Pergamon

Wat. Sci. Tech. Vol. 28, No. 11-12, pp. 9–14, 1993.

0273–1223/93 $7·00 + 0·00

FUTURE DIRECTIONS IN INSTRUMENTATION, CONTROL AND AUTOMATION IN THE WATER AND WASTEWATER INDUSTRY

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ABSTRACT

The need to optimize treatment plant performance and to meet increasingly stringent effluent criteria are two key factors affecting future development of instrumentation, control and automation (ICA) applications in the water and wastewater industry. Two case studies are presented which highlight the need for dynamic modelling and simulation software to assist operations staff in developing effective instrumentation control strategies, and to provide a training environment for the evaluation of such strategies. One of the limiting factors to date in realizing the potential benefits of ICA has been the inability to adequately interpret the large number of existing instrumentation inputs available at treatment facilities. The number of inputs can exceed the number of control loops by up to three orders of magnitude. The integration of dynamic modelling and expert system software is seen to facilitate the interpretation of real-time data, allowing both quantitative (instrumented) and qualitative (operator input) information to be integrated for process control. Improvements in sensor reliability and performance, and the development of biological monitoring sensors and control algorithms are also discussed.

KEYWORDS

Wastewater treatment instrumentation; process control strategies; dynamic modelling; simulation; expert systems; biological nutrient removal; NADH sensors; oxidation-reduction probes.

INTRODUCTION

While water and wastewater treatment plants are usually designed under steady-state conditions, their performance is sensitive to time-varying conditions and other environmental factors which are usually beyond the control of the plant operators. The performance of wastewater treatment facilities is particularly dependent on the experience of the operations staff, who develop a "feel" for the operation, allowing them to cope reasonably well to changing influent conditions, using conventional treatment technologies. However, operations staff do not have the knowledge and experience base to apply to the increasingly complex wastewater treatment facilities, with the associated inter-dependence of process operations. This is resulting in poor plant performance, and the inability of treatment processes to achieve optimal levels of treatment.

One of the key factors inhibiting the development and incorporation of instrumentation for the control and automation of water and wastewater treatment processes is that sensors are often used primarily for monitoring or status purposes. The number of input/output points to a control system for a large-scale (i.e.

greater than 100 MGD) plant can exceed the number of control loops by up to three orders of magnitude. Little of the monitored data is actually used within a control loop. There is a need for effective control strategies which can take advantage of available real-time information.

The factors which limit the ability to meet performance objectives are directly related to limitations in existing instrumentation, control and automation (ICA) capabilities. The need to optimize plant performance and meet increasingly stringent effluent standards are two key factors which will influence the development of ICA technologies in the future.

ICA TECHNOLOGY NEEDS

The following describes two wastewater treatment process case studies (industrial and municipal) which demonstrate some of the needs in ICA technology development.

Pulp and Paper

The pulp and paper industry is faced with increasingly stringent effluent standards, with requirements to reduce toxic organic contaminants such as dioxins and furans to levels approaching the analytical detection limits. While there is no clear understanding regarding the biodegradability of these compounds (e.g. whether the reduction is more dependent on hydraulic retention time or sludge age), it is recognized that conventional aerated lagoon treatment is incapable of effectively achieving the required treatment levels, and that a mechanical process is required. In the absence of specific process guidelines, the mechanical treatment facilities are typically activated sludge processes, which are designed to be as flexible as possible. For example, one such facility (located in British Columbia) incorporates an existing aerated lagoon system, in addition to five new activated sludge bio-reactors which can be operated either in series or parallel, with the added option of step-feed. In the absence of effective dynamic models, the process design has been based on steady state assumptions, with some sensitivity assessment with respect to these design assumptions. The purpose of providing process flexibility is to allow the operations staff to change the process configuration if the plant has difficulty meeting the Discharge Permit quality criteria. The problem lies in determining what process change will improve effluent quality considering: the lack of operations staff experience, and training; the lack of knowledge regarding which process parameters most affect optimal performance; and lack of adequate sensors to reflect the performance levels (i.e. AOX, dioxin and furan levels in the effluent). There is also a need to have the wastewater treatment I&C integrated into the existing pulp and paper process control systems, and to automate where possible to minimize cost.

Biological Nutrient Removal (BNR)

An extensive amount of municipal wastewater treatment plant rehabilitation and new construction has been carried out in recent years as a result of more stringent discharge standards, with particular world-wide emphasis on nutrient removal. Single sludge BNR treatment plants, capable of simultaneously removing both nitrogen and phosphorus, represent the state-of-the-art in wastewater treatment technology. The degree of process complexity can be demonstrated by considering the BNR facility constructed at Penticton, British Columbia. Based on extensive pilot scale research carried out at the University of British Columbia, the Penticton BNR plant is capable of reducing effluent phosphorus and nitrogen concentrations to below 0.1 and 3.0 mg/l, respectively. Although intended to operate primarily in a four stage modified University of Cape Town (UCT) configuration, the plant process configuration, a schematic of which is illustrated in Figure 1, can be readily changed to achieve a wide range of BNR system configurations. This is accomplished by adjusting the discharge gates leading into, and out-of, the recirculation channels, and by varying the mixing and aeration characteristics of each of the reactor cells. Up to 30% of the plant reactor volume (i.e. bioreactor cells 10 and 11) can be taken out of service to accommodate wide seasonal hydraulic variations due to the influx of tourists during the summer months. The relative proportions of each of the anaerobic, anoxic and aerobic reactor zones can also be adjusted. For example, bioreactor cells 6 through 11 can operate with or without an air supply, and the gate positions (open or closed) from the recirculation channels, leading to bioreactors 1 through 5, can be used to adjust the anoxic and anaerobic reactor volumes.

Optimization of such a flexible plant presents a challenge for operations staff. The technology is relatively new and rapidly advancing, requiring operations staff to make process control decisions based on "hands-on" experience, and experimentation. Effective and optimal plant performance is limited by a number of factors including: the lack of operations staff experience, and training; the lack of knowledge regarding which process parameters most affect optimal performance; and the absence of adequate sensors to assess specific environmental conditions in each bioreactor. Despite the large number of inputs to the distributed control system, there are few control loops, and the process requires an extensive amount of operator intervention.

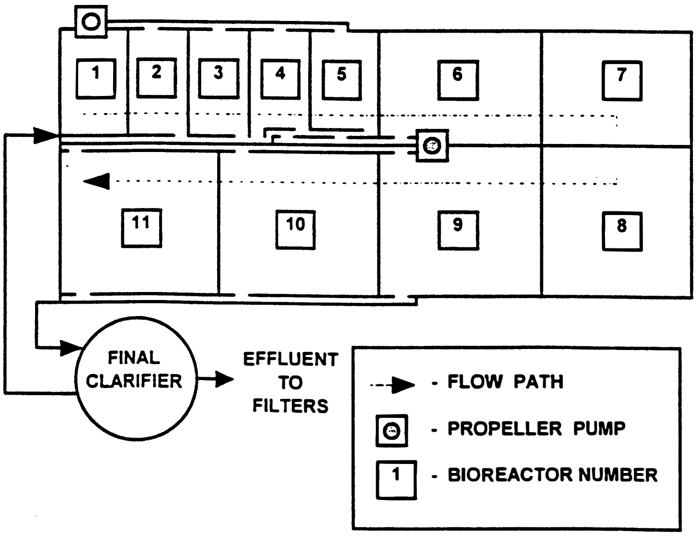

Fig. 1. Process schematic for the penticton, British Columbia, BNR plant.

Both of the above case studies outline a number of potential performance problems which could be addressed through improved ICA technology applications, specifically:

1. Modelling/simulator software, which can incorporate real-time data, to assist in operator training and evaluation of process control alternatives;

2. Expert system (artificial intelligence) software tools to incorporate qualitative information into the control loop, and aid in data interpretation;

3. Instrumentation and sensor developments to provide reliable information for use in control loops.

MODELLING AND SIMULATOR SOFTWARE ADVANCES

Before operations staff can consider alternative configurations, they need to have a much larger experience base upon which to base process decisions, and a method to assess what the outcome of a change will be. Without the ability to verify the outcome of process changes, optimal biological treatment conditions will be difficult to achieve

Up until very recently, the only means by which an operator could determine the effects of process control modifications was experimentation. Recent advances in dynamic models, artificial intelligence, neural network modelling, and computer technology, now make it possible to accurately simulate plant processes for use as an operations control and diagnostic tool.

There are a number of dynamic activated sludge modelling programs available which have great potential for process design, operator training and process control. One such program has been developed over the past eight years by an Ontario based firm (Hydromantis, Inc.), with the financial assistance of Environment Canada. This state-of-the-art dynamic modelling, and simulation, computer program is referred to as the **General Purpose Simulator (GPS)**, and makes use of the latest developments in mathematical modelling and computer simulation. The GPS is designed to assist in the planning, design, operation and control of wastewater treatment plants. The simulator can also be effectively used for operator training, allowing plant personnel to experiment with operational strategies without affecting the normal operation of the plant. Already being applied to a number of large-scale wastewater treatment plants in Canada, the U.S. and U.K., this approach is proving to be very successful, and an important key to improved process automation.

Where there is both limited design and operating experience available for a particular wastewater treatment facility, a simulator could be used to great advantage to prepare contingency plans for emergency conditions, and to train operations staff prior to commissioning the plant. This is particularly important for industrial wastewaters where the feed stock can originate from a number of unit processes with widely varying wastewater characteristics, in addition to fluctuations in hydraulic loading. Application of simulators to wastewater treatment processes has also proven to facilitate the identification of critical process conditions and control loops.

Incorporating a calibrated computer simulation program, operations staff will be able to determine the effect of process changes on effluent quality before they are actually carried out on the plant. Used as a training tool, plant operators will be able to learn about the process and make mistakes without impacting the receiving environment.

For the process modelling and simulation software to be effective, the process model must first be calibrated using reliable on-line data, collected from the plant under existing plant operating conditions. This data is also needed to ensure the model remains calibrated and accurately represents the treatment plant. The calibrated model can then provide information on the time varying performance of the plant, subject to a variety of dynamic events, including:

1. Variations in hydraulic loading to the plant;

2. Changes in influent composition;

3. Operational scenarios of interest, including alternative process configurations, adjusted reactor zones and sizes, and chemical supplementation conditions.

EXPERT SYSTEM ADVANCES

There have been a number of knowledge based expert systems (KBES) for wastewater treatment operation, and control, reported in the literature (Beck *et al.*, 1990; Berkmen *et al.*, 1990; Lai and Berthouex, 1990). Although most of the rule-based systems reported to date are described as being prototype, and few have been used in practice, there is great potential in this approach. The major problems reported concern acquisition of knowledge and subsequent validation of the knowledge base (Barnett and Patry, 1992). These problems are due to the use of inappropriate knowledge representations, where rules alone are insufficient to represent the many different kinds of knowledge required for diagnosis and control of wastewater treatment processes.

One approach to address the deficiencies of past KBES applications is to develop a flexible framework for knowledge, with sufficient expressive power to facilitate the capture of different types of knowledge, as well as the manipulation of knowledge in the inference process. The use of an object-oriented model-based knowledge framework (Kunz *et al.*, 1989) is a recent and promising innovation within the artificial intelligence field. It has the advantages of being flexible, extensible and highly modular in design, and enables a variety of inferencing schemes to be implemented.

The coupling of a comprehensive dynamic treatment plant model with a computer-based expert system, could be an effective process control tool for use in process optimization. Integrated into the instrumentation and control system, such software would have the following characteristics:

1. Adaptability to changing influent and process conditions;

2. Ability to incorporate both qualitative and quantitative data;

3. Auto-calibration and modelling verification capabilities.

In the absence of operating experience, a dynamic model could be used to develop the preliminary knowledge base that will be used in the early phases of the plant operation. This concept of using rule-extraction from simulation has been previously proposed by Patry and Olson (1987) to develop some of the basic operational rules that will make up a significant part of the knowledge base, incorporating qualitative modeling and rule extraction techniques.

Rule extraction techniques can be applied to the dynamic mechanistic model as the basic source of knowledge prior to the plant construction, and serve as one of the major components in the development of the knowledge base. This could be used as a powerful tool for the development and assessment of operational strategies before and after construction of the plant. The resulting process simulator, incorporating both quantitative and qualitative data could be coupled with a real-time operational control system, forming a key component in the computer-based training program.

INSTRUMENTATION IMPROVEMENTS

Improvements in instrumentation equipment are a critical factor in the implementation of effective control strategies for water and wastewater treatment plants. The Water and Wastewater Instrumentation Testing Association (ITA) has played an active role in assessing sensor reliability, and establishing installation, testing, maintenance and calibration protocols for a number of process monitoring components, including: chlorine residual analyzers; suspended solids sensors; dissolved oxygen sensors; and flow measuring devices.

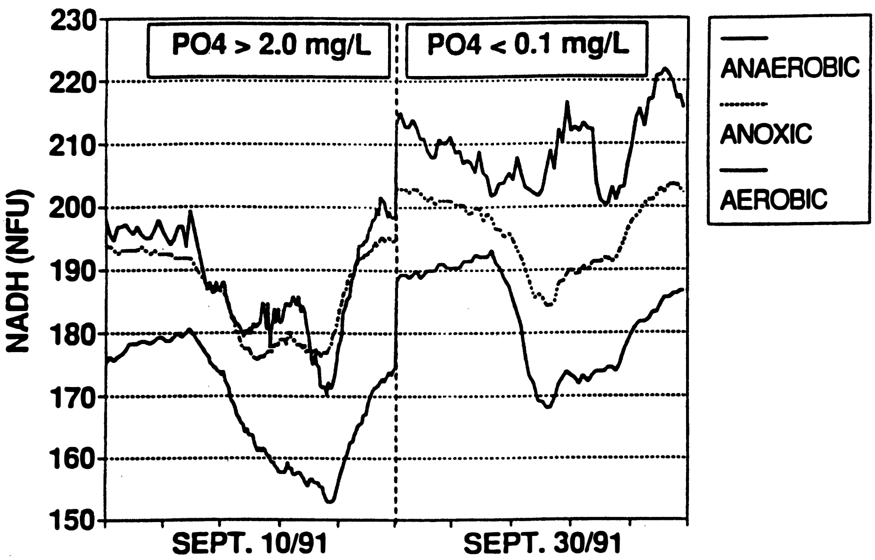

Fig. 2. NADH probe response characteristics under optimal and sub-optimal BNR phosphorus removal conditions.

The development of control strategies for BNR processes which incorporate specific ion probes (i.e., NH_3, NO_X) and bio-activity levels (i.e. respirometers, oxidation reduction potential [ORP], and NADH probes) show great promise for use in process optimization. Figure 2 illustrates the application of NADH probe data in establishing an optimum BNR process "fingerprint". Optimal phosphorus and nitrogen removal depends on maintaining anaerobic, anoxic and aerobic conditions within the process. The relative NADH level in each of the bioreactor zones (i.e. anaerobic, anoxic and aerobic), and the degree of separation in signal levels between the zones, can be used to indicate optimal phosphorus removal conditions. As noted in Figure 2, higher NADH levels and greater bioreactor signal separation is indicative of optimal phosphorus removal efficiencies. Oxidation reduction potential (ORP) sensors can also be used in a similar manner. Consequently, methods of assessing bioreactor conditions (i.e. ORP and NADH) could be used for process control using pattern recognition techniques, such as neural network based modelling.

CONCLUSION

The development of ICA applications for the water and wastewater treatment industry will be directly affected by the development of software which enables operations staff to effectively use the information gathered for process control. In addition, there is a need for the development of effective control strategies which can take advantage of available real-time information. Two key driving factors are the need to optimize the performance of existing treatment facilities, and the need to meet increasingly stringent treatment standards.

Dynamic modelling and simulation software, as an integral component of instrumentation applications, will play a significant role in developing control strategies and in optimizing plant performance. With continuous calibration, such software could be effectively used to train operations staff, and provide a "safe" environment to evaluate alternative process control strategies. Expert system (artificial intelligence) software tools will likely become integrated into dynamic modelling and simulation systems, incorporating qualitative information into the control loop, and assisting in data interpretation. Finally, continued advances are expected in instrumentation and sensor equipment to improve the reliability of inputs, and to provide information pertaining to biological activity within unit processes.

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