AUTOMATION IN WASTEWATER TREATMENT

G. Olsson and **C. Rosen**
Lund University, Lund, Sweden

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Summary

Urban water systems are vital infrastructures in the society. The systems are widely distributed and often they are operated by different organizations. Despite a large variety of demand the system has to operate around the clock, providing a drinking

water quality that is consistently good and a wastewater treatment effluent that all the time satisfies the required standard, so that the environment and public health are protected. Traditionally urban water systems have been designed from static principles with large safety margins. New economic incentives together with progress in sensor and computer technology and improved process knowledge have made it possible to design and operate the systems with a design that takes dynamic operation into consideration. The large variations should be handled with smaller volumes, but in combination with more advanced control and operation. Automation will provide the robustness of the system to provide a consistently good quality. Operation and control of wastewater treatment systems is the main emphasis here. The various incentives for automation are discussed and a review of the state-of-the-art of automation and operation is given. Models express our current knowledge of the processes. Instrumentation, process monitoring and process control are the major ingredients of automation. Current practice and the state-of-the-art of these areas are described and discussed. Aspects of the development in instrumentation, control and automation summarize the chapter.

1. The Urban Water System

Urban water is today an industry in progress. Urban water systems have been developed during almost a century and enormous investments have been made in the infrastructure of today. In a country like Sweden, with a population of about nine million, there is a capital investment of about 50 000 M USD, including the sewer and water distribution network, which corresponds to about 5-6000 USD per inhabitant. It is quite apparent that this kind of system does not change rapidly. Therefore it is mandatory to maximize the performance of the existing systems. At the same time, water is such a fundamental component of life, that any change of an urban water system will have significant environmental consequences.

Urban water systems are widely distributed systems. From a superficial point the function is apparent, to supply the customers with sufficient amount of water with good quality. Furthermore the waste products from industrial and municipal customers have to be treated both economically and environmentally soundly. Most systems today often have an unfortunate technical and economic disparity that is mostly a result of organizational tradition. Several organizations may share the responsibility of drinking water production and distribution, sewer network and wastewater treatment plant operation. Still other groups have the responsibility to ensure the receiving water quality.

Characteristically the systems are subject to large variations in demand and highly varying disturbances. In a wastewater treatment system, the ratio between low and high load may be an order of magnitude within a few hours. The systems are subject to changes both in terms of flow rates, concentrations and composition. These disturbances depend not only on the demand variations but also on the weather and on purposeful or un-purposeful waste from industries and households. Consequently, the processes and systems are hardly ever in steady state but can be considered to be in a transient state all the time. Typically, in today’s systems, each unit process can be started, operated and maintained with no or little synchronization with other parts of the system. Often this leads to large – and sometimes erroneous – sub-optimizations. For any viewer it is quite evident that there are strong couplings between different parts of the urban water flow. However, most information and control systems today do not take this into consideration.

The complexity of the urban water system comes from both the great number of different disturbances and from the challenge to coordinate and integrate many unit processes. Since the system is a service system, the delivery of the product must be highly reliable. The economical potential of automation in urban water systems is not only to save resources like energy, chemicals and personnel costs, but also to decrease investment costs by achieving a better use of existing volumes.

The traditional urban water systems are designed using static considerations with average and maximum loads and safety margins as key parameters. Such methodology often leads to over-design of both piping systems and processes. With new economic incentives in many organizations, the interest for total cost minimizations has been apparent and large expenses can be saved by better information and automation systems. The design has to consider the dynamics of the system, so on-line information of the states will be demanded during operation. Furthermore, traditional design of urban water systems has not considered the potential of system-wide information between various parts. Using coordinated information new performance can be obtained, illustrated by an example:
The volumes of the sewer networks are often quite significant and can be used as buffer volumes during periods of large flow rates. However, the water quality will be influenced by the storage time. Furthermore, the pumping costs may vary during the day. Thus, the pumping has to optimize the conditions for the wastewater treatment plant, satisfying many constraints. It will also require advanced and reliable on-line information.

2. Wastewater Treatment Operation

The treatment of municipal and some industrial wastewaters generally uses a combination of primary, secondary and tertiary treatment. Primary treatment simply screens and settles large particles and skims off floating greases and oils. Secondary treatment biologically removes organic carbon and in newer plants soluble nitrogen and/or phosphates. Tertiary treatment attempts to limit the microorganisms and other pathogens in the treated water by membrane filtration or deep-bed filters and some form of disinfection using chlorine, ozone or ultraviolet light. Chemical precipitation of phosphates is also common at this stage.

The biological reactors involve several reaction types, such as anaerobic fermentation, anaerobic activated sludge, anoxic activated sludge, and aerobic activated sludge. There is also an increasing number of physical configurations, such as tanks with loose or fixed packing, fixed-film processes such as trickling filters, and sequenced batch reactors. With increasing pressures to reduce volumes, the variety of fixed-film configurations increases rapidly. After the reaction processes, the other important class of processes is separation - separation of water from biomass and/or other solids. Traditionally this has involved simple settling tanks and clarifiers. Again the pressure on volume reduction is increasing the interest in filtration - both using conventional filtration equipment and using membranes.

There are many flow sheet configurations, often of a proprietary nature, which attempt to obtain the optimal combination of anaerobic, anoxic and aerobic conditions for the microorganisms. Chemical treatment often replaces or complements the biological reactions. The flow sheets used in a particular instance depend on a several factors, such as the influent characteristics, the relative importance of carbon, nitrogen and phosphorus removal, the experience of local operators, and the expertise of the designers.

For the operation of a wastewater treatment plant there are several mechanisms that have to be understood. The hydraulics is a key feature in any plant. The volume of the wastewater is so large that the pumping has to be minimized. Pumping also involves the recycles of mixed liquor and sludge. It is crucial that the pumping is operated in such a way that one unit process will not deteriorate the performance of another one. The nutrient reactions are fundamental for the operation of the biological processes. They form the basis for a proper control of air or oxygen supply and for the best balance of nutrients. In a biological nutrient removal plant there are several simultaneous reactions taking place in the system. Thus, both carbon, nitrogen and phosphorus removal take place in the same reaction basin. They compete for the same resources, such as oxygen. Therefore control becomes increasingly important as the plant complexity grows. The air supply and the dosage of chemicals make up a major cost of the operation of a plant. To save energy and chemical resources is therefore an important driving force for better control.

The trend in wastewater treatment is toward more diversified and complex processes. This is naturally an effect of the increased knowledge on the physical, chemical, biological and biochemical mechanisms that govern the processes. Also, stricter regulations on the treated water are imposed and even stricter will be imposed in the future. The industry is today in a transitional phase with a change in attitudes, from a societal service treating wastewater to a high-tech business ensuring and providing clean water in the environment.

Application of automation in wastewater treatment operation can be said to have two primary functions: information acquisition and process control. For the former function, the level of automation is relatively high. Many, often thousands of variables, are today gathered on-line in the SCADA systems of treatment plants and more or less sophisticated data analyses are standard components of the treatment operation and quality monitoring. However, the latter function, process control, is less developed and often limited to a few unit process control loops. Traditional explanations why this is the case generally refer to issues like inadequate process knowledge, lack of sensors for crucial parameters and insufficient control authority of the process.

There are several indications that the situation is changing and that the treatment industry is experiencing a transition towards a higher level of automation for both information acquisition and process control. In a recent European study on the use of ICA (Instrumentation, Control and Automation) it was stated *“Wastewater industry in*

Europe is currently in a transitional phase with driving forces for ICA too strong to ignore. The opportunity for a change of paradigm with regards to ICA is imminent!" The study shows that sensors are now available, although the need for more robust and self-validating designs is significant before they will be used for control. Also, actuators have been developed with an increased control authority as a result. Other reasons for this change may be attributed to structural issues, such as stricter effluent standards, higher demands on operational efficiency, looser links between treatment industry (providers of treatment services) and government (the enforcer of effluent standards), etc. Yet another important reason is the increase in the plant complexity due to new and enhanced treatment technologies.

The introduction of automation has increased the capacity of biological nutrient removing (BNR) wastewater treatment plants (WWTP) by 10 - 30%. The better understanding of basic mechanisms results in an increased understanding of the processes and the possibility to control them. If these possibilities are exploited in the future by intelligent use of measurements and IT the improvements due to automation may reach another 20-50% of the total system investments within the next 10-20 years.

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Biographical Sketches

Prof. Gustaf Olsson got his MS in engineering physics in 1964, his *Teknologie licentiat* degree in Automatic Control at the Royal Institute of Technology, Stockholm, in 1966. He was awarded *Docent* in Automatic Control at Lund University in 1978. He became Assoc. Prof. and the chairman of the Department from 1971 until he was appointed professor in Industrial automation in 1987 at Department of Industrial Electrical Engineering and Automation, Lund University. He has spent several periods abroad as visiting scientist or professor, at Univ. of California, Los Angeles, MIT, Cambridge, Mass., Univ. of Houston, Texas, Systems Control Inc., Palo Alto, California, Kyoto University, Japan, Univ. of Queensland, Brisbane, Queensland, Australia, Univ. of New South Wales, Newcastle, NSW, Australia, Univ. of Wisconsin, Madison, WI, USA. He has also been consultant in environmental issues for Weyerhaeuser Company, Tacoma, Washington, USA, the city of Houston, Texas, the city of Ann Arbor, Michigan, the city of Hamilton, Ontario, Canada. He is an international advisor on environmental research at the Univ. of Queensland, Australia. He is currently a member of the IWA (International Water Association) Strategic Council. He has been an invited guest lecturer to a large number of international events in the USA, Canada, Japan, Korea, Singapore, Malaysia, Australia, the Netherlands, Italy, Poland, and the Nordic countries. He has written three international books and contributed to 5 other books. In the area of wastewater treatment he has published more than 80 papers. Since 1990 he has supervised 8 completed PhD and 13 licentiates. Currently he is supervising 8 PhD students and more than 10 MSc students every year. He has been the external examiner for many PhD and licentiate theses in Sweden, Norway, Denmark, Finland and USA.

Dr. Christian Rosen received his MSc in civil engineering in 1995 and PhD in industrial automation in 2001 at Lund University, Sweden. At present, he holds a position as a research associate at Department of Industrial Electrical Engineering and Automation, Lund University. His work is focused on on-line operational monitoring and process control in wastewater treatment systems. Other interests include modeling and simulation of wastewater treatment plants. He has been author or co-author of more than 20 publications in the wastewater treatment area. Parts of his studies have been carried out at the Advanced Wastewater Management Centre (AMWC), the University of Queensland, Australia.