus, associated sludge-handling and treatment costs are comparable.

5. TF/SC technology is stable and relatively simple, requiring much less equipment, electrical control, and operator attention than other technologies, so the total O&M costs are substantially lower.

6. TF/SC consumes less than half the estimated annual energy demand of conventional technology because of its lower overall horsepower requirements. Reduced sludge recycle compared to the activated sludge process is significant.

The TF/SC process should be considered as a valid approach for improving the Army wastewater treatment plant infrastructure as regulations call for increased quality of final effluent. Upgrades to existing plants must be designed on a case-by-case basis with an economic analysis performed to evaluate all factors affecting the cost and payback period. In addition to retrofitting applications, TF/SC should be considered as a feasible alternative for new construction.

For additional information on TF/SC, contact Richard Scholze, USA-CERL-EN, P.O. Box 4005, Champaign, IL 61820-1305; telephone, (217) 373-6743 (COMM) or 800-USA-CERL outside Illinois, 800-252-7122 within the state (toll-free).

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APPENDIX A:

THE TF/SC PROCESS ILLUSTRATED

The following photos are primarily of the Elk River treatment plant at Eureka, CA, designed by Brown and Caldwell.

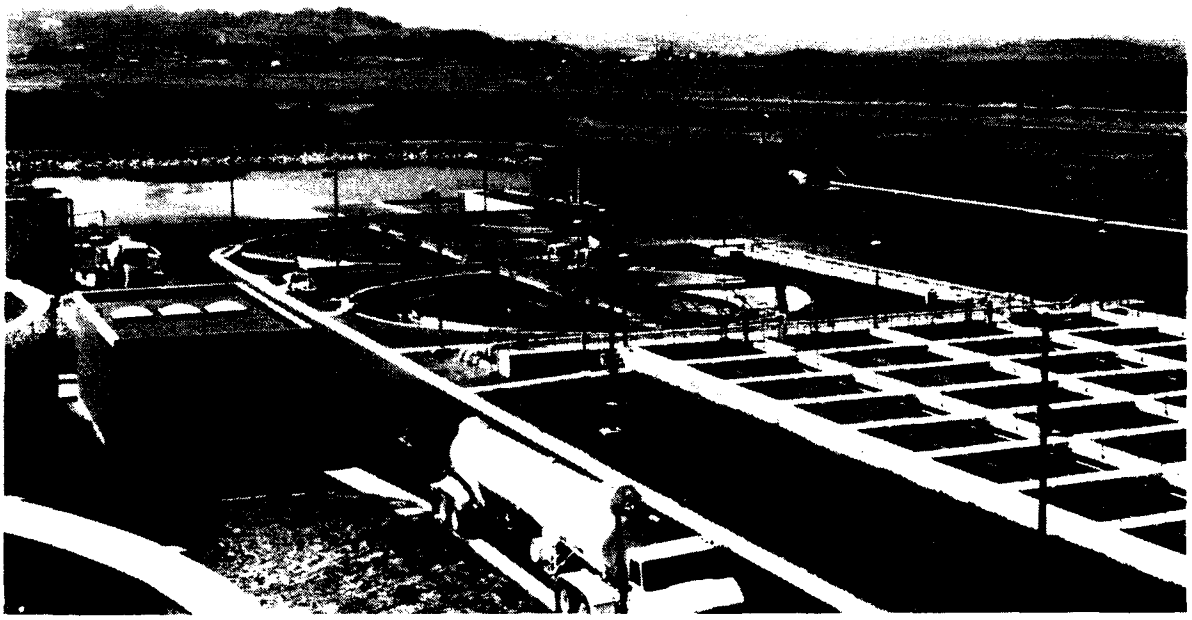

Figure A1. **Overview of the Elk River trickling filter/solids contact treatment plant at Eureka, CA. Primary sedimentation tanks are in the right foreground. The L-shaped aerated solids contact tank can been seen between the primary and secondary clarifiers. Secondary clarifiers are in the center, and the effluent holding pond is behind the clarifiers.** (Source: Brown and Caldwell Consulting Engineers. Used with permission.)

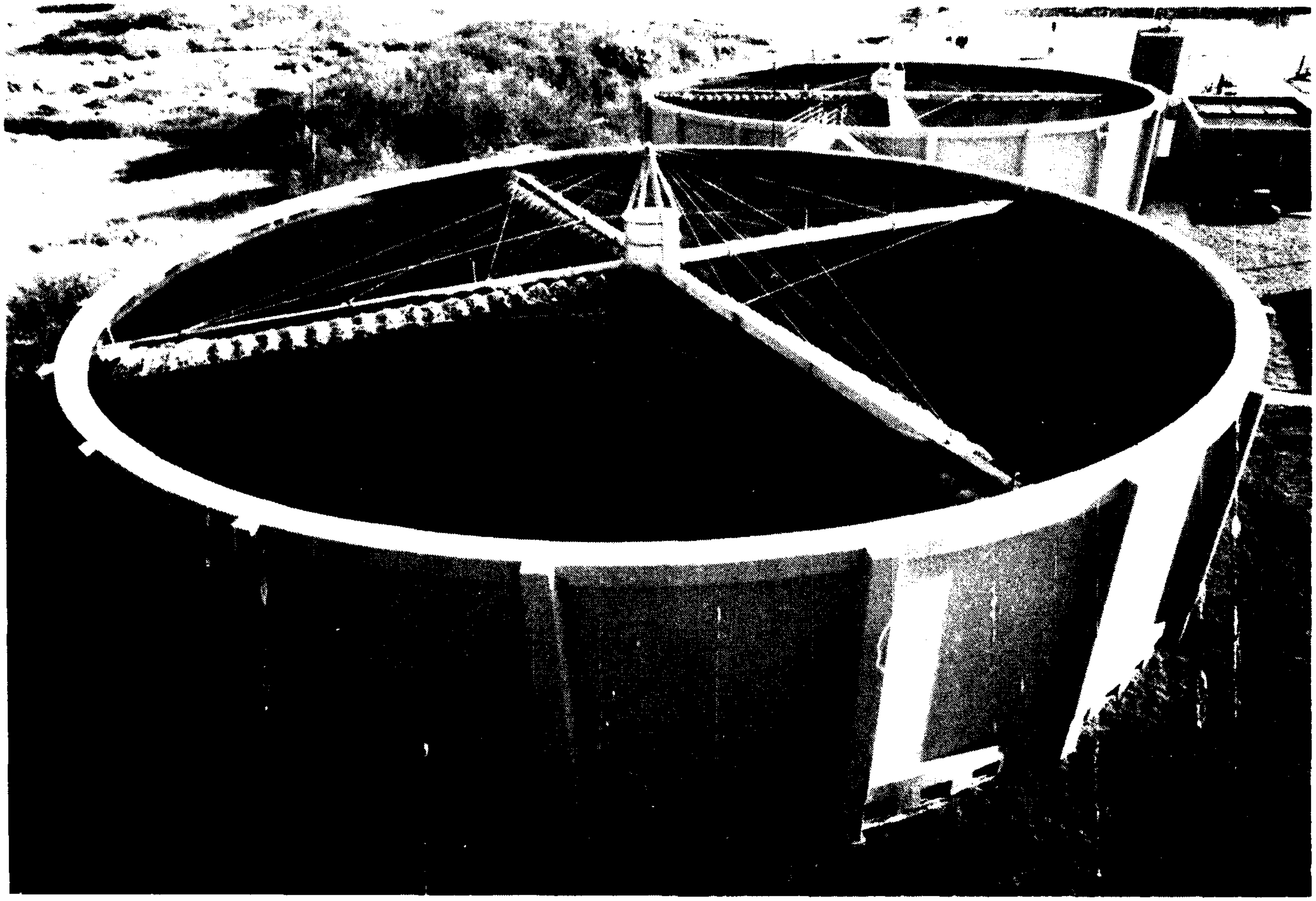

Figure A2. Plastic media trickling filters which are the first secondary treatment unit in the TF/SC process. Primary effluent trickles through the filter media. Bacteria attached to the media feed on the waste and grow continually larger. These bacteria break away in clumps called biological floc, leaving with the filter effluent and entering the aerated solids contact channel. (See also Figure 4 in the text). (Source: Brown and Caldwell Consulting Engineers. Used with permission.)

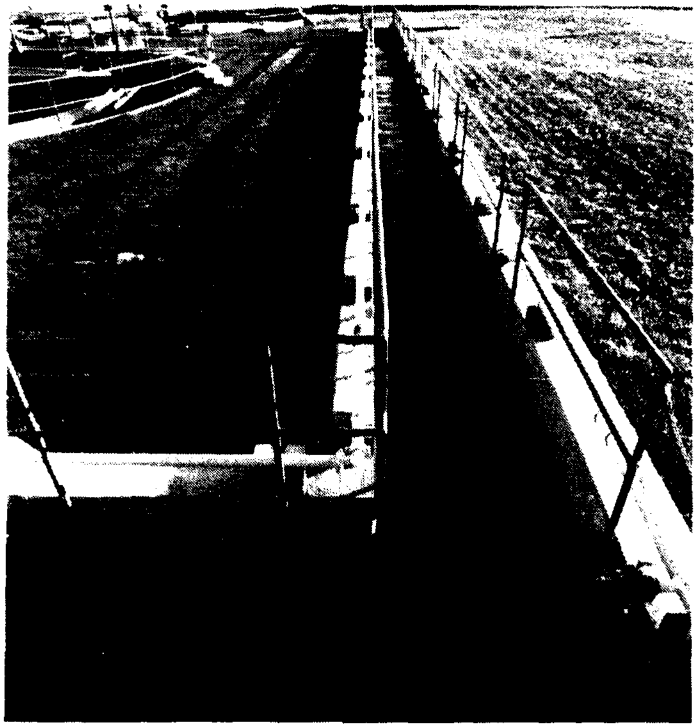

Figure A3. Aerated solids-contact channel. In this channel, trickling filter effluent mixes with the recirculated sludge from the secondary clarifier with its heavy concentration of biological floc. The floc act as nuclei, dramatically quickening flocculation and improving the agglomeration of fine particles. The floc also remove additional soluble organics. (Source: Brown and Caldwell Consulting Engineers. Used with permission.)

Figure A4. Aerated solids contact tank at Tolleson wastewater treatment plant. The blowers for the solids contact tank are above ground at this location.

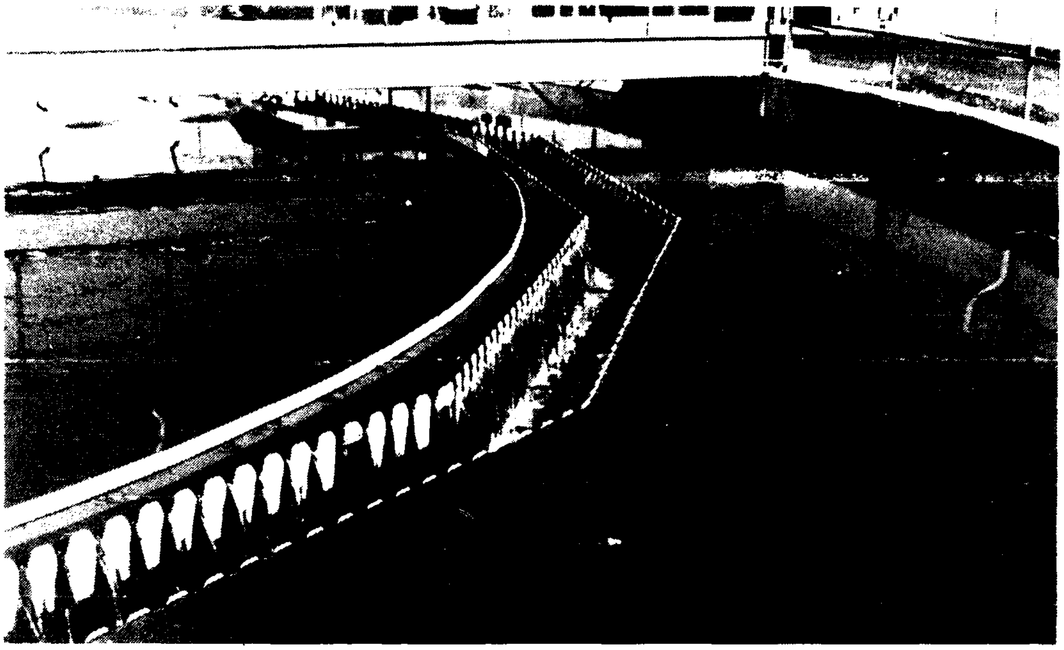

Figure A5. Secondary clarifier. This specially designed flocculator–clarifier has a gently stirred flocculation chamber at the center of the clarifier where floc continue to enlarge. The clumps then settle out as a sludge, leaving a high-quality effluent. (See also Figure 2 in the text). (Source: Brown and Caldwell Consulting Engineers. Used with permission.)

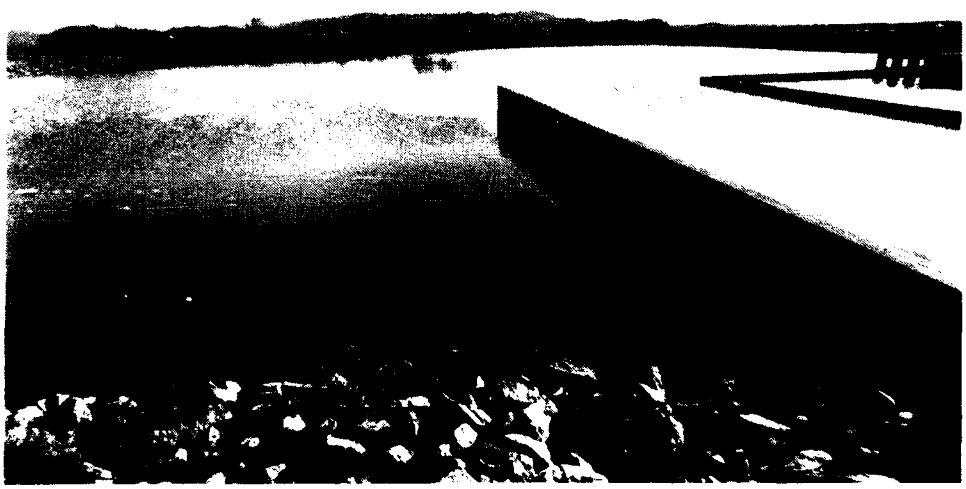

Figure A6. Effluent holding pond with chlorine contact tanks at right. The high-quality effluent permits split-stream treatment during wet weather. The TF/SC effluent is mixed with primary effluent in the holding basin. The mixture meets ocean discharge requirements for wet weather and is discharged with the outgoing tide through a submarine outfall. (Source: Brown and Caldwell Consulting Engineers. Used with permission.)

APPENDIX B:

ARMY CASE STUDY

The TF/SC process was considered for upgrading one of the wastewater treatment plants at a large Army installation. Although the system was never demonstrated, the design work done will serve to illustrate that the technology is feasible for use at Army wastewater treatment plants. This case study addressed the following specific objectives:

1. A measurable improvement in effluent quality over baseline conditions should be demonstrated. For the TF/SC operating mode selected as the baseline case, expected reductions in SS levels are 25 to 50 percent and 10 to 25 percent for BOD_5.

2. Incorporation of solids contact features to convert the plant to the TF/SC process should have a relatively low capital cost so as to demonstrate its high potential in upgrading treatment plants.

3. Operation of the process during the demonstration period will serve to substantiate its simplicity. The existing wastewater treatment plant consists of two 119-ft-diameter trickling filters with primary and final clarifiers. Sludge from the final clarifiers may be recirculated to the plant influent or may be wasted to existing sludge digesters. The proposed modification would add a solids contact process consisting of a 10,000-gal aerated solids contact tank and a 40,000-gal sludge reaeration tank capability that includes eight 5000-gal preformed tanks, plus attendant blowers and appurtenances between the trickling filters and the final clarifiers. Existing recirculation and waste pumps could be used to serve both the existing and proposed facilities.

Table B1* lists operating results for the existing system over 12 months of service. Final effluent values are lower than secondary effluent values because of solids settling in the chlorine contact tank.

Recommended Application Criteria

Selection of TF/SC process application criteria was influenced by the desire to keep the cost of treatment plant upgrading to a minimum, while ensuring that the physical facility is easy to operate as well as reliable, safe, and of permanent quality. To minimize costs, TF/SC Mode I (Figure 1 in the text) was chosen which has both a solids contact tank and a sludge reaeration tank. The site layout for this mode and the existing plant is shown in Figure B1. This mode also offers maximum flexibility for demonstrating the process.

Figure B2 shows a new 40,000-gal sludge reaeration tank system. Also shown is the conversion of manhole "X" and the existing channel over the pump room to aerated solids contact tank functions. All of these tanks would be fitted with medium-bubble diffusers which were selected because their efficiency is nearly equal to fine-bubble diffusers so that they impart the minimum energy possible while still maintaining dissolved oxygen in the basins. This is the most favorable condition for flocculation of the solids.

The design is flexible to allow additional operating parameters to be evaluated. For example, the sludge reaeration tank is composed of eight 5000-gal tanks to allow variation in the mixed liquor solids inventory so that solids residence time (SRT) can be varied.

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*Tables and figures are located at the end of this appendix.

Another built-in capability permits the sludge reaeration tank to be bypassed. This design allows a test of Mode I operation, but it is also possible to turn off the air supply to the diffusers in the solids contact tank to allow a test of Mode II. In addition, all modifications are designed to permit the plant staff to return the plant to its original operating mode should they choose to do so.

Design criteria for the modified portions of the plant are shown in Table B2. All criteria are shown in terms of current flows and loads (plant design capacity is higher at 4.6 mgd versus an average flow of 2.15 mgd now). The loadings are such that the plant can be operated safely with only one secondary clarifier in service (as is currently practiced) or with only one trickling filter in service.

Design follows the usual strict Corps of Engineers guidelines in all aspects. However, much of the information not pertinent to actual process design is omitted here for brevity (i.e., geotechnical surveys and analysis, materials specifications, procedural specifications, construction policies).

Volume Calculations

The required volume for the solids contact tank was calculated using Equation B1:

$$V = V = \frac{(Oc)\ (Q)\ (Y)\ (\Theta E)]}{(X)\ [1 + (Kd)\ (\Theta E)]} \qquad \text{[Eq B1]}$$

where:
- Oc = solids retention time, 5 days
- Q = flow = 2.15 mgd at ADF
- Y = maximum cell yield coefficient = 0.6 mg/mg
- So = influent soluble BOD_5 = 8.25 mg/L
- S = effluent soluble BOD_5 = 5 mg/L
- Kd = endogenous decay coefficient
- X = MLVSS, 2400 mg/L
- V = volume required, Mgal

Thus, for the solids contact tank:

$$V = \frac{(5D)(2.15\ \text{mgd})(0.6)(3.25\ \text{mg/L})}{(2400\ \text{mg/L})\ [1 + (0.06\ d^{-1})\ (5d)]}$$

$$= 6720 \text{ gal (use 10,000-gal tank)}$$

For the sludge reaeration tank volume, it was assumed that SRT = 1 day and MLSS = 1500 mg/L at 25 percent return. Thus:

$1500(Q) = 0.25Q_r$

$xr = 6000$ mg/L

max. BOD_5 load = 2500 lb/day

W = 2500 x 0.8 lb TSS/lb BOD_5 removed

W = 2000 lb/day yield

Volume/8.33 x 6000 = 2000

Volume = 0.040 million gal

= 40,000 gal

To check hydraulic retention time:

$$T = \frac{V}{Q} \qquad \text{[Eq B2]}$$

where: T = time, days
V = volume, Mgal
Q = Flow, 2.15 mgd

For the solids contact tank:

$$T = \frac{0.01 \text{ Mgal}}{2.15 \text{ mgd}}$$

$$T = 0.005 \text{ days} = 7 \text{ min (OK)}$$

The system as designed should provide an effective upgrade to the treatment facility. Effluent quality would be improved and capacity would be increased over current levels should the installation need these enhancements (e.g., due to population growth or more stringent regulations for effluent quality.

For details not presented here due to site-specificity, contact the author (see p 38).

Table B1

Operating Results for the Existing Plant

Date	Average flow, mgd	BOD_5, mg/L			SS, mg/L		
		Raw	Primary	Final	Raw	Primary	Final
March 1984	2.13	177	NA	23	143	NA	21
April 1984	1.99	215	NA	30	186	NA	12
May 1984	2.13	172	NA	26	163	NA	13
June 1984	2.10	180	NA	20	206	NA	16
July 1984	2.62	144	NA	14	151	NA	20
August 1984	2.44	143	NA	13	161	NA	14
September 1984	2.26	198	NA	18	165	NA	13
October 1984	2.31	182	NA	28	158	NA	16
November 1984	1.95	152	NA	35	161	NA	25
December 1984	1.89	120	76	20	136	52	11
January 1985	1.91	113	83	17	132	65	18
February 1985	2.12	158	104	26	155	77	30
Annual average	2.15	163	NA	23	160	NA	17

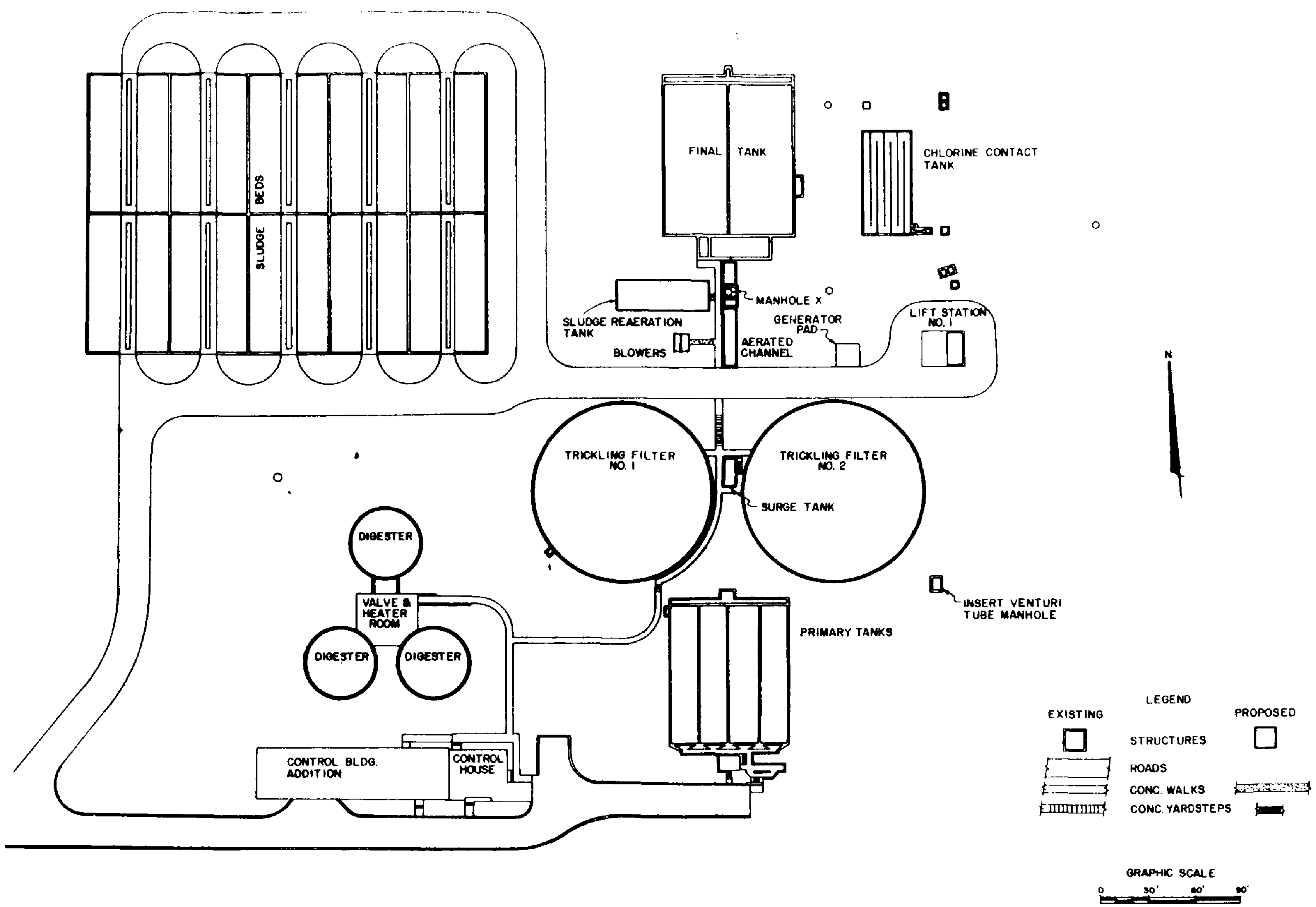

Figure B1. Proposed site layout showing existing plant.

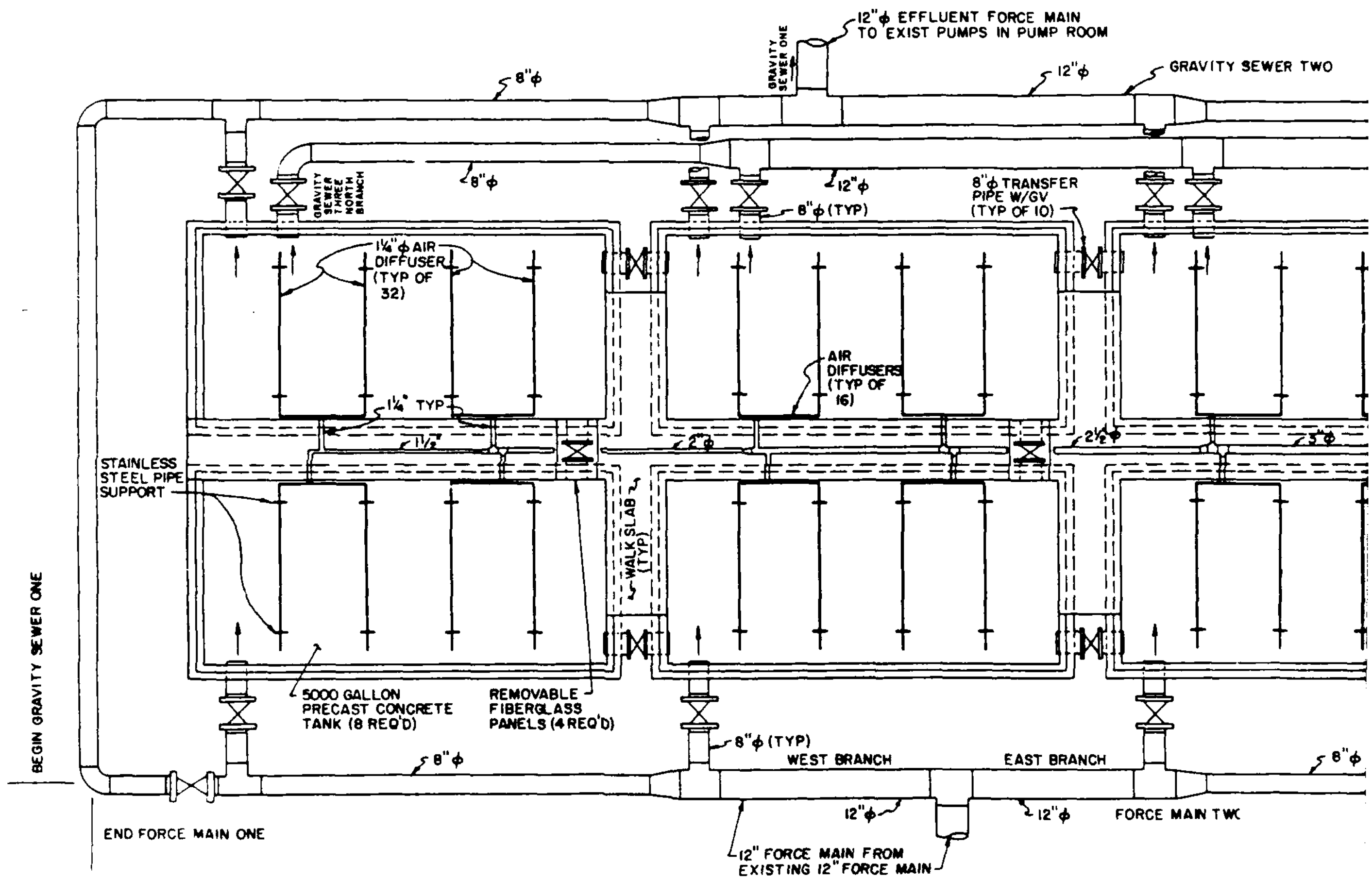

Figure B2. Sludge reaeration tank system.

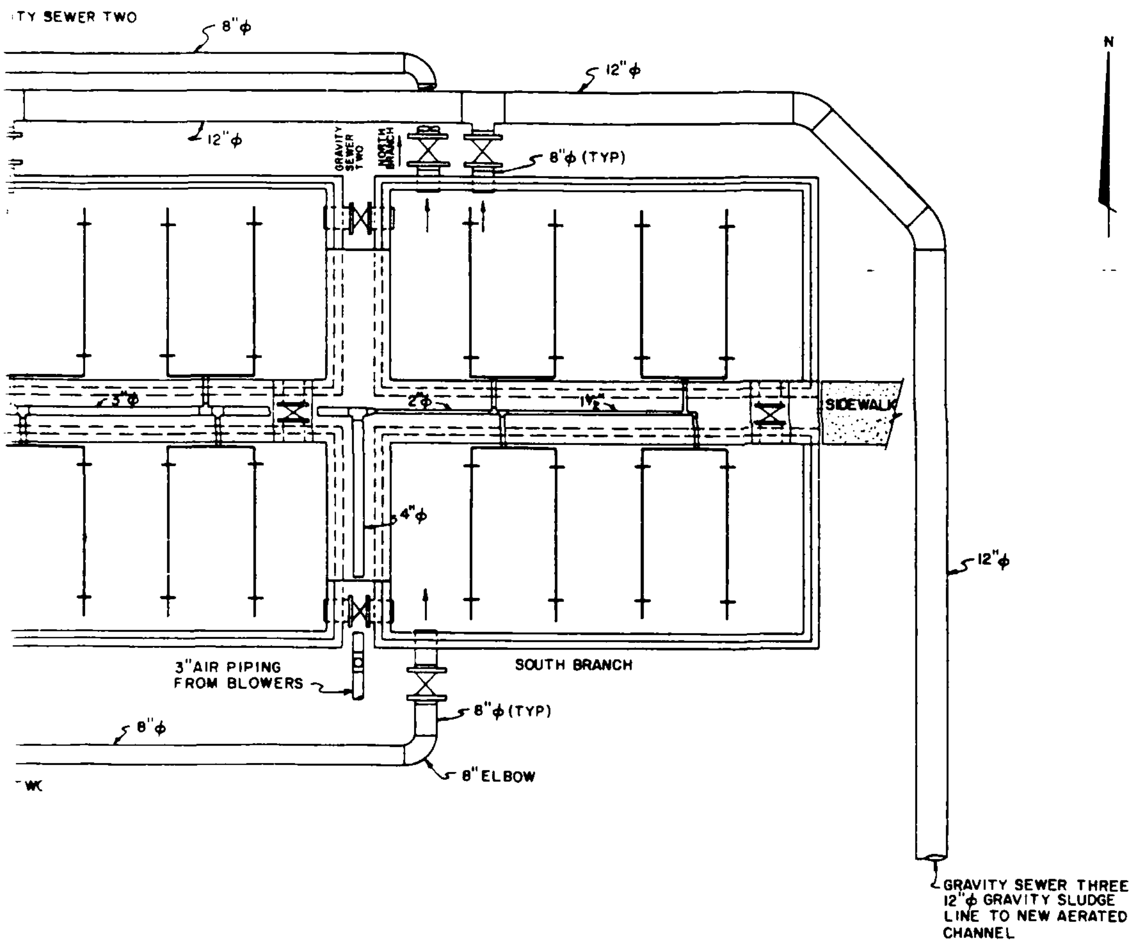
TY SEWER TWO
8"φ
12"φ
12"φ
GRAVITY SEWER TWO
NORTH BRANCH
8"φ (TYP)
N
3"φ
2"φ
1½"
SIDEWALK
4"φ
12"φ
3"AIR PIPING
FROM BLOWERS
SOUTH BRANCH
8"φ (TYP)
8"φ
8"ELBOW
GRAVITY SEWER THREE
12"φ GRAVITY SLUDGE
LINE TO NEW AERATED
CHANNEL

Table B2

Summary of Design Data—TF/SC Modification

Component/Criteria	Value
Trickling filters	
Number of units	2
Diameter, ft	119
Media depth, ft	5.25
Media type	Rock
Organic loading, 2 units in service, lb BOD_5/1000 cu ft/day*	16.5
Organic loading, 1 unit in service, lb BOD_5/1000 cu ft/day*	33
Solids contact tank**	
Volume, gal	10,000
Residence time, min*	7
Mixed liquor suspended solids, mg/L	1,500
Sludge reaeration tank**	
Volume, gal	40,000
Quantity	8 @ 5,000
Mixed liquor suspended solids, mg/L	6,000
Blower	
Number***	2
Type	Centrifugal
Discharge, cfm each	600
Secondary clarification	
Number of units	2
Surface area each, sq ft	4,300
Sidewater depth, ft	10
Average overflow rate, 1 unit in service,* gpd/sq ft	500
Average overflow rate, 2 units in service, gpd/sq ft	250

*At average annual flow of 2.15 mgd and primary effluent BOD_5 of 109 mg/L.
**Both tanks equipped with medium bubble diffusers.
***Includes one standby.

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