ANOXIC OR ANAEROBIC SELECTORS: WHICH IS BETTER?

Denny Parker, Ron Appleton, John Bratby, and Henryk Melcer
Brown and Caldwell
P. O. Box 8045
Walnut Creek, CA 94596-1220

ABSTRACT

Obtaining reliably high compaction characteristics and low SVI values has enormous economic consequences on activated sludge plant design and operation. Now that use of selectors has become more common for achieving low SVI values, the assessment of the full-scale performance characteristics of activated sludge plants incorporating selectors has high value for the design and operation of future plants. Treatment plant effluent quality is seldom analyzed solely on an average basis and the impact peak events have on effluent quality must be considered in design and operation. Descriptive statistics should also be used to assess selector performance, so that the influence of infrequently occurring values on plant design and operation can be assessed. The performance of 21 activated sludge plants incorporating selectors was evaluated. All the selector plants for which post installation data were available showed that the operating SVI values were significantly improved. One plant studied in detail showed that final effluent quality was significantly better after the selector installation. As a group, activated sludge plants with anaerobic selectors outperform those with anoxic selectors. Dissolved oxygen control is just as important in activated sludge plants with selectors as in conventional activated sludge plants.

KEY WORDS

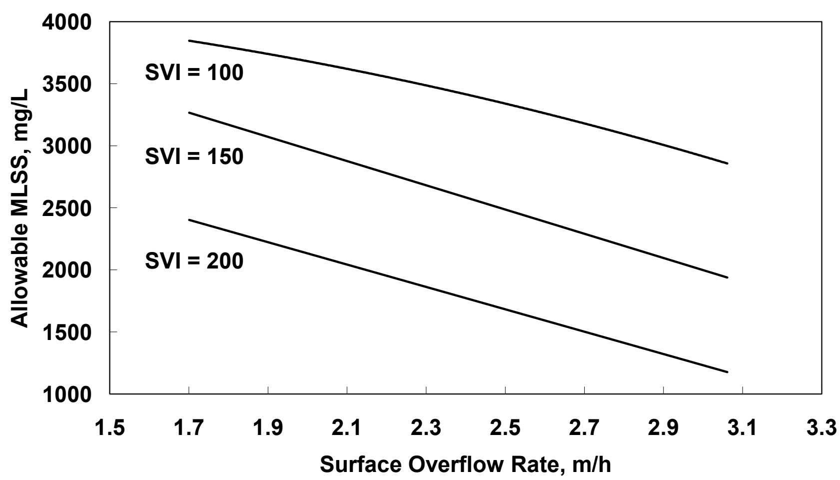
Activated sludge, anoxic selector, anaerobic selector, bulking, effluent suspended solids, secondary clarifier, sedimentation, sludge volume index (SVI)

INTRODUCTION

Selector applications for bulking control in full-scale activated sludge plants are becoming much more common now that laboratory research and some full-scale trials have provided a technical basis for the design of such systems (e.g., Jenkins *et al.* 1993, Wanner, 1994). Reduced propensity for sludge bulking has allowed more efficient activated sludge system design through the ability to carry higher mixed liquor suspended solids levels in the system, allowing rerating of aeration tanks and secondary clarifiers, or in the case of new plants, construction of smaller tanks overall. There also have been some benefits in terms of reduced operating costs, including reduced sludge chlorination for bulking control and reduced energy requirements.

To show the profound influence that SVI has on secondary clarifier capacity, Figure 1 was prepared using a solids flux analysis model to show the mixed liquor suspended solids (MLSS) concentration at which a blanket would just form in the secondary clarifier, assuming a 50 percent return rate. This is the condition often assessed to establish peak wet weather flow capacity in municipal plants. The thickening equation of Wahlberg and Keinath (1995) was used, which relates the settling coefficients to SVI. It can be seen that at a typical surface overflow rate used at peak wet weather flow, 2.55 m/h, an operating SVI of 150 mL/g would support a MLSS level of 2,400 mg/L, while a SVI of 200 mL/g would only support an MLSS concentration of 1,600 mg/L. If somehow, an SVI of 100 mL/g could consistently be achieved, then a MLSS level of 3,300 mg/L could be sustained, double that of the value at a SVI of 200 mL/g. So, the economic consequences of attaining consistent selector performance are very high. Indeed, in a country the size of the US, reliably achieving a goal of 100 ml/g would save billions of dollars in new construction.

Figure 1 - Influence of Three Different SVI Levels (mL/g) on Allowable MLSS In the Aeration Tank at 50 Percent RAS Rate



There are many case histories reported for anoxic and anaerobic selectors. Unfortunately, only a few of these report descriptive statistics for the performance results, even though there has been general agreement that this should be done (Parker *et al.*, 1998, Marten and Daigger, 1998). All too often, neither SVI statistics nor even SVI trend charts are given and only an average value is provided (e.g. Janssen *et al.*, 2002). The average SVI doesn't represent the critical design condition or the condition establishing the actual capacity of the plant. It is generally held that the mean or median value of SVI should not be used, as the critical peak hydraulic loading (and solids loading) conditions may occur simultaneously with higher than average SVI values. Therefore, the 90 or 95 percentile value is a reasonable value to use (Parker *et al.*, 1998, Marten and Daigger, 1998). This means that supplemental SVI control measures (e.g., RAS chlorination, polymer addition), might be needed only 18 to 36 days per year (and only if peak SVIs occur coincident with peak flows) rather than approximately 180 days per year if the mean or median value is used.

There is no absolute agreement on what constitutes successful selector operation in the US, but in general US design consultants tend to design for an SVI of 150 mL/g. This approach is taken when there is no appropriate site-specific information available on settling rates. The purpose of this paper is to summarize available anoxic and anaerobic selector data and to compare their performance. Further, potential areas for additional research are identified.

APPROACH

Our approach was to obtain a large enough set of operating data from activated sludge plants with anoxic and anaerobic selectors to characterize their performance. Only plants with long term data sets were used (typically nine months or longer). The first source of information was data available in the literature. To supplement this, operating records of plants were also obtained and the data analyzed. The 50th and 90th percentile values for SVI were identified for each data set. No special additional field work was undertaken as part of this work, but where normal plant operating data permitted it, the data were examined for identification of any trends that might impact selector or plant performance. Only plants incorporating primary treatment were included in the survey.

SURVEY RESULTS

Data for ten plants with anoxic selectors and eleven plants with anaerobic selectors are summarized in Tables 1 and 2, respectively. By comparing the tables, it can be seen that in most cases, both the anoxic and anaerobic selector plants seem to produce quite acceptable median values for SVI, although as a group the plants with an anaerobic selector generally have lower median values. However, they do differ significantly in terms of the 90th percentile values. Of the ten plants with anoxic selectors, there are only four with 90th percentile SVI values less than 150 mL/g. On the other hand, of the eleven plants with anaerobic selectors, there are ten plants with SVI values less than 150 mL/g. As a group, the anaerobic selector plants clearly outperform the anoxic selector plants.

Table 1 - Performance of Activated Sludge Plants with Anoxic Selectors

Location	SVI, mL/g 50th Percentile	SVI, mL/g 90th Percentile	Data or statistics source
North Plant, Green Bay	110	145	Marten and Daigger, 1997
South Plant, Green Bay	130	175	Marten and Daigger, 1997
Landis	160	250	Marten and Daigger, 1997
Tri-City	125	150	Marten and Daigger, 1997
Beloit	85	110	Marten and Daigger, 1998
Boise	NA	125[1]	Clark *et al.*, 2001
Whittier Narrows,	98	120	CSDLAC[2]
Greeley	114	195	Plant operating data
Colorado Springs	90	227	Plant operating data
Teresa St., Lincoln	174	338	Plant operating data

[1]Actually this is the reported 93 percentile number
[2]County Sanitation Districts of Los Angeles County

OPERATIONAL AND DESIGN IMPACTS

The varied selector applications provide an opportunity to examine the impacts of the selectors on the design and operation of the plants. Among the impacts examined are the improvements in SVI obtained upon installing a selector in an existing plant, the impact on effluent quality, operational considerations with respect to dissolved oxygen control and the impact of selector choice on energy, chemical and reactor costs.

Effect on SVI of Selector Installation in Existing Activated Sludge Plants

Immediate improvements were found upon installing selectors in existing activated sludge plants, as has been reported in other cases (Jenkins *et al.*, 1993). Figures 2, 3 and 4 report before and after results for three of the cases encompassing both anoxic and anaerobic selectors.

The Livermore plant had one of its two aeration basins modified to incorporate an anaerobic selector. The initial period shown in Figure 2 was the SVI history of the plant with the aeration basin without a selector in service. When the mixed liquor was transferred to the basin with a selector and the basin placed in operation, the improvement was dramatic. Installing a selector in the second basin, coupled with a plant rerating study completed by our firm, will allow a very economical upgrading of plant capacity by 30 percent.

The Teresa St. plant in Lincoln, Nebraska (Figure 3) is subject to highly variable food processing loads. The very high SVIs prior to the retrofit are typical of many North American municipal plants receiving food-processing wastewaters. As can be seen, the performance improvement with the selector retrofit was dramatic. Even so, the plant still experiences rather high SVIs relative to other plants. Performance improvements at King County, a high rate activated sludge plant, were also dramatic (Figure 4). To determine if selector operation impacted the dewaterability of the anaerobically digested solids at the plant, the staff operated the selector intermittently (selector zones can be either mixed or aerated at this plant). As can be seen from the data, switching the selectors on and off had an immediate impact on the thickening quality of the solids as measured by SVI. No measurable differences could be found in dewaterability of the anaerobically digested solids, however.

Table 2 - Performance of Activated Sludge Plants with Anaerobic Selectors

Location	SVI, mL/g 50th Percentile	SVI, mL/g 90th Percentile	Data or statistics source
Fayetteville	90	120	Daigger and Nicholson, 1990
JWPCP, CSDLAC	75	88	CSDLAC
Philadelphia	105	132	Husband *et al.*, 2002
Livermore	89	104	Plant operating data
Haskell R. Street, El Paso[1]	49	75	Plant operating data
CCCSD, Concord	120	145	Plant operating data
Utoy Creek, Atlanta[1]	73	114	Plant operating data
R. M. Clayton, Atlanta[1]	90	132	Plant operating data
Vacaville[1]	67	99	Plant operating data
Metro, St. Paul[1]	84	103	Plant operating data
South plant, King County	127	166	Plant operating data

[1]Plant nitrifies; mixed anoxic/anaerobic selector meaning nitrate in the return sludge entered the selector

Figure 2 - Impact of Anaerobic Selector Operation at Livermore

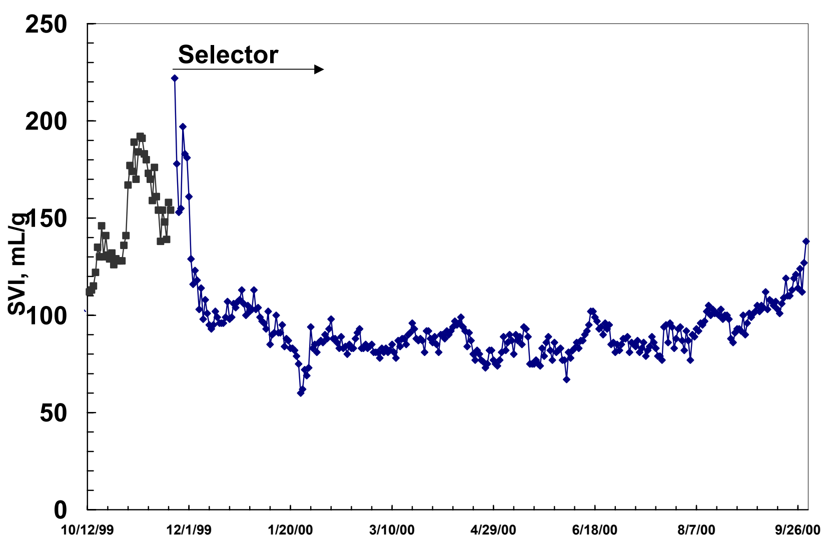


Figure 3 - Impact of Anoxic Selector Operation at Lincoln (After Whitlock *et al.*, 2002)

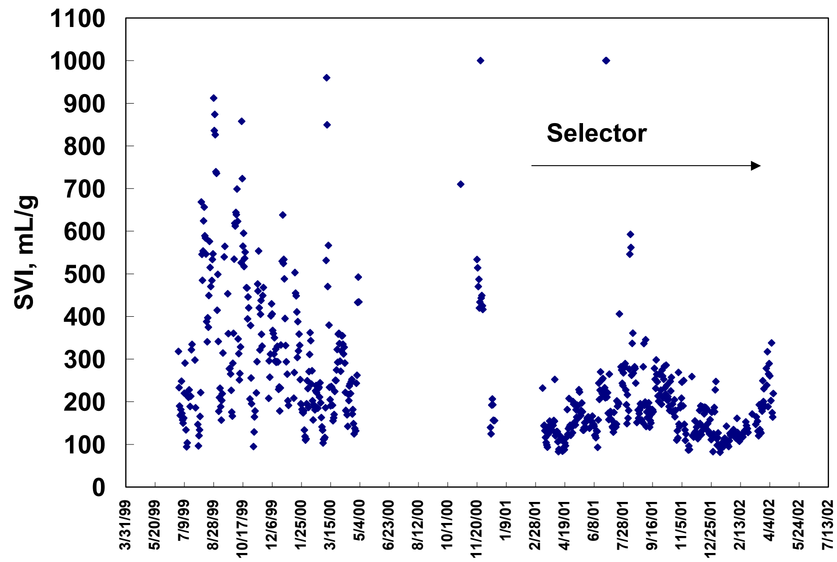
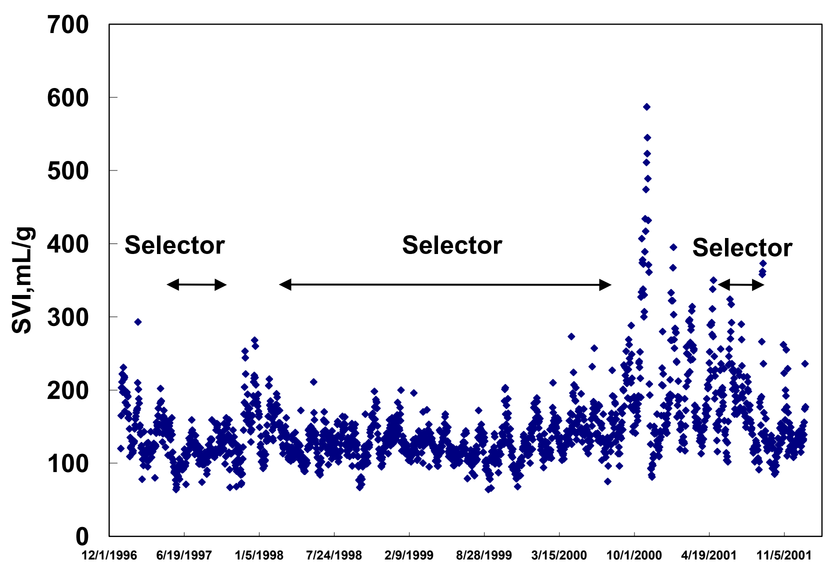


Figure 4 - Impact of Anaerobic Selector Operation at King County

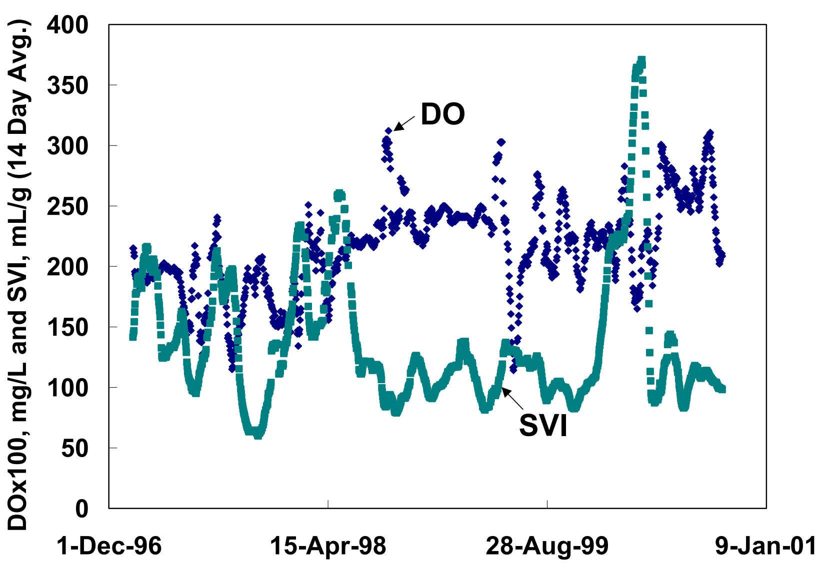


Impact of Dissolved Oxygen Control on Selector Performance

The action of the selector is to remove readily biodegradable BOD from solution, thereby reducing the immediate oxygen demand in the aeration zone immediately following the selector. This has two impacts that operate to encourage floc former growth over filamentous growth: 1) substrate is now unavailable for filamentous organisms in the aerobic zone, and 2) higher dissolved oxygen levels can more easily be maintained. However, care must be taken in both design and operation to provide adequate dissolved oxygen (DO) control in the aerobic zones (particularly the initial zones) as these zones have relatively high oxygen demands, particularly if the plant is nitrifying.

Bratby *et al*. (2001) showed that for one period at the Colorado Springs plant, high SVIs resulted from declining DO values in the aeration zones. Longer-term trends of SVI with DO are shown in Figure 5. In general, dips in DO levels below 2 mg/l cause higher SVI values, whereas consistently high DO values result in lower SVI values. This demonstrates that state-of-the-art dissolved oxygen control is just as important in a plant with a selector as in a conventional activated sludge plant. Our findings are similar to those of Thomas *et al*. (1997) who found that aeration level (and DO concentration) in the aerobic zone of a BNR plant significantly effected mixed liquor settleability. Also, based upon South African experience, Pitman (1991) recommends that that the aeration system be designed so that the DO never drop below 1.0 mg/l.

Figure 5 - Impact on Aeration Basin DO Level on Anoxic Selector Performance at Colorado Springs



Influence of Selector on Effluent Quality

The impact of mixed liquor SVI on effluent quality is usually thought of in dramatic terms. That is, high SVI values can result in high sludge blankets in secondary clarifiers with resultant catastrophic solids loss during high flow events. In fact, SVI impacts effluent quality every day in more subtle ways, even through typical diurnal flow variations. Typically, the higher the blanket, the higher the effluent suspended solids level (Parker *et al*., 2001). Table 3 shows the impact of the selector at Renton on effluent quality. Note that, although the median value of Effluent SS does increase modestly without the selector in operation, the 90th percentile value shows a dramatic increase over that when the selector is in operation.

Table 3 - Impact of Selector on Final Effluent Quality at King County

Parameter	50th Percentile	90th Percentile
SVI, mL/g		
Selector on	127	166
Selector off	154	260
Effluent SS, mg/L		
Selector on	9.5	14.8
Selector off	12.4	24.5

It is sometimes observed that operation at low SVIs with selectors results in weaker floc owing to the absence of a filament backbone, manifesting in higher effluent SS at those conditions (Daigger and Nicholson, 1990, Clark *et al.*, 2001, and Husband *et al.*, 2002). When this occurs, it is due to an absence of a flocculation zone between the aeration basin and the secondary clarifier, as it has been demonstrated that the incorporation of a flocculation zone mitigates the impact of low SVIs in a number of plants (Parker *et al.* 2001). Effluent SS was correlated against SVI for three of the plants, all of which had some form of flocculation zone. No impact of low SVIs is found for the rectangular clarifiers at Vacaville (Figure 6). Essentially the same finding was found for the circular flocculator clarifiers at the Utoy Creek plant in Atlanta, as shown in Figure 7. Again for the circular flocculator clarifiers at El Paso, there was no discernable impact of low SVIs on effluent SS (Figure 8).

Figure 6 - Lack of Impact of Low SVIs on Effluent Suspended Solids at Vacaville

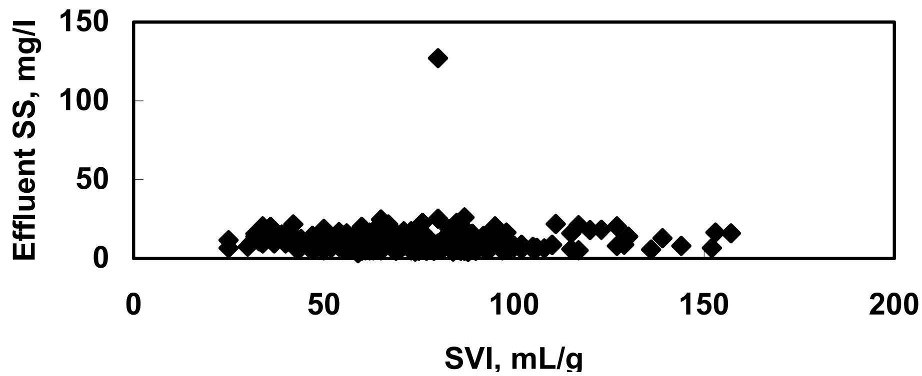


Figure 7 - Lack of Impact of Low SVIs on Effluent Suspended Solids at Utoy Creek

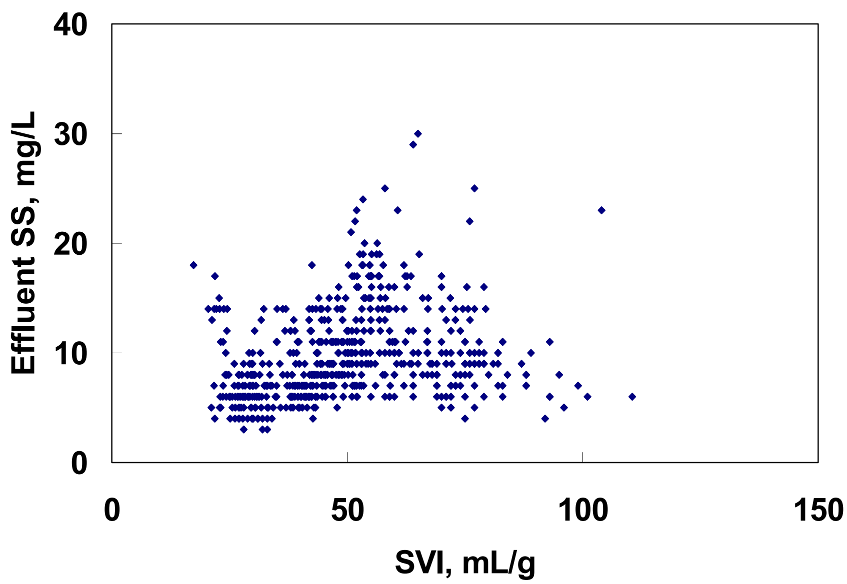
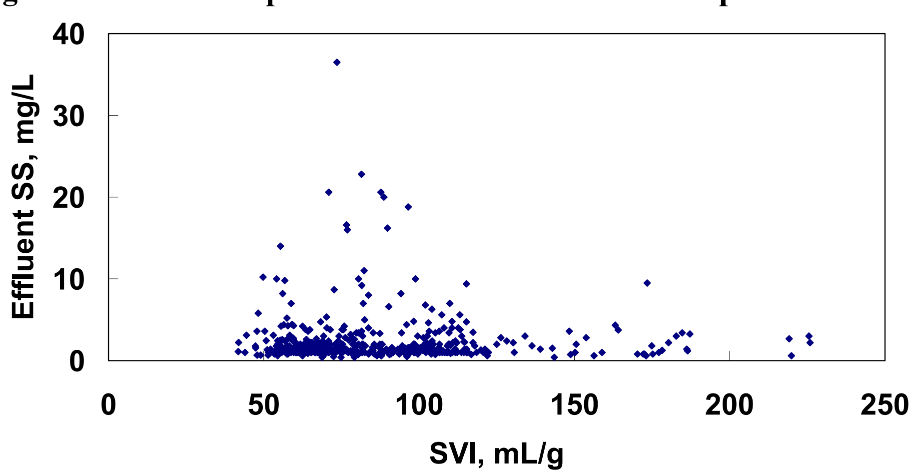


Figure 8 - Lack of Impact of Low SVIs on Effluent Suspended Solids at El Paso



Another important impact of selectors on effluent quality relates to the potential for trapping scum, particularly when an unaerated anoxic or anaerobic zone passes to an aerated zone. When designing inter-zone baffles it is important to provide a head loss which allows surface foam to pass freely. Since selectors have not generally provided consistent elimination of foam causing organisms, we have developed and provided classifying selectors at strategic locations within the reactor to eliminate or control foam-causing organisms, and thus avoid deterioration of effluent quality (Parker *et al.*, 2003).

Influence of Selector Choice on Energy, Chemical Usage and Reactor Requirements

Often stated advantages of anoxic selectors are the recovery of energy through the substitution of nitrate for oxygen as the electron acceptor for a portion of the BOD removed and the recovery of alkalinity. The latter is important for alkalinity deficient wastewaters and is common when the source water for potable use is surface water. Alkalinity recovery can often eliminate the need for and cost of alkalinity supplementation.

Anoxic selectors are typically only used for plants that also have to nitrify, because the cost of nitrification in the absence of an effluent need can be excessive in terms of capital and operations cost. However, anaerobic selectors have been successfully used in plants that are nitrifying. In these cases, the concentration of volatile fatty acids in the influent to the secondary process must be sufficient to both support denitrification of the nitrate in the return sludge as well as to support the energy cycling of the BioP organisms responsible for selecting against filamentous organisms. For the anaerobic selector, there is alkalinity recovery from the denitrification of nitrate in the return sludge and there is documented COD loss resulting in less sludge production and oxygen requirements. While the mechanism is not well understood, it is well documented and incorporated in a General Model for the activated sludge process (Barker and Dold, 1996 and 1997). Basically, COD loss is accounted for in the fermentation reactions occurring in the anaerobic selector. Less COD loss was found in activated sludge plants with anoxic selectors.

Dold's General Model was used to compare the alkalinity and energy requirements for anoxic and anaerobic selectors for a synthetic case example. The General Model is implemented on the computer model platform BioWin32 (Envirosim Associates, Flamborough, Ontario, Canada). Key assumptions and results are shown in Table 4. Except for the waste strength composition and plant flows which were reasonable but arbitrary, model default values were used with the exception that the nitrifier growth rates and decay rates were adjusted to those determined by recent research by Melcer *et al.* (2003).

Our survey was used to estimate the design SVI for each selector, based on 90^{th} percentile values. For the plant with the anoxic selector an SVI of 150 mL/g was used and for the anaerobic selector, the corresponding SVI was 114 mL/g was employed. For peak surface overflow rates of 2.55 m/h and 50 percent return rates, "safe" mixed liquor concentrations were determined by a solids flux analysis using the settling coefficient correlations from Wahlberg et al.(1995). Those MLSS values were 2,400 mg/L and 3,000 mg/L for the plant with anoxic and anaerobic selectors respectively. The higher MLSS level allowed somewhat smaller reactor sizing as shown in Table 4. An aerobic SRT of 8 days was chosen for both systems to prevent nitrifier washout at the design temperature of 12˚ C. Three stage anoxic and anaerobic selectors were designed, with the anoxic volume proportioned to prevent nitrate leakage to the aerobic stage and the anaerobic selector sized to attain low final effluent ortho phosphate levels, so as to maximize the uptake of readily biodegradable BOD in the selector. An internal mixed liquor recycle ratio of 3:1 was used for the anoxic selector design. Effluent qualities reported in Table 4 are for steady state results; dynamic conditions (diurnal variations and storm events) can be expected to raise the values by for nitrate and ammonia by as much as 25 to 50 percent.

Examination of Table 4 shows some interesting results. First, the oxygen required for each type of selector is predicted by the General Model to be the same, despite the differing mechanisms for energy reduction involved with each type of selector. For the example picked, there is no alkalinity deficiency in either case, but this is the result of the assumption of influent alkalinity. If there were an alkalinity deficiency, the production of alkalinity is greater in a plant with an anoxic selector than an anaerobic selector, due to the greater recycling of nitrate to be denitrified. The production of alkalinity by each process can be valued as the avoided cost of sodium hydroxide addition. At a unit cost of $750/ton NaOH, the potential avoided cost of the plant with an anoxic selector is $100,000 per annum while for the avoided cost for the plant with the anaerobic selector is lower at only $34,000 per annum, for a difference of $66,000 per annum.

The plant with an anaerobic selector requires less total reactor volume than the plant with the anoxic selector. The difference at current capital costs in metropolitan areas would be on the order of 2.0 to 3.5 million dollars, for a potential annual cost savings of 200,000 to 350,000 dollars. Overall, considering both reactor and chemical costs, anaerobic selectors appear to have a cost advantage, at least for conditions similar to those examined in this case example.

Differences in cost alone do not dictate choice of selector type. For instance, if nutrient removal is envisioned in the future, a future nitrogen removal requirement could justify a current choice for an anoxic selector. Similarly, a potential future phosphorus removal objective could tip the scales towards an anaerobic selector.

And for alkalinity deficient wastewaters, if the anoxic selector would eliminate the need for alkalinity supplementation, while an anaerobic selector would not, plant owners may choose the former type simply to avoid the handling problems with dealing with a hazardous chemical on the treatment plant site.

In the last analysis, the choice of selector type is case specific.

Table 4 - Comparison of Activated Sludge Plant Designs for Different Types of Selectors

	Parameter	Anoxic selector	Anaerobic selector
Secondary influent			
	Max Month Flow, m^3/d (mgd)	95,000 (25)	95,000 (25)
	COD, mg/L	300	300
	BOD, mg/L	148	148
	TKN, mg/L	24	24
	TP, mg/l	6	6
	Alkalinity as $CaCO_3$, mg/L	180	180
	ISS, mg/L	9	9
Aeration tank			
	Total volume, m^3 (mil gal)	32,800 (8.65)	28,600 (7.56)
	SVI, ml/g	150	114
	MLSS, mg/l	2,400	3,000
	Aerobic SRT, days	8	8
	Oxygen required, Kg/d (lb/d)	17,800 (39,300)	17,800 (39,300)
Secondary effluent			
	Ammonia-N[1], mg/L	1.0	0.64
	Nitrate-N[1], mg/L	9.0	8.9
	Orthophosphate P, mg/L	3.5	0.05
	Alkalinity as $CaCO_3$, mg/L[2]	116	93

[1]Ammonia-N and Nitrate-N of plant without a selector: 0.8 and 12.4 mg/L
[2]Alkalinity of a plant without a selector: 81

DISCUSSION

The literature was evaluated for similar surveys, and four relevant surveys for European plants were identified (Table 5). The European surveys were not done in the same fashion as those reported herein, in that the European work was on a seasonal campaign basis by a research investigation team, rather than the continuous plant monitoring available from plant records. The former has the advantage of consistency of methods, while the latter's advantage is the greater database available for statistical analysis.

The Danish survey showed that plants with anaerobic zones outperformed those with just anoxic zones, which is consistent with the findings for North American selectors. Andreason and Sigvardsen (1996) attributed this to a denser floc structure caused by clusters of Bio-P bacteria. Subsequent research (Schuler *et al*., 2001) has confirmed this. They showed that for Bio-P sludges, biomass density correlated positively with P content and the lowest SVI values were associated with the highest biomass density. However, the surveys for the BNR plants with anaerobic zones in Denmark and the Czech Republic showed much higher SVI values than we found for the North American plants with anaerobic selectors. One major difference is that unlike the Danish and Czech plants, none of the North American plants with anaerobic selectors had been designed for high degrees of nitrogen removal. The North American plants lacked the large anoxic zones with internal mixed liquor recirculation that many of the European BNR plants had. The SVI response of the Czech and Danish BNR plants is similar to what we found with plants equipped with anoxic selectors.

The plant with an anaerobic selector in Budapest, Hungary and the Italian plants with anoxic selectors are similar in performance to our findings for North American plants.

The tendency for full BNR plants (those with both biological nitrogen and phosphorus removal) to have significant periods of sludge bulking and also for some of the plants with anoxic selectors to bulk for extended periods remains a matter of significant research interest. One group has published a plausible theory and much data in support of the concept that incomplete denitrification results in passage of denitrification intermediates into the downstream aerobic zone, thereby inhibiting floc forming organisms and not filamentous organisms, resulting in filament growth (e.g. Casey *et al*., 1994). Others (e.g. Wanner, 1998) are of the opinion that the theory remains unproven, as it has not been confirmed by other investigations. Our survey did not confirm or invalidate the theory of Casey *et al*. (1994), as it did not attempt to elucidate basic bulking mechanisms. However, our work does confirm their experience with respect to bulking tendencies of different activated sludge design configurations.

One design difference that cannot be completely accounted for is the typical use of fine bubble diffused aeration in activated sludge plants equipped with selectors in the US. It is far more common in Europe, particularly in Denmark, to use mechanical aeration. The aerobic zones of mechanically aerated plants are highly variable in terms of spatial distribution of DO. It is notable that Pittman (1991) found that the fine bubble diffused air equipped BNR plant in Johannesburg had consistently low DSVI values (never exceeding 60 mL/g) while the two mechanically aerated BNR plants had DSVI values up to 300 mL/g.

There is a pressing need for additional full-scale research on selectors to improve their performance, so that that the their full potential can be gained in terms of construction and operating cost savings in activated sludge plants. This research should encompass the use of in-basin sensors to provide information for process control, evaluation of alternative selector design configurations (staging, mixing, etc.), and the influence of wastewater characteristics.

Table 5 - Performance of European Activated Sludge Plants with Selectors (all with Primary Treatment)

Location	SVI, mL/g 50th Percentile	SVI, mL/g 90th Percentile	Data or statistics source
4 Czech BNR plants with anaerobic zones	143	221	Krhutkov *et al.,* 2001
Budapest, Hungary, anaerobic selector	95	125	Jobbagy *et al.,* 1999
Danish BNR plants with anaerobic zones	132[1]	192[1]	Andreason and Sigvardsen,1996
Danish BNR plants with coprecipitation	156[1]	252[1]	Andreason and Sigvardsen,1996
4 Italian plants with anoxic selectors	89 to 153[1,2]	Na[2]	Davoli *et al.,* 2001

[1]Dilute Sludge Volume Index (DSVI) was measured; values converted to SVI based on relationship SVI = 1.20DSVI + 12 after Andreason and Sigvardson.
[2]Means reported rather than medians; maximum values reported not 90th percentile.

SUMMARY AND CONCLUSIONS

Obtaining reliably high compaction characteristics and low SVI values has enormous economic consequences on activated sludge plant design and operation. Now that use of selectors has become more common for achieving low SVI values, the assessment of the full-scale performance characteristics of activated sludge plants incorporating selectors has high value for the design and operation of future plants. Treatment plant effluent quality is seldom analyzed solely on an average basis and the impact peak events have on effluent quality must also be considered in design and operation. Descriptive statistics should also be used to assess selector performance, so that the influence of infrequently occurring values on plant design and operation can be assessed. The performance of 21 activated sludge plants incorporating selectors was evaluated. All the selector plants for which post installation data were available showed that the operating SVI values were significantly improved. One plant studied in detail showed that final effluent quality was significantly better after the selector installation. As a group, activated sludge plants with anaerobic selectors outperform those with anoxic selectors. Dissolved oxygen control is just as important in activated sludge plants with selectors as in conventional activated sludge plants.

The choice of selector type for a particular situation depends not only on proven selector effectiveness, but should consider economics of energy, chemical and reactor construction cost, as well as future requirements for nutrient removal. And if alkalinity supplementation needed for nitrification may be eliminated by an anoxic selector, plant owners may decide to select that technology simply because it eliminates the need for handling another hazardous chemical on the treatment plant site. In the last analysis, the choice of selector type is case specific.

Most of the prior basic research on selector design and operation has been at bench scale or pilot scale. Our industry has likely already learned what can be learned at that scale, and the next round should be practically oriented research at demonstration or full-scale. The following areas of research are suggested:

1. Sensor applications useful in control strategies (such as ORP) have demonstrated their usefulness in discontinuous systems such as sequencing batch reactors; there is limited success with continuous applications. Potential applications are the use of nitrate or ORP sensors in the anoxic selector zones to adjust the level of internal mixed liquor recycle. Other examples are the use of ammonia sensors to manage the return from equalization tanks of high ammonia strength return streams.

2. Analysis of the influence of selector zone geometry, feed point introduction, baffle arrangements, number of zones, mixer placement, and type of mixing on the overall selector reactor characteristics needs to be done. For example, can a closer approach to theoretical plug flow conditions be obtained through creative mechanical/process design, thereby yielding the improved SVI response seen at bench scale?

3. The consistency of the presence of volatile fatty acids (VFAs) may affect anaerobic selector reliability in terms of SVI response. Accurate measurement of volatile fatty acids at the levels of significance in wastewaters can be a challenge for any plant laboratory. Can instrumentation and methods be improved so that "research quality" information is readily available routinely at the plant level? In addition, we recommend regular selector influent and effluent study of other characteristics that are today within the capabilities of plant labs, such as readily biodegradable COD.

4. How do the individual situations of wastewater characteristics, plant design, and operational parameters influence selector effectiveness for each type of selector, and the optimum choice of type?

5. Descriptive statistics should always be used in reporting selector performance.

REFERENCES

Andreasen, K. and Sigvardsen, L. (1996). Experiences with sludge settleability in different process alternatives for nutrient removal. *Water Sci. Technol.*, **33** (12), 137-146.

Barker, P. S. and Dold, P. L. (1996). Sludge production and oxygen demand in nutrient removal activated sludge systems. *Water Sci. Technol.*, **34** (5-6), 43-50.

Barker, P. S. and Dold, P. L. (1997). General model for biological nutrient removal activated sludge systems; model presentation. *Water Environ. Res.*, **69** (5), 969-984.

Bratby, J., Johnson, L., Parker, D. and Van Derveer, B. (2001). Are activated sludge simulation models useful to operators? WEFTEC 2001 Conference Proceedings CD ROM, Water Environment Federation, Alexandria, VA.

Casey, T. G., Wentzel, M. C., Ekama, G. A., Loewnthal, R. E., and Marais, GvR. (1994). A hypothesis for the causes and control of Anoxic-Aerobic (AA) filament bulking in nutrient removal activated sludge systems. *Water Sci. Technol.*, **29** (7), 203-212.

Clark, S. F., Krumsick, T. A., Bishop, R. P., Daigger, G. T. and Linder, C. (2001). Performance of step-feed activated sludge systems with anoxic selectors. WEFTEC 2001 Conference Proceedings CD ROM, Water Environment Federation, Alexandria, VA.

Daigger, G. T., and Nicholson, G. A. (1990). Performance of four full-scale nitrifying wastewater treatment plants incorporating selectors. *Res. J. Water Pollut. Control Fed.,* **62** (5), 676 – 683.

Davoli, D., Madoni, P., Guglielmi, L. and Pergetti, M. (2001). Testing the effect of selectors in the control of bulking and foaming in small activated sludge plants. Proceedings of the 3rd IWA International Specialized Conference on Microorganisms in Activated Sludge and Biofilm Processes, CD ROM.

Husband, J. A., McKeon, W. R., and Lendzinski, R. (2002). Selector technology save Philadelphia $25,000,000 in renewal of secondary treatment process. WEFTEC 2002 Conference Proceedings CD ROM, Water Environment Federation, Alexandria, VA.

Janssen, P. M. J., Meinema, K., and van der Roest, H. F. (2002). *Biological Phosphorus Removal, Manual for design and operation.* IWA Publishing, London, UK.

Jenkins, D., Richard, M. G. and Daigger, G. T. (1993). *Manual on the Causes and Control of Activated Sludge Foaming*, 2nd Edition, Lewis Publishers, Chelsea, Michigan.

Jobbagy, A., Garai, Gy., Farkas, F., Sevilla, F. and Oszoly, T. (1999). Enhanced nitrogen removal at the Northpest wastewater treatment plant. Proceedings, 8th IAWQ Conference on Design, Operation and Economics of Large Wastewater Treatment Plants, 255-262.

Krhutkov, O., Ruzickova, I. and Wanner, J. (2001). Microbial evaluation of activated sludge and filamentous population in 8 nutrient removal plants during Year 2000. Proceedings of the 3rd IWA International Specialized Conference on Microorganisms in Activated Sludge and Biofilm Processes, 369-376.

Marten, W. L. and Daigger, G. T. (1997). Full-scale evaluation of factors affecting the performance of anoxic selectors. *Water Environ. Res.*, **69** (7), 1272-1289.

Marten, W. L. and Daigger, G. T. (1998). Closure to: Full-scale evaluation of factors affecting the performance of anoxic selectors. *Water Environ. Res.*, **70** (6), 1229-1231.

Melcer, H., Tam, P, Dold, P. L., Jones, R. M., Bye, C. M., Takacs, I., Stensel, H. D., Wilson, A. W., Sun, P. T., and Bury, S. (2003). *Methods for Wastewater Characterization in Activated Sludge Modelling.* Water Environ. Res. Foundation, Arlington, VA.

Parker, D., Ekama, G., Melcer, H. and van Niekirk, A. (1998). Discussion of: Full-scale evaluation of factors affecting the performance of anoxic selectors. *Water Environ. Res.*, **70** (6), 1225-1228.

Parker, D. S., Kinnear, D. J., and Wahlberg, E.J. (2001). Review of folklore in the design and operation of secondary clarifiers. *Journal of Environmental Engineering,* **127** (6), 476-484.

Parker, D., Geary, S., Jones, G., McIntyre, L., Oppenheim, S., Pedregon, V., Pope, R., Richards, T., Voigt, C., Volpe, G., Willis, J. and Witzgall, R. (2003). Making classifying selectors work for foam elimination in the activated sludge process. *Water Environ. Res.*, **75** (1), 83-91.

Pitman, A. R., (1991). Design considerations for nutrient removal activated sludge plants. *Water Sci. Technol.*, **43** (4-6), 781-191.

Schuler, A. J., Jenkins, D., and Ronen, P., (2001). Microbial storage products, biomass density, and settling properties of enhanced biological phosphorus removal activated sludge. *Water Sci. Technol.*, **43** (1), 173-180.

Thomas, M. T., Ostarcevic, E. R., and Bliss, P. J. (1997). Control of BNR activated sludge bulking. Proceedings, BNR 3 Conference, Australian Water and Wastewater Association, Artamon, NSW, Austrialia, 362-368.

Wahlberg, E. J. and Keinath, T. M. (1995). Development of settling flux curve using SVI: An addendum. *Water Environ. Res.*, **67** (5), 872-874.

Whitlock, D., Wilson, R., Brandt, G., and Kinnear, D. (2002). An overview of the Lincoln, NE nitrifying activated sludge system, control of filamentous bulking with an anoxic selector. WEFTEC 2002 Conference Proceedings CD ROM, Water Environment Federation, Alexandria, VA.

Wanner, J., (1994). *Activated Sludge Bulking and Foaming Control.* Technomic Publishing Co. Inc., Lancaster, Pennsylvania.

Wanner, J., (1998). Stable foams and sludge bulking: The largest remaining problems, *J.CIWEM,* **12** (10), 368-374.