TRICKLING FILTER MYTHOLOGY

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ABSTRACT: Engineering practice in trickling filter design has been influenced by the propagation of myths as much as by the analysis of data and factual determinations. In this paper, several common myths encountered by the writer in his engineering practice are examined. The myths are tied to source(s) where possible, and then the factual underpinnings (if any) are examined. Common myths include the following: (1) Trickling filter processes are less reliable than activated sludge processes; (2) trickling filters are poor performers in cold weather; (3) trickling filters are more expensive; (4) motorized distributor speed control is always needed; (5) cross-flow media should not be used at total organic loadings exceeding 1.6 kg $BOD_5/m^3 \cdot d$ and (6) all media are created equal.

INTRODUCTION

Modern trickling filter (TF) design, particularly its process design aspects, remains as much an art as a science. The waning of popularity of the TF occurred in the seventies when conventional units were often unable to meet U.S. Environmental Protection Agency (EPA) national secondary treatment requirements. This caused many TFs to be abandoned in favor of activated sludge (AS) and at the same time research activity at university and governmental centers turned away from TFs. It is the writer's experience that teaching in universities in this unit process also declined, with few advanced courses offering more than a single hour on the topic during a quarter or a semester.

With a general lack of rigor surrounding our understanding of the process, opinion rather than fact-based research supports many of today's popular judgments about the TF process. Unfortunately, there has been a body of opinion built up concerning the process that dictates much of current design practice. These opinions have the characteristics of mythology rather than a basis in fact. Unfortunately, these opinions are accepted by many as fact, in some cases due to their repetition in government and professional society design manuals as well as in textbooks. In many cases, myths have suppressed the use of TFs in situations where they may have been the best alternative available. The purpose of the present paper is to stimulate interest, research, and discussion concerning the trickling filter process. The writer invites responses in the *Journal of Environmental Engineering* in the form of discussions. The focus of the present paper is the design of modern TFs equipped with corrugated plastic sheet media, although other media types are touched upon.

MYTH 1: TRICKLING FILTER PROCESSES ARE LESS RELIABLE THAN ACTIVATED SLUDGE PROCESSES

Myth

This is perhaps the most commonly held belief that the writer has encountered in the practice of environmental engineering. In summary, it is commonly held that trickling filters are incapable of matching the activated sludge process either in terms of carbonaceous removal or in degree of nitrification.

When the U.S. EPA issued its secondary treatment regulations in the early seventies, typical TF effluent qualities were found wanting [i.e., they typically could not meet the monthly average requirements for BOD_5 and effluent suspended solids (ESS) of 30 mg/L]. This was true for many existing rock TFs, and surprisingly, this also seemed to apply to modern units fitted with corrugated plastic sheet media. The U.S. EPA issued relaxed regulations for existing trickling filters, requiring them to meet a monthly requirement for ESS and BOD_5 of 45 mg/L (''Secondary'' 1984). In the early eighties, a consulting engineering firm for a municipal plant in California proposed to design a conventional TF plant with corrugated sheet media. The state regulatory agency questioned the use of this technology and indicated that, as a grant condition, the consulting engineer would have to provide a survey of similar plants meeting the EPA secondary treatment regulations. The consultant contacted the media suppliers, and not a single plant could be identified.

As another example, a recent design manual (*Nitrogen* 1993) states that nitrifying TFs may not produce effluent ammonia levels less than 2.5 mg/L as reliably as the activated sludge process. And a recent manual of practice (MOP) notes that predators can overgrow nitrifying TFs, causing them to lose activity, resulting in performance declines (*Design* 1992).

In the case of conventional trickling filter plants, there was a factual basis for the myth, at least as far as the then-existing technology was concerned. However, the perpetuation of this myth is not reasonable due to subsequent technology developments.

Facts

It is this writer's judgment that part of the poor performance of conventional TF plants is related to poor secondary sedimentation tank design. Typically, higher surface overflow rates and lower sidewater depths (SWDs) were used in TF plants than in activated sludge plants. In support of this assertion, it is noted that the original Coeur d'Alene rock TF plant had very shallow secondary clarifiers (SWD = 2.1 m), peripheral weirs, and scraper sludge collection. When replaced with deeper flocculator-clarifiers with in-board weirs, the effluent suspended solids (ESS) dropped from 25 mg/L to 18 mg/L (Matasci et al. 1988). Conventional rock TFs equipped with flocculator-clarifiers were demonstrated as capable of meeting secondary treatment requirements with 28 mg/L ESS at Morro Bay, California, and 20 mg/L ESS at Corvallis, Oregon (Norris et al. 1982; Matasci et al. 1988). However, these ESS values are still higher than what the activated sludge process is capable of producing, indicating that adequate secondary clarification was not the only difference in the processes. Even with good secondary clarification, part of the solids in the trickling filter underflow is highly dispersed and is not removed.

In 1979 at Corvallis, the development of the trickling filter/solids contact (TF/SC) process showed that an aerobic solids contact and sludge reaeration channel could be used to floc-

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Note. Associate Editor: J. B. Neethling. Discussion open until December 1, 1999. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on June 22, 1998. This paper is part of the ***Journal of Environmental Engineering***, Vol. 125, No. 7, July, 1999. ©ASCE, ISSN 0733-9372/99/0007-0618–0625/$8.00 + $.50 per page. Paper No. 18615.

culate the finely divided solids exiting a rock TF (Norris et al. 1980, 1982). Before conversion to the TF/SC process, this rock filter plant produced ESS and BOD values between 20 and 45 mg/L. The full-scale demonstration compared the conventional activated sludge process to the TF/SC process, and showed that the TF/SC process could produce essentially the same effluent quality (less than 10 mg/L ESS) as could an activated sludge process.

Application of the process at many other plants (Parker and Matasci 1989; Parker et al. 1993) showed that improvements seen at Corvallis with the TF/SC process were general and applicable to both conventional rock and plastic media plants. The process differed from the TF/AS process in several respects, including the use of a smaller aeration tank (residence typically 10–60 min) and solids residence times of less than 1 d. This meant that upgrades to conventional TF plants could be done relatively economically.

Later developments of the TF/SC process have taken advantage of the newer plastic corrugated sheet media to support simultaneous BOD removal and nitrification. Studies show that the organic loading per unit surface area and type of media govern the extent of nitrification by the TF (Parker and Richards 1986). The process is capable of producing average effluent ammonia nitrogen levels less than 2.5 mg/L in at least four treatment plants, and in some cases at temperatures down to 7°C (*Design* 1992; Daigger et al. 1993). More recently, TF/SC process applications with chemical primary treatment for phosphorus removal and high density media have shown similar efficiency at temperatures down to 10°C (Parker et al. 1998).

TF/SC plants have also demonstrated good resiliency when subjected to shock loadings. Fig. 1 shows the nominal impact on effluent quality of abruptly doubling the load on the trickling filters at the Omaha plant. This occurred when one of the two trickling filters at this TF/SC plant was taken down for service. Despite this shock loading impressed on the single TF remaining in service, the effluent solids and BOD did not rise significantly. The same pattern has held true on five other occasions when the plant took one of its trickling filters out of service (Swan 1993).

A survey of five tertiary nitrifying trickling filters (NTFs) units showed that monthly average effluent ammonia nitrogen levels were less than 2.5 mg/L for more than 90% of the time in four of the plants (Parker et al. 1989b). Monthly wastewater temperatures dropped to lows of 9°C. Parallel studies of tertiary NTFs and activated sludge plants showed they had virtually identical reliability (Gujer and Boller 1983). Developments in tertiary nitrification units have demonstrated the ability to produce effluent ammonia levels as low as 1 mg/L

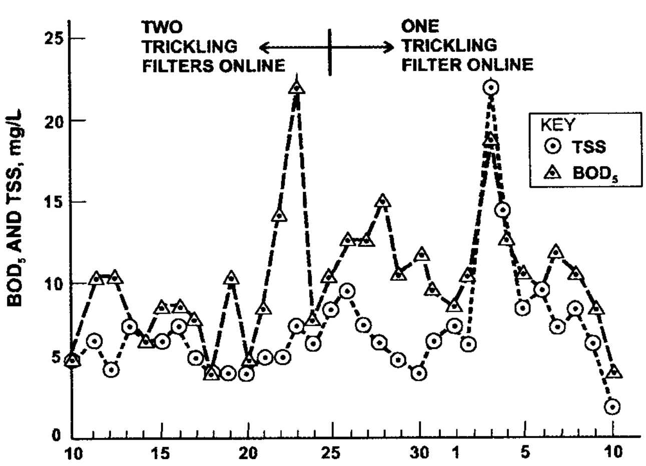

FIG. 1. Effect of Shock Loading on TF/SC Process at Omaha

ammonia nitrogen by adjusting the level of recirculation and using alkaline backwash in NTFs that can be flooded to control or eliminate predators (Parker et al. 1997).

In the mid-nineties, the writer developed a technology that can be used to control snails in NTFs that cannot be flooded. The technology can also be used to control snails in TFs used for carbonaceous removal. The scheme employs a dedicated trickling filter pumping circuit that involves chemical application and snail removal. In use, the TF to be treated would be taken off-line and connected to the dedicated pumping circuit. Appropriate chemical control would be applied at concentrations toxic to snails, but not toxic to or only temporarily inhibiting the desired bacterial population (nitrifiers or heterotrophs, depending on the application). In its first application, the technology has returned a nitrifying trickling filter to compliance with its discharge requirements (Parker 1998).

Improvements in conventional trickling filter technology (e.g., TF/SC and tertiary nitrifying trickling filters) have led to equality of performance of TFs and activated sludge in many applications. However, a TF placed early in the flow sheet does have some disadvantages with respect to nutrient removal. Readily biodegradable substrate is removed that would otherwise drive rapid denitrification or support phosphorus-accumulating organisms. However, this does not mean that TFs must necessarily be abandoned. For instance, the Orange Water and Sewer Authority has developed a process that uses a fermenter to produce a volatile acid-rich stream to support biological phosphorus removal in an activated sludge step downstream of rock trickling filters (Kalb et al. 1991).

MYTH 2: TRICKLING FILTERS ARE POOR PERFORMERS IN COLD WEATHER (COMPARED TO ACTIVATED SLUDGE PROCESS)

Myth

Belief in this myth is also very common. Moreover, this opinion is repeated in design manuals (*Process* 1971; *Nitrogen* 1993). In this writer's view, the opinion probably derives from experience with rock TFs that often suffered in performance during winter months. Uncovered rock TFs were subject to excessive cooling with cold ambient temperatures, as ventilation was usually unrestricted and the units operated essentially as cooling towers. And rock trickling filters are typically much more shallow than modern plastic media units, making them more susceptible to wind-induced ventilation and cooling.

Facts

When plastic media TFs have their ventilation rate controlled and are covered, our firm's experience is that the temperature decline is usually less than 2°C in winter months. An in studying tertiary NTFs, Parker et al. (1995) found that the percentage decline in reaction rates with temperature drop was less than would be expected for the activated sludge process. When wastewater temperatures fell from 20.2 to 13.8°C, rates in the NTFs fell 24% while when using a commonly accepted design equation for nitrifier growth rate (*Nitrogen* 1993), an activated sludge process' rates were predicted to decline 47% over the same temperature range.

MYTH 3: TRICKLING FILTERS ARE MORE EXPENSIVE

Myth

It is commonly held that trickling filters are more expensive as a treatment alternative than is the activated sludge process. This is a popular, often repeated myth. In the writer's judgment, it likely derives from experience with low-rate rock trickling filter where structure and land requirements are very large compared to conventional activated sludge technology.

Facts

It is not possible to generalize for all situations; because every situation is specific, no generalizations can be drawn. But there are numerous published case examples where trickling filters processes have proven less costly than conventional activated sludge processes (Fedotoff et al. 1982; Hyde and Bellows 1984; Parker et al. 1989b; Gorder et al. 1990; Parker et al. 1994; Parker et al. 1998).

MYTH 4: MOTORIZED DISTRIBUTOR SPEED CONTROL IS ALWAYS NEEDED

Myth

Since the nineties, virtually every U.S. manual of practice has almost unequivocally recommended that motorized speed control be provided for every trickling filter application (*Design* 1992; *Automated* 1997; *Draft* 1997). The need for motorized control has been emphasized because it has been asserted that at least once per day the distributor should be slowed to very slow speeds so that the media will be flushed of excess biomass; hydraulic control is not able to obtain these slow speeds. There is the commonly held belief that excess biomass development will not only cause performance declines, but that without motorized control, the excess biomass will build up to such an extent that the media will collapse. The need for such motorized control needs reexamination by our profession to determine the benefits of distributor speed and to determine the best means to implement it (motorized or hydraulic).

The argument for slowing distributors is as follows (Albertson 1989):

> If a trickling filter accumulates excess solids, performance will decrease. The reason is simple: The aerobic surface area will decrease with increased biomass. As a result, oxygen transfer will decrease and the simple BOD_5 conversion and ammonia oxidation capability will be reduced. High instantaneous flow rates will continuously remove the excess biomass and thus enhance the treatment performance. Because the oxygen does not penetrate more than 1 to 1.5 mm of film thickness, there is no benefit of more than 1/32-in. biomass on the media surface. . . . However, available aerobic surface area will further decrease with thicker biomass as occlusion of converging surfaces occurs.

The specter of media collapse is raised as well if motorized distributor speed control is not practiced (*Draft* 1997):

> Filter media should be able to withstand a static load up to 18 lb/cu ft at the maximum temperature for at least 20 years. . . . Excess biomass should be controlled within this range or less with routine flushing as previously discussed. Excess biomass and inadequate specifications have caused several media collapses.

Hydraulic flushing induced by slowed distributor speeds is typically defined in terms of Spülkraft (SK), as follows:

$$SK = \frac{(q + r)(1{,}000 \text{ mm/m})}{(a)(n)(60 \text{ min/h})} \quad (1)$$

where $q + r$ = total hydraulic application rate, $m^3/m^2 \cdot h$; a = number of arms on the distributor; and n = rotational speed of the distributor, revolutions/min.

A typical range in SK values for both performance enhancement (normal operating conditions) and daily flushing is given in Table 1 (*Design* 1992). Albertson (1995) has subsequently modified these recommendations to account for variations in daily flow rate, but the order of magnitude of recommended SK values remains the same.

TABLE 1. Suggestions for Distributor SK Rates (*Design* 1992)

TOL[a] (kg $BOD_5/m^3 \cdot d$) (1)	Design SK (mm/pass) (2)	Flushing SK (mm/pass) (3)
0.25	10–100	>200
0.50	15–150	>200
1.00	30–200	>300
2.00	40–250	>400
3.00	60–300	>600
4.00	80–400	>800

[a]TOL = total organic loading.

Facts: Research Supporting Flushing for Excess Biomass Removal

The early U.K. work by Lumb and Barnes (1948) and Tomlinson and Hall (1955) is cited by Albertson (1995) in support of distributor speed control. However, these investigators studied atypical low-rate rock filters. Lumb and Barnes' media size was only 19 mm on the top of the bed. Tomlinson and Hall's media size was only 25–63 mm (Wishart and Wilkinson 1941). Most U.S. rock filters today use media of 60–150 mm. Low-rate filters in the United Kingdom that had such small media were typically subject to ponding, and slowing distributor speed was of one of the most successful remedies investigated. However, the SK values were very low even after slowing (1–29 mm/pass), which is not very different than the range of U.S. practice prior to distributor speed control. The controlled SK values are much less than the ''flushing'' SK values in Table 1. Thus, these early U.K. data are not really applicable to U.S. practice, owing to the fact that such small rock media offer many sites for solids accumulation not present in corrugated sheet media. More relevant is the later U.K. pilot work that showed that when larger rock media were used (100–150 mm), none of the rock filters experienced plugging in over 3.5 yr of operation at total organic loadings (TOLs) up to 1.7 kg $BOD_5/m^3 \cdot d$. This was despite the use of calculated SK values of less than 2 mm/pass (Bruce and Merkens 1970).

Albertson (1995) also cites the work of Orr and Lawty (1990) in support of the speed-control argument. Orr and Lawty studied deep trickling filter towers fitted with dumped plastic media in Auckland, New Zealand. The towers were plagued with excessive biomas and had severe odor problems. Implementation of distributor speed control with an SK value of 226 mm/pass significantly reduced the biomass inventory relative to the control trickling filter with an SK value of 7 mm/pass. Given the propensity of dumped media to accumulate solids due to their many horizontal surfaces, such experience is not easily translatable to corrugated sheet media.

An unprecedented number of trickling filter collapses occurred in the last decade. With respect to the need for speed control to prevent trickling filter media collapse, the writer reviewed the causes of 12 catastrophic trickling filter failures that have occurred since 1990 (Table 2). Data supporting the evaluation of probable cause of failure were obtained from the writer's personal involvement in forensic investigations or by survey of the operators and plant designers. The most common cause of catastrophic failure was actually weak media (fabrication or placement problems). Of the seven failures due to this cause, six were from a single supplier who went out of business after this string of events. The supplier had apparently

TABLE 2. Probable Cause of Plastic Media Trickling Filter Catastrophic Failures since 1990

Cause (1)	Number (2)
Weak media (fabrication, installation)	7[a]
Media support system failure	3
Influent specifications for media exceeded	1
Excess biomass accumulation	1[b]
[Total]	12

[a]Three equipped with vertical-flow media, four with cross-flow media.
[b]Industrial wastewater without adequate pretreatment.

had quality problems (and weakened the media) compared to the quality previously produced.

The next most frequent cause of failure in Table 2 was from inadequately designed or constructed media support systems. Only a single case of excessive biomass accumulation was found conclusively to be the cause, and this was for a high-strength industrial wastewater application lacking proper pretreatment. While in several cases there was found to be excessive amounts of biomass in the collapsed media, particularly in the bottom layers, the indicated order of events was failure of the media followed by biomass accumulation, since the biomass no longer had a pathway to be flushed from the media. Thus, the lack of motorized distributor speed control was not a significant factor in most of the trickling filter media collapses in the nineties.

It should also be noted that there was no comparable period in the seventies or eighties when a similar number of trickling filter failures occurred. The question has to be asked: Since motorized control was not practiced during this earlier 20 yr period, why was there no comparable experience with TF collapses?

There are other concerns relating to slow distributor speeds, such as concern over varying dynamic transient water loads on the media. Manufacturers use a constant weight for the applied hydraulic load (Mabbott 1982), and the concern is that the daily high flushing SK application may induce extraordinary cyclic loads on the media. Such loads have never been measured. Will these cyclic loads affect media life through fatigue failure modes?

Facts: Research Supporting Slow-Speed Distributors for Performance Improvement

Three low-rate municipal applications fitted with corrugated sheet media are reported where improvements in effluent ammonia were observed by slowing distributor speeds (Albertson 1995). One of these, Central Valley, in Utah was fitted with cross-flow media having a specific surface of 98 m^3/m^2 and had motorized controls that varied the SK with flow throughout the day according to Albertson's algorithms. Albertson reports a 3 mg/L improvement in effluent ammonia level for February 1993. A full year of data for this plant (William Fox, personal communication, 1997) are shown in Fig. 2. A significant improvement in ammonia removal was obtained with motorized control. Interestingly, when the motor failed on July 15, 1995, there was a continuing benefit in ammonia removal. Unfortunately, a regime of high but constant SK was not tested, so it cannot be determined if the extreme daily flushing SK values had a separate beneficial impact. It was found at Central Valley that slowing the distributor to too great an extent under cold ambient conditions could inhibit nitrification activity, presumably due to excessive cooling of the biomass (William Fox, personal communication, 1997). This was corrected by increasing the distributor speed.

The Water Environment Federation (WEF) and ASCE (*Design* 1992) provide a list of 15 plants were media fouling, odor occurrences, excessive sloughing, or performance problems occurred, and report that slowing the distributor fixed these problems. Except for Auckland, no quantitative information was provided. Two-thirds of the plants did not have motorized distributors, but successfully used reverse thrusting jets to slow the distributors and obtain the performance benefit without recourse to a daily high SK flushing cycle.

Operating data from a high-rate trickling filter application fitted with vertical flow media at Stockton, California, were analyzed for canning season performance. Distributor arms were slowed to 15 min/pass (SK of 78 mm/pass) and did not use a flushing cycle. While there was no control for this experiment, detailed data from an earlier canning season with conventional SK values were available for comparison. The Logan trickling filter model (LTF) (Logan et al. 1987a,b) was calibrated to these earlier data (Brown and Caldwell 1980) and used to project performance without speed control (Table 3). There was a remarkable improvement with constant speed control. However, the possibility exists that some portion of the apparent improvement could be due to a change in wastewater characteristics between canning seasons.

Only one study has been published about the effect of SK on the performance of tertiary nitrifying trickling filters (Parker et al. 1995). Carefully conducted parametric tests showed optimum nitrification rates at 40 mm/pass and showed that

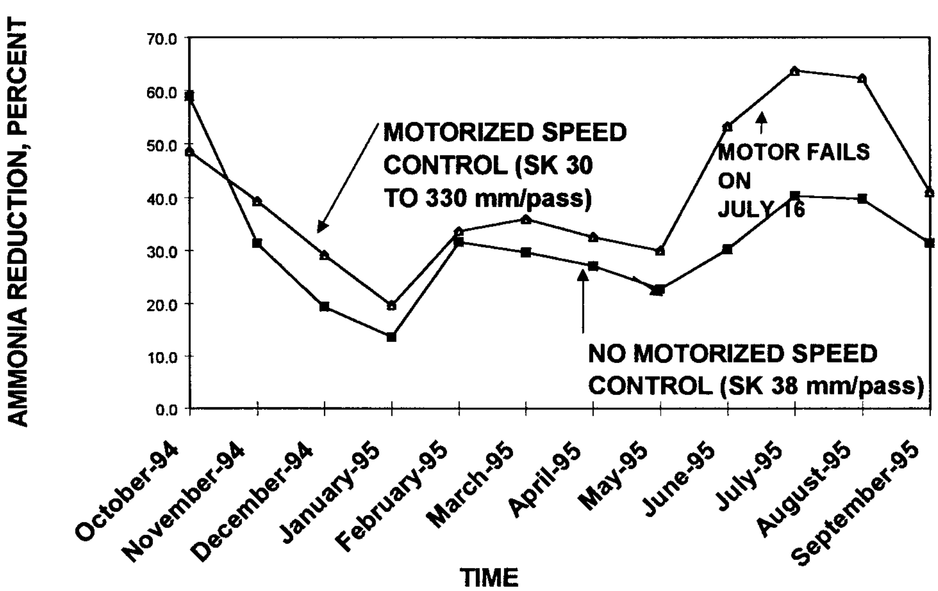

FIG. 2. Ammonia Reduction at Central Valley As Function of Distributor Speed Control

TABLE 3. Effect of Distributor Speed Control at Stockton

Month, 1995 (1)	Influent soluble BOD_5 (mg/L) (2)	Effluent soluble BOD_5 (mg/L[a]) (3)	LTF model predicted effluent soluble BOD_5 (without speed control) (mg/L) (4)
June	115	11	32
August	375	32	105
September	262	21	74

[a]Actual effluent data at high SK value.

higher SK values had no performance benefit. This level of speed control can be obtained with reverse thrusting jets, and no motorized distributor speed control is required. Moreover, since the biofilm is thin on an NTF, there would be no expectation that a daily high SK flushing cycle would be required for excess biofilm control.

Need for Additional Distributor Speed Research

A review of the data available shows that distributor speed optimization will yield performance benefits for municipal trickling filter applications using plastic corrugated sheet media for all common applications. However, the prescription of universal motorized speed control with a daily high flushing SK cycle is not justified by published data. And the absence of motorized control apparently was not a significant factor in most of the catastrophic failures of trickling filters in the nineties.

Research is needed in roughing and low-rate trickling filter applications with corrugated plastic sheet media to demonstrate the benefits (if any) of daily high SK flushing cycles with motorized distributors. It may be that the reported successes can be repeated in most applications with nearly constant SK values throughout the day using either reverse thrusting jets or constant motorized speed control. In addition to typical performance measures (odor, process efficiency), the amount of biomass accumulation should be measured directly rather than by inference. This could be done by equipping full-scale trickling filters with load cells containing the various media types. Such research should be oriented to determining whether each media type has a different optimum SK regime and whether the SK optimum regime varies with TOL. The load cells would allow direct determination of biomass accumulation as a function of process parameters (TOL, hydraulic application rate, SK regime, and so on). The influence of slowed distributor speed could also be assessed; actual measurements of these time-varying loads are in order so that the extent of the problem can be evaluated and media suppliers can account for them in design.

MYTH 5: CROSS-FLOW MEDIA SHOULD NOT BE USED AT TOTAL ORGANIC LOADINGS EXCEEDING 1.6 kg $BOD_5/m^3 \cdot d$

Myth

A former leading supplier of corrugated plastic sheet media recommended this TOL limitation on cross-flow media in its advertising literature in the eighties and an even lower limitation in the early nineties. The WEF and ASCE (*Design* 1992) published the following recommendation concerning cross-flow media in roughing applications:

> All media that redistribute flow . . . are more prone to solids retention and fouling because of reduced flushing effects. Applications such as BOD roughing tend to produce more and thicker biomass. Wood and vertical media are preferred for these applications.

Roughing applications were defined as TOLs exceeding 1.6 kg $BOD_5/m^3 \cdot d$. The implication of these statements is that plastic media module weights will increase with TOL and that cross-flow media will accumulate more biomas than will vertical flow media.

Facts

It is notable that in the same time period, the aforementioned limitations were not repeated in the literature of other plastic corrugated sheet media suppliers. There are a number of industrial TF plants in the United States operating at TOLs exceeding 1.6 kg $BOD_5/m^3 \cdot d$. And there are many successful applications in Europe with cross-flow media at TOLs higher than 1.6 kg $BOD_5/m^3 \cdot d$ (Martin Marggraff, personal communication, 1998). No data could be found that indicated that there should be a TOL limitation on the media.

There is limited available literature on comparative biomass accumulation of various media, and available data are summarized in Table 4. There are several media types represented in this table. The following definitions apply:

- XF: Cross-flow media. Corrugations are at a 60° angle and sheets are placed opposing so that contact points are made at frequent intervals.
- VFFC: Vertical flow media. Corrugations are vertical and every sheet is a corrugated sheet.
- VFSC: Vertical flow media. Corrugations are vertical and every other sheet is a flat sheet.

When both the qualitative and the quantitative data are inspected, and considering comparisons made at each site between media pairs for Hillsborough, Garland, and Stevenage, the following order of media weights can be found:

$$\text{VFFC} > \text{XF} > \text{VFSC}$$

In other words, at Hillsborough, VFFC accumulated more biomass than XF media did, while at Garland, XF accumulated more than VFSC media did. Although XF media were not tested at Stevenage, the finding that VFFC media exceeded VFSC weights at Stevenage confirms the overall trend. Note that there is site-to-site variability for the same media type. For example, VFSC media weighed considerably more at Garland than at Stevenage. This may be due to differences in waste characteristics as well as measurement methods.

The foregoing ranking was based upon media net weight, which excluded the weight of transient water. Calculations were made with the hydrodynamic component of the LTF model (Logan et al. 1987a,b) to determine film thickness in order to determine the weight of the transient water. The transient water weights were found to follow the same trend as that mentioned previously (although the difference between VFFC and XF was slight), which means that the order of total module weights is also as given previously. While available data are sparse and collection of additional data is an important research need, ironically it does appear that cross-flow media accumulate more solids than one type of vertical media and not the other. There certainly is no basis in these data for stating that there should be a TOL limitation on cross-flow media.

There needs to be additional work at full scale with rotary distributors to verify the relationships seen at pilot scale. It also should be noted that none of the comparative weight data discussed earlier fall into a range of concern with regard to media strength. Media suppliers (Mabbott 1982) base their de-

TABLE 4. Side-By-Side Measurements of Corrugated Sheet Media Module Wet Weight

Location/media (1)	Investigators (2)	Unit Weight (kg/m^3) (3)	Total organic load ($kg\ BOD_5/m^3 \cdot d$) (4)	Remarks (5)
1. Garland/XF	Brown and Caldwell (1983)	Average: 136	Up to 1.1	"There was no evidence of plugging. Based upon the inspection, we feel there would be no problems with either media at full scale."
2. Garland/VFSC	Brown and Caldwell (1983)	Average: 93	Up to 1.1	"There was no evidence of plugging. Based upon the inspection, we feel there would be no problems with either media at full scale."
3. Hillsborough/XF	"A comparison" (1984)	—[a]	0.6–6.0	"No plugging observed. Sparse biogrowth."
4. Hillsborough/VFFC	"A comparison" (1984)	—[a]	0.6–6.0	"Open vertically. Best biogrowth."
5. Atlanta/XF and VFSC	Richards and Reinhart (1986)	—[a]	Up to 1.3	"Although none of the media flow channels were completely blocked, partial blockages were evident. The cross flow media were partially blocked by large (2.5 to 5 cm diameter) black gelatinous deposits within the media as well as the interfaces between the packs, as shown in Figure 11. Most of the solids accumulated in the pack media where two parallel sheets touched. A large number of the same gelatinous deposits were associated with the VF media; however, they occurred primarily at the interfaces between the packs and not in the packs (Figure 12). Even so, plugging in the cross flow media may not affect efficiency as much as the same degree of plugging in vertical flow media." Note that no conclusion was made about which media accumulated more solids.
6. Stevenage/VFSC	Bruce and Merkens (1973)	Average: 58, peak: 83	1.3–4.5	Calculated from average depth of liquid film, which, over the period, averaged 0.3 mm and peaked at 0.6 mm. Assume clean media weigh 32 kg/m^3.
7. Stevenage/VFFC	Bruce and Merkens (1973)	Average: 83, peak: 121	1.5–3.3	Calculated from average depth of liquid film, which, over the period, averaged 0.6 mm and peaked at 1.1 mm. Assume clean media weigh 32 kg/m^3.

Note: Corrugated sheet media wet weights exclude value of "transient water." Also, media weights in third column are averages for whole tower, even when word "peak" is applied. Only media reviewed were those having specific surface area of 82–98 m^2/m^3.
[a]Only qualitative observations were made; see remarks.

TABLE 5. Comparison of Film Thickness versus Loading for VFFC and VFSC Media at Stevenage (adapted from Bruce and Merkens 1973)

Phase (1)	Duration (months) (2)	VFFC total organic load ($kg\ BOD_5/m^3 \cdot d$) (3)	VFFC film thickness (mm) (4)	VFSC total organic load ($kg\ BOD_5/m^3 \cdot d$) (5)	VFSC film thickness (mm) (6)
1	10	1.7	5	1.7	4
2	12	3.3	6	3.3	2.5
3	12	1.5	5	4.5	2
4	5	1.7	7	1.3	2

signs on wet media weights (including transient water) of 256 kg/m^3.

The literature was also searched to determine if a trend could be found between module weight and TOL. Only two studies reported enough data to evaluate this aspect of the myth. Bruce and Merkens (1973) report film thickness for various operating periods for parallel operation of VFFC and VFSC media, and their results are summarized in Table 5. No trend in biofilm thickness with TOL can be seen, and in some cases the film thickness is lower at higher TOLs.

Studying fish processing wastewater, Battistoni et al. (1992) report data on the effect of temperature, BOD_5 concentration, and hydraulic application rate on dry solids accumulation in cross-flow media. The writer prepared Fig. 3 from Battistoni et al.'s regression equations to show the effects of application rate and waste strength. A doubling of TOL would be obtained by either doubling waste strength or doubling the application rate at constant waste strength. When doubling waste strength, the biofilm density would increase, but its increase would be moderated at high application rates. On the other hand, a doubling in application rate at constant waste strength always results in a decline in biomass accumulation. If application rates are initially low, the decline is dramatic. If application rates are initially high, the decline is marginal. Since increased TOL can have opposite effects on biomass accumulation, it can be seen that there is no fundamental relationship between biomass weight and TOL for XF media.

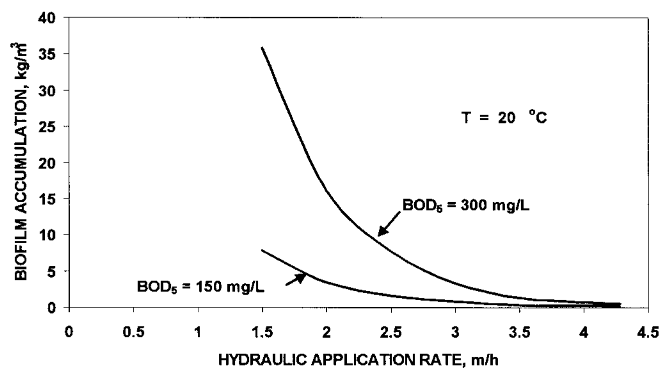

FIG. 3. Solids Accumulation in XF Media As Function of Application Rate and BOD (Battistoni et al. 1992)

The data does not support a presumption that cross-flow media will accumulate excessive amounts of biomass at high TOLs, and available data indicate that the situation is more complex given that high hydraulic application rates will mitigate biomass accumulation.

MYTH 6: ALL MEDIA ARE CREATED EQUAL

Myth

It is a very common misconception that as long as the specific surface area of one media is the same as the next, then performance will be equal. However, this problem has been perpetuated in recent MOPs (*Design* 1992; *Draft* 1997; *Biological* 1998) by either not recognizing the performance differences between cross-flow and vertical-flow media, or by treating the matter as one of controversy.

Facts

Differences in media types are probably clearest for tertiary nitrification applications, as data tend to be more comparable on a site-to-site basis. Table 6 shows data for zero-order nitrification rates for both cross-flow and vertical-flow media in tertiary NTFs. These rates have been expressed on a unit-area basis to ensure comparability, and show consistently higher rates for cross-flow media. These results are consistent with nitrification rate predictions based on calculations of the oxygen transfer capacity of the two media types (Parker et al. 1989a; Logan 1993). Considering the combined effects of higher rates per unit surface and higher density (60% higher specific surface), volumetric rates for cross-flow media are about three times higher than for vertical-flow media.

Parker and Richards (1986) evaluated the nitrification capabilities of various media used in combined carbon oxidation-nitrification duty. Random media proved ineffective, while cross-flow media significantly outperformed vertical-flow media at two sites.

The situation with carbonaceous removal applications is more complex. Table 7 summarizes the results of comparative studies obtained to date. Cross-flow media outperform vertical-flow media in all cases except for the higher TOL Hillsborough data. The latter data suggest a switchover effect in efficiency at high TOLs that is not seen in the other data. The reasons for the inconsistency of the Hillsborough data with other work are unexplained, although Richards and Reinhart (1986) list the following possible causes: (1) use of VFFC media instead of VFSC media; (2) use of grab instead of composite sampling; and (3) significantly higher BOD concentrations. During the higher loading periods of the Hillsborough study, there was a major component of food processing wastewater. None of the other studies were similarly impacted. Modeling with the LTF model shows no such crossover effect, and the LTF model has accurately predicted the performance of high-rate trickling filters (Logan et al. 1987a).

The problem of the data comparisons of Table 7 is that they are all at pilot scale and the influence of the rotary distributor on performance is not accounted for, as fixed distributors were used in all cases. It would be logical to resolve any remaining controversy over criteria for media selection with full-scale studies whereby each media has been separately optimized for distributor speed.

TABLE 6. Zero-Order Nitrification Rates for Vertical- and Cross-Flow Media

Media type and location (1)	Zero-order nitrification rate ($gN/m^2 \cdot d$) (2)	Temperature range (°C) (3)
(*a*) Vertical Flow (89 m^2/m^3)[a]		
Midland, Michigan	0.9–1.2	7–13
Lima, Ohio	1.2–1.8	18–22
Bloom Township, Illinois	1.1–1.2	17–20
(*b*) Cross Flow (140 m^2/m^3)		
Central Valley, Utah[b]	2.3–3.2	11–20
Malmö, Sweden[c]	1.6–2.8	13–20
Littleton/Englwood, Colorado[d]	1.7–2.3	15–20

[a]Original references and basis of calculation given in Parker et al. (1989a).
[b]Parker et al. (1989a).
[c]Parker et al. (1995).
[d]Parker et al. (1997), from 12/1/94 to 2/31/96.

CONCLUSIONS

The environmental engineering profession needs to regularly examine claims made about the efficacy of treatment methods, whatever the source of those claims. Unchallenged claims, upon repetition, become accepted and form part of the ''mythology'' of our profession and impact our practice, without ever having been factually substantiated. Challenges to mythology tend to stimulate the necessary research that can provide data to support or dispute such claims. On the other hand, the continual perpetuation of the mythology has the opposite effect of suppressing further investigations; practitioners and researchers may assume that an issue is resolved and devote scarce research resources in other directions.

Examination of some popular myths regarding trickling filter design in the present paper has exposed little or no supporting data for the myths. Moreover, in some cases there are insufficient data to fully resolve the issues. Most of these could be resolved by research on full-scale trickling filters to determine the following:

1. Measurement of module wet weights to assess biomass development with the different media types under a variety of loadings and distributor speeds.
2. Determination of the benefits (if any) of a daily high SK or flushing period to remove excess biomass versus hydraulic control without the daily flushing period.
3. Investigation of the effect of hydraulic transients on trickling filter media and their effect on media life.
4. Determination of whether different types of plastic media have different distributor speed optima for best performance (at various TOLs).
5. Resolution of any remaining controversies regarding comparative media performance under high TOLs.

TABLE 7. Review of Media Comparison Studies for Carbonaceous Removal

Location (1)	Investigator(s) (2)	Media performance ranking (3)	Tested TOL ($kg\ BOD_5/m^3 \cdot d$) (4)
Malmö, Sweden	Sarner (1977)	XF140 > VFSC90	Up to 3.0
Garland, Texas	Parker and Merrill (1984)	XF98 > VFSC100	Up to 1.1
Omaha, Nebraska	Brown and Caldwell (1985)	XF98 = XF140[a]	Up to 2.0
Atlanta, Georgia	Richards and Reinhart (1986)	XF98 > VFSC100	Up to 1.3
Hillsborough County, Oregon	Harrison and Daigger (1987)	XF98 > VFFC88,[a] VFFC88 > XF98,[b] VFFC88 > XF98[b]	0.59, 2.64 5.95

[a]Performance was so close that it could be said to be equal.
[b]Mixed municipal and food processing wastewater during this period.

ACKNOWLEDGMENTS

The present paper was given as the American Academy of Environmental Engineers Lecture in Chicago on June 9, 1998 at the ASCE 1998 National Conference on Environmental Engineering. The writer gratefully acknowledges the value of the treatment plant performance data offered by the plants cited in the paper.

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