Fuzzy-Supported Estimator for HPO-AS Process[a]

Discussion by R. Iranpour,[4] Y. J. Shao,[5] R. Meyer,[6] and S. Oh[7]

This is a paper that provides an excellent example of combining advanced knowledge from several fields. It should be extremely interesting for environmental engineers who want to advance the intellectual and technical quality of their research.

The paper evidently represents recent work in a research program on AS process control that has produced the PhD dissertations of the first two authors and also C. J. Tzeng, as well as several previous journal papers and conference presentations by Professor Stenstrom and various coauthors. Hence, it is clear that a very prolonged effort has been required to achieve the combination of long-established engineering control theory and more novel fuzzy logic in the estimator system, as well as the previously developed structured model used for the simulations.

Reading the paper prompted the following few questions, comments, and suggestions.

1. The text makes it clear that Table 3 is a condensation of thirty fuzzy rules that, in a conventional if-then form, would be stated as, for example, ''If DSVI is NORMAL and INFLUENT_FLOW_RATE is LOW, then EFFLUENT_TSS is NORMAL.'' Likewise, Fig. 4 and the description of the fuzzy rules for influent BOD_5 percentage as a function of time suggest that a typical rule would be something like ''If TIME is MID_MORNING, then BOD_5_PERCENTAGE is MODERATE_DESCENDING_RAPIDLY''; and a rule for responding to an anomalous condition apparently could be ''If INFLUENT_FLOW_RATE is EXTREMELY_HIGH, then FEED_POINT is STAGE_4.''

   If this is the way it was done, did the authors use a standard software package for fuzzy logic and integrate it with their previous software? This question is raised because the piecewise linear relation depicted in Fig. 4 for the influent BOD_5 percentage could have been implemented without formulating it in terms of fuzzy logic. Fig. 5 suggests that the rules summarized in Table 3 also are converted into $X_{TSS,t}$ in (13) by a piecewise linear function of two variables. However, switching the feed point and other responses to anomalous events are not simple numerical functions, so it seems like a good idea to take advantage of the capabilities of a fuzzy logic software package to perform a wide range of actions that are outside the boundaries of conventional numerical evaluation of model equations.
2. Is there any plan to use the more advanced structured model for this kind of real-time estimation? The description of how substrate storage gives a better description of the biodynamics suggests that this could improve estimator performance, unless there are numerical problems with speed or convergence.

   Also, is there any expectation of extending the present work to include any of the other three concentrations in (2), which were not used in most of the rest of the paper? In particular, the CO_2 concentrations at a HPO-AS plant in Carson, CA, operated by Los Angeles County, have been high enough to pose problems with corrosion of the concrete effluent channel, so that the fourth stages of their reactors have recently been operated with ordinary air to strip out the CO_2 (Pettit et al. 1998). This suggests that there might be some value in being able to predict CO_2 concentrations. On the other hand, the corrosion effects occur on time scales of months or years, so it is clearly less urgent to know CO_2 than, for example, effluent TSS.
3. Most of the results of this paper are comparisons between the fuzzy-supported single-substrate estimator and the simulations of the structured model. It appears that it would be reasonable to perform offline measurements of actual effluent BOD_5 or COD, effluent TSS, etc., as listed in Table 1, and to compare them with the estimator and simulator results, as was done in Table 5 with OUR and MLVSS. Probably there are extensive comparisons of laboratory data with the simulator results somewhere among the earlier papers or the dissertations, but since the estimator system is new, this paper gives the impression that the estimator predictions may not yet have been compared with laboratory measurements of these other quantities.

   Two other points are suggested by these comments about comparisons with laboratory results. First, have there been any comparisons with operational results from a full-scale HPO-AS system? Second, what is the source of the primary effluent used in the authors' laboratory-scale system that is described in Tables 4 and 5?
4. Since effluent TSS and turbidity are particular concerns for efforts to reclaim effluent from HPO-AS secondary treatment systems for ground-water recharge, it would be extremely desirable if this kind of real-time estimation made it possible to control an HPO-AS in a way that consistently produced lower effluent TSS values than are achieved in current operation. The alternative for lowering TSS is to install filters and other tertiary treatment equipment, which obviously imposes substantial costs, both for installation and for operation and maintenance. On the other hand, disinfection greatly increases the range of possible uses of reclaimed wastewater, so some tertiary treatment may be inescapable, even with low effluent TSS values. These issues of planning and system design are obviously larger-scale and longer-term considerations that may be affected by improved system control, as compared with the more immediate desires to prevent process failure or permit violations that are mentioned as motivations for developing this estimation system. Nevertheless, there may be a time when some thought should be given to the planning impact of the potential value of this research.
5. Have the authors given any attention to the possibility that the prediction process could be improved if influent or effluent BOD, or perhaps soluble BOD, could be measured online? This may seem to be primarily a hypothetical question, since present online BOD instruments are clearly unable to cope with the solids concentration if influent is fed into them directly, and may also be clogged, although more slowly, by the turbidity of the effluent. However, recent experimental studies suggest

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that a small self-backwashing microfiltration unit with a submicron pore size would be able to reduce the particle content of the sample flow to the instrument to levels at which the combined filtration and measurement system could run for months or years with little maintenance, and the instrument outputs would still be calibratable into reliable estimates of BOD_5 (Iranpour et al. 1997a,b). These studies were done on the assumption that online BOD monitoring might by itself be useful in preventing process upsets due to biological shock loads in AS systems that use air, but it is possible that it would be even more valuable as part of an HPO-AS control system along the lines discussed in this paper.

6. In two minor ways the figures can be improved. First, in the lower panel of Fig. 6, trace E2 is not reproduced in the published version. Since the placement of the label indicates that at least part of the trace is up around 100 mg/L, and hence is far from the corresponding part of S2, the figure still has some value in demonstrating the discrepancy described in the text, but it is clear that what was printed is not what the authors intended. Second, readers might find Fig. 8 more convenient if it included labeling to indicate that the upper panel represents system response in reaeration mode to a hydraulic shock load, while the lower panel represents the response in step feed mode to the same load charge.

Let us close by repeating that this is an excellent paper, combining many important ideas. Moreover, it clearly has the potential to lead to many further developments. The discussers congratulate the authors for their excellent interdisciplinary research project and strongly believe that this paper is of award quality.

APPENDIX. REFERENCES

Iranpour, R., Straub, B., and Jugo, T. (1997). ‘‘Real time BOD monitoring for wastewater process control.’’ *J. Envir. Engrg.*, ASCE, 123(2), 154–159.

Pettit, M., Gary, D., Morton, R., Friess, P., and Caballero, R. (1998). ‘‘Operation of a high-purity activated sludge plant employing an anaerobic selector and carbon dioxide stripping.’’ Preprint.

Closure by Mark T. Yin,[8] Weibo Yuan,[9] and Michael K. Stenstrom[10]

The writers are grateful for the very kind and thorough review of our paper. We reply to his points as follows:

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1. The discussers are correct in that certain functions that used fuzzy logic for their implementation could have been implemented by piecewise linear, continuous functions. However, the writers chose to use a fuzzy logic implementation because it was more general and would allow application of the developed software for more general applications. At the time of our research, the writers were using a product called GS from GenSym Corporation (Boston, MA) in combination with code written in Fortran and C for this work and other work cited in our paper. Since the time of our original research, this software package has evolved, and several other packages have also been developed. When using these packages, less programming effort is required, although their cost in some instances is prohibitive. In our case, the writers generally found it easier to implement our own code, except in the case of the graphical user interface. The research was performed using AIX on a Risc 6000 workstation. Much of the software the writers used is now available on Windows NT, which would allow the routines in the estimator to be coupled with graphically oriented programming languages. This change would make the entire project much easier.
2. At present, the writers have no plans to implement the more advanced structured model into the Estimator, but we agree that this would be an important improvement. Estimating the carbon dioxide production is also an important aspect of HPO-AS modeling, but phenomena such as the corrosion problems cited can be addressed with a deterministic model such as Tzeng’s (1992).
3. The Estimator has not been compared with a full-scale operational HPO-AS plant. Such plants rarely collect the data required to make an evaluation. The basic process model has been calibrated using data from full-scale plants. The writers would welcome the opportunity to work with an agency that might want to validate and use the estimator for an HPO-AS plant. The pilot plant data described in the paper were collected as a part of Seattle Metro’s Westpoint plant expansion (Samstag 1989; Stenstrom 1990).
4. The writers believe that effluent TSS could be better understood and predicted using knowledge-based tools. The most important advantage might be identifying operating variables that affect effluent TSS and, through this improved knowledge, operating the plant to lower effluent TSS. Many effects in treatment plants change too slowly or in subtle ways that are hard to observe using conventional tools. ‘‘Data mining’’ large collections of operating data might reveal trends or effects that are could be useful for control.
5. Real-time collection of BOD or COD would improve prediction. The writers assumed that such instruments are generally unavailable to treatment plants. Real-time measurement of oxygen uptake rate in several places in the process would also improve prediction.
6. The writers appreciate and agree with the discussers’ comments regarding the figures.