Fifth IFSA World Congress (1993), 1102-1105

Fuzzy Expert System for Bulking Prediction and Mitigation in the Activated Sludge Process

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ABSTRACT

A fuzzy expert system for prediction and mitigation of sludge bulking was developed for an activated sludge process which treats waste water from a food industry. The developed system is able not only to infer the degree of progress of sludge bulking but also to generate remedial operation guides which may be sent to the local controllers as remote set points.

One of the important consequences through this study is the BI (Bulking Index) inferred by the bulking prediction expert system was found to have a close correlation with the SVI (Sludge Volume Index) which is a practical measure of degree of bulking but needs tedious chores for its measurement.

1. BACKGROUNDS

Sludge Bulking in the Activated Sludge Process :

The activated sludge process consists of two phases, aeration and sludge settlement. (Fig. 1) In the first phase, wastewater is added to the aeration tank containing the mixed microbial population and air is added via a diffusers using compressed air.

The aeration has a dual function ; to supply oxygen to the aerobic micro-organisms in the reactor for respiration and to maintain the microbial flocs in a continuous state of agitated suspension, ensuring maximum contact between the surface of the floc and the wastewater.

In the second stage, the flocculated biomass settles rapidly out of suspension to form a sludge with the clarified effulent.

Depending on the characteristics of waste water such as toxicity, suspended solids, BOD level and so forth, a series of different processes are usually involved in treating industrial waste water. At the final stage of treatment, however, the activated sludge process is employed almost without exception. The activated sludge process is composed of a series of aeration tanks, where aerobic microorganisms are cultured in a mixed state using organic wastes as their feed, and a clarifier, where microorganisms floc together, settle down and are withdrawn from the bottom while cleared water is overflowed and discharged. Part of the microorganism floc is recycled to the aeration tanks and the rest is disposed. It is ususally understood that about twenty different microorganisms play important roles in clearing water which contains organic wastes. Since the microorganisms are in a mixed cultured state, it is very important to maintain the operating conditions to be favourable to the amiable microorganisms. If such maintenance fails, which is very likely in practice because there may be frequent large changes in influent quantity as well as quality in industrial waste water, hostile microorganisms may gain strength and the process loses its purifying function. Nevertheless, finding the favourable operating conditions is not an easy task because a good part of metabolic effects of many operating conditions is still veiled.

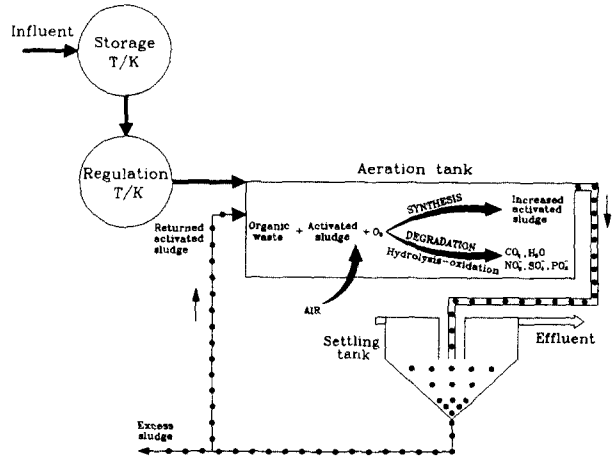

Fig.1. Schematic Diagram of Activated Sludge Process

Among the many operational problems of the activated sludge process, sludge bulking, when it is caused by filamentaous mcroorganisms, is usually accepted as the most catastrophic one. The filamentaous microorganisms metabolite organic wastes, too, but they don't form tight floc, settle down, so arn't separated from the purified water in the clarifier. In addition, the filamentaous microogranisms are so viable, that once the filamentaous microorganisms become influential, it is hard to recover the process to the normal state even with every remedial action conceivable. It becomes, therefore, a very important task to early detect the symptom of sludge bulking and to take advance remedial actions before the filamentaous microorganisms gain power.

Need of Fuzzy Expert System :

To devise a system which performs early prediction of sludge bulking and control actions for bulking mitigation, the bulking phenomenon should be modeled first in any means (mathematically or linguistically). Although many studies have been carried out to discover this phenomenon, many things are still in the veil. Although limited, some qualitative relationships between operating conditions and metabolic behaviors of filamentaous microorganisms are available from open literatures and papers. With this proven knowledge on one hand, operation-oriented knowledge were obtained from skilled field operators and through analyses of historical operation data on the other hand. Development of the intended bulking prediction and mitigation system based on this knowledge, therefore, should rely on some kind of expert system techniques which can treat fuzzy linguistic terms.

2. OBJECTIVES

Based on the above considerations, the present work has been aimed to develop a fuzzy expert system which performs early prediction of sludge bulking and provides remedial control actions before the sludge bulking significantly proceeds. The developed system has been intended for an activated sludge process for a particular industrial plant, but the underlying idea of the system is believed to be applicable to other similar processes, either.

3. MAJOR FEATURES OF THE BULKING PREDICTION AND MITIGATION SYSTEM

The developed system has dual functions; early prediction of sludge bulking and appropriate remedial control actions depending on the degreee of bulking. The prediction part again consists of three parts; cause, effect parts and combination of these two. (Fig. 2) Independent inferences are made in each of the cause and effect parts. The two inference results are combined and the final conclusion, degree of bulking, is drawn in the combination part. The control part generates overriding set points of local controllers such that the growth of filamenatous microorganisms is suppressed and the process is returned to the normal state.

Rule-based fuzzy expert techniques were used to build the system. The required rules were gathered from various domain experts such as literatures, environmental engineers, field operators and others.

More descriptions of each part of the developed system are as follows :

3.1 Fuzzy Expert System for Bulking Prediction

Degree of bulking from causes

In this part, the degree of bulking, more accurately, the possibility of bulking is inferred through fuzzy reasoning from monitored values of operating conditions and changes of them. It has a ground on the experimental fact that sludge bulking may be induced when the operating conditions move beyond suitable ranges and/or undergo sudden changes. The input variables used in the antecedent parts of the production rules

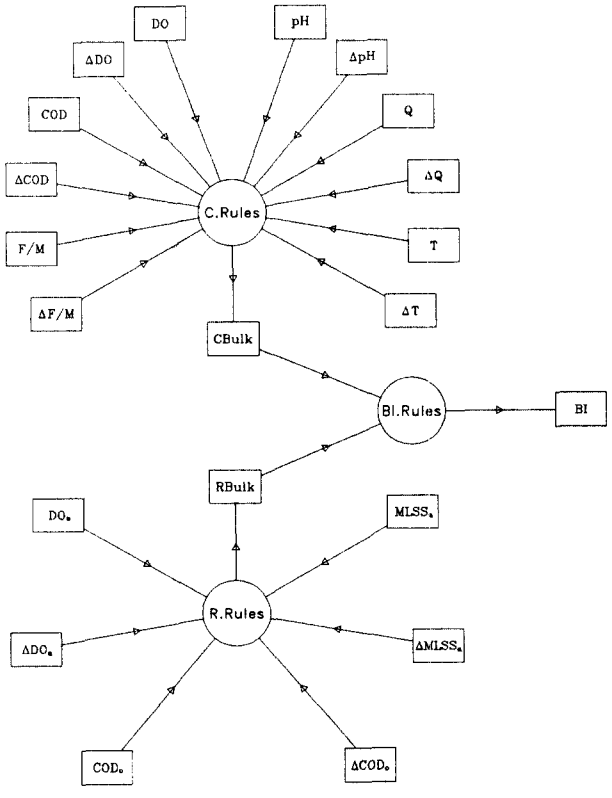

Fig. 2. Hierachical Structure of the Expert Systems

are DO concentration, pH, F/M (Food / Microorganism) ratio, temperature, COD loading and influent flow rate, and changes of them. For each input variable, three fuzzy sets were defined; L (low), M (medium), and H (high). The conclusion parts of the production rules has one output variable, BI (Bulking Index) which denotes the inferred degree of bulking. Seven fuzzy sets were assigned to BI from N (Normal) to HH (high high). All the fuzzy sets were defined to have the triangular-shape membership functions. Max-min composition rules were used in the fuzzy resaoning and the center of gravity method was used to draw the final defuzzified output.

Degree of bulking from effects

Once the bulking starts, operational problems such as increased BOD or suspended solids in the final effluent, low MLSS concentration in the aeration tank compared with the sludge recycle rate, and reduction in oxygen utilization rate with respect to blower load are caused. In this part, degree of bulking is inferred from the above effects and changes of them. The same fuzzy reasoning method as in the cause part was used.

Combination of the results

This part combines the two bulking indicies from the cause and effect parts, and gives the final bulking index. Combination is performed by the weighted sum of which the weights are defined by membership functions.

3.2 Fuzzy Expert System for Bulking Mitigation

This system generates appropriate remedial control actions to mitigate the bulking based on the bulking index inferred by the prediction system. This system has one input and four output variables. The input variable is the bulking index. The output variables are overriding set points for DO, influent flow rate, pH and MLSS of the local controllers. In this system, too, the max-min composition is used for fuzzy reasoning and the triangular membership function was associated for each of the fuzzy sets.

4. RESULTS AND DISCUSSIONS

Retaining the basic structure introduced above, the expert system has been tuned until the suggested bulking indicies and remedial control actions for various situations conform well with the operational know-how of skilled operators. Adjustment was done majorly for the membership functions, more precisely for the support and the vertex of each triangular shape membership function.

One of the important results after tuning was completed is that the bulking index suggested by the developed system was revealed to have a very close correlation with the SVI (Sludge Volume Index), which is a frequently used index to diagnose the degree of bulking in many field processes but of which the measurement requires tedious chores. (Fig. 3, 4 and 5) Through this result, we could have confidence that the proposed fuzzy expert system can replace the tedious SVI measurement and play as a practicable tool for bulking prediction and mitigation.

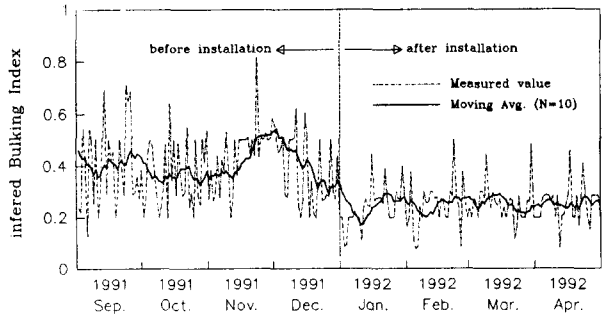

Fig. 3. Infered BI (Bulking Index)

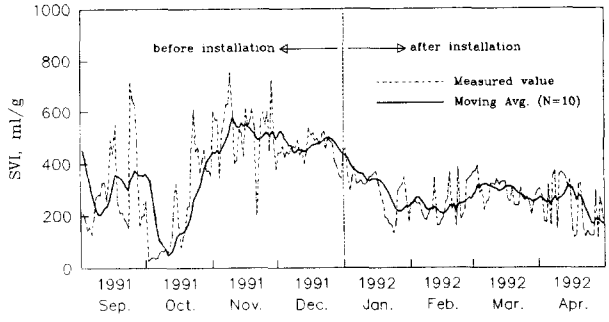

Fig. 4. Actual SVI (Sludge Volume Index)

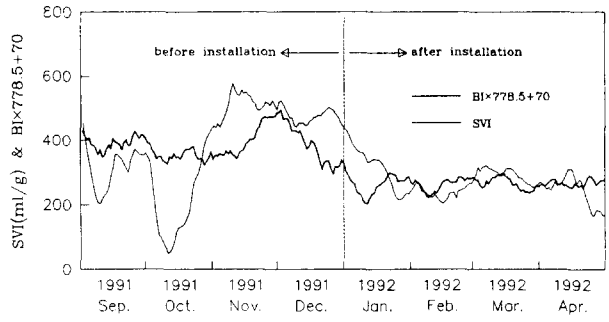

Fig. 5. Infered BI and Actual SVI

5. CONCLUSIONS AND SIGNIFICANCES

A fuzzy expert technique was used to develop an operation-aid system for early prediction and mitigation of sludge bulking in an industrial activated sludge process, where mathematical model is hard to set up but operation-related qualitative knowledge is abundant. In the developed system, the max-min composition rule was used for fuzzy reasoning and the triangular-shape membership fuctions were used for the fuzzy sets. Some of the important conclusions obtained from field use for months as well as application to past operation are as follows:

1. The fuzzy expert technique is a suitable means for describing the complicated behaviors of activated sludge processes.
2. The cause-effect-combination structure is considered to be pertinent in reliable prediction of the degree of sludge bulking.
3. The bulking index inferred by the developed system is an appropriate indicator of the degree of sludge bulking, in that the inferred value has a close correlation with the SVI measurement.

This system has been successfully in use in an industrial process. Since the basic scheme and behavioral characteristics of activated sludge processes are usually similar, the underlying concepts in the proposed expert system are expected to be applicable for improvement of the performance of activated sludge processes in other plants.

6. REFERENCES

1. Hawkes, H. A., Activated Sludge, Academic Press, London. (1983).

2. Gray, N. F., Biology of Wastewater Treatment, Oxford University Press, Oxford (1989)

3. Gray, N. F., Activated Sludge, Theory and Practice, Oxford University Press, Oxford (1990)

4. Gupta, M. M. Yamakaya, T., Fuzzy Logic in Knowledges-based Systems, Decision and Control, North-Holland, (1988)

5. Gupta, M. M., Kandel, A., Bandler, W., and Kiszka, J.B., Approximate Reasoning in Expert Systems, North-Holland, (1985)

6. Yager, Ovchinnikov, Tong, and Nguyen, Fuzzy Sets and Applications : Selected Paper by L.A. Zadeh, John Wiley & Sons, Inc (1987)

7. Kandel, A., Fuzzy Mathematical Techniques with Applications, Addision-Wesley Publishing Company, (1986)

8. Mamdani, E. H., and Gaines, B. R., Fuzzy Reasoning and Its Applications, Academic Press, London (1981)

9. Proceedings of International Conference on Fuzzy Logic & Neural Networks Vol I, II, IFSA JNNS, (1990)

10. Tomlinson, E.J. and Chambers, B. "Methods for Prevention of Bulking in Activated Sludge", Water Pollution Control, Vol. 78, PP. 524-538, (1979)

11. Jenkins, D., Richard, M. G., and Neethling, J. B.,"Causes and Control of Activated Sludge Bulking", Water Pollution Control, Vol 83, PP 455-472, (1984)

12. Strom, P. F., and Jenkins, D. "Identification and Significance of Filamentous Micro-organisms in Activated Sludge",Journal of the Water Pollution Control Federation, Vol. 56, PP. 449-459, (1984)

13. Lau, A. O., Strom, P. F., and Jenkins, D., "The Competitive Growth of Floc-Forming and Filamentous Bacteria" Journal of the Water Pollution Control Federation, Vol. 56, 41. (1984)

14. Sezgin, M., Jenkins, D. and Parker, D. S, "A unified Theory of Filamentous Activated Sludge Bulking", Journal of the Water Pollution Control Federation, Vol 50 , pp 352-381, (1978)