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# Automation Development in Water and Wastewater Systems

Gustaf Olsson†

*Department of Industrial Electrical Engineering and Automation, Lund University, Lund, Sweden*

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**Abstract**

Advanced control is getting increasingly demanded in water and wastewater treatment systems. Various case studies have shown significant savings in operating costs, including energy costs, and remarkably short payback times. It has been demonstrated that instrumentation, control and automation (ICA) may increase the capacity of biological nutrient removing wastewater treatment plants by 10-30% today. With further understanding and exploitation of the mechanisms involved in biological nutrient removal the improvements due to ICA may reach another 20-50% of the total system investments within the next 10-20 years. Disturbances are the reason for control of any system. In a wastewater treatment system they are mostly related to the load variations, but many disturbances are created also within the plant. In water supply systems some of the major disturbances are related the customer demand as well as to leakages or bursts in the pipelines or the distribution networks. Hardly any system operates in steady state but is more or less in a transient state all the time. Water and energy are closely related. The role of energy in water and wastewater operations is discussed. With increasing energy costs and the threatening climate changes this issue will grow in importance.

*Keywords:* Instrumentation, control and automation (ICA)

## 1. Driving Forces and Motivations for Control

Instrumentation, control and automation (ICA) got the attention in the water and wastewater industry already in the 1970s. Still, however, dynamical systems and process control is seldom part of the general civil engineering or environmental engineering curricula. Consequently many water and wastewater systems designers are unaware of the potential of ICA. It has been demonstrated that ICA may increase the capacity of biological nutrient removal (BNR) wastewater treatment plants (WWTP) by 10-30% today. The advanced knowledge of the mechanisms involved in biological nutrient removal that is being gained today is producing an increased understanding of the processes and the possibility to control them. There is a sophisticated relationship between the operational parameters in a treatment system and its microbial population and biochemical reactions, and hence its performance. With further understanding and exploitation of these relationships the improvements due to ICA may reach another 20-50% of the total system investments within the next 10-20 years. Various case studies of advanced control in water and wastewater treatment systems have shown significant savings in operating costs and remarkably short payback times (Olsson et al., 2005).

† Corresponding author
E-mail: Gustaf.olsson@iea.lth.se
Tel: +46-46-222-4788, Fax: +46-46-14-21-14

## 2. Disturbances

A major incentive for control is the presence of disturbances, and the impact of them has to be compensated. Compared to most other process industries, the disturbances that a wastewater treatment plant is subject to are extremely large. The wastewater influent typically varies substantially both in its concentration, composition and flow rate, with time scales ranging from fraction of hours to months. Discrete events such as rainstorms, toxic spills and peak loads may also occur from time to time. As a result, the plant is hardly ever in steady state, but is subject to transient behavior all the time (Olsson & Newell, 1999).

In a water supply system the major disturbances instead occur at the load or customer side. The inflow to the water plant can be kept relatively constant, while the demand from the customers will vary depending on the time of the day, the weather and the season. Sudden bursts or leakages cause disturbances than look more like discrete events. They have to be discovered at an early stage and countermeasures - preferably automatic - have to be realized quickly.

Consistent performance must be maintained despite the disturbances. The traditional way of dampening the disturbances has been to design plants with large volumes to attenuate large load disturbances. This solution incurs large capital costs. On-line control systems, which have been demonstrated to cope well with most of these variations, are a much more cost-effective and thus attractive alternative. Disturbance rejection is indeed one of the major incentives for introducing on-line process control. Many disturbances in a wastewater treatment system are related to the plant influent flow. Any of these changes have to be measured and compensated for. If the effect of the disturbance is measured *within* the plant, such as a change in the dissolved oxygen level, a rising sludge blanket, or a varying suspended solids concentration, the measured information is *fed back* to a controller that will activate a pump, a valve, or a compressor, so that the influence on the plant behavior is minimized.

Too often unnecessary disturbances are created within the plant itself. Often this depends on a lack of understanding how the various parts of the plant interact. Just one example: if the influent flow rate cannot be varied continuously but the pumps are operated in an on/off mode the consequence is that the plant will be subject to sudden flow rate changes. In particular, the settler operation will suffer from such sudden flow rate changes.

Recycling of water and sludge in a wastewater treatment plant creates apparent couplings between various unit processes. If these interactions are not considered, then the plant operation will suffer. For example, if sludge supernatant is recycled to the plant influent during a high load, then the nitrogen load to the plant may be very large and can be measured as an increase in the oxygen uptake rate. It is crucial to identify the sources of disturbances in order to obtain a high performance operation of a plant. Then the control system can be structured so that disturbances are attenuated or even avoided (Olsson et al., 2005). Further *internal* disturbances may be generated due to inadequate or inappropriate operations including human errors, unsuitable or malfunctioning actuators and/or sensor breakdowns. These may potentially cause major operational problems. Many of the internal disturbances may be avoided (or their impacts minimized) through introducing on-line control systems, including early warning systems.

## 3. The Role of Control and Automation

ICA in wastewater treatment systems have come a long way and is now an established and recognized area of technology in the profession. A number of factors have combined made this progress possible:

- *Instrumentation technology* is today so much more mature. Complex instruments like on-line in-situ nutrient sensors and respirometers are now regularly used in the field.
- *Actuators* have improved over the years. Today variable speed drives in pumps and compressors are commonly used to allow a better controllability of the plant;
- *Computing power* can be considered almost “free”;
- *Data collection* is no longer a great obstacle. Software packages and SCADA systems are available for data acquisition and plant supervision;
- *Control theory* and *automation technology* offer powerful tools. Benchmarking and various tools for evaluating control strategy performance have been developed;
- Advanced *dynamical models* of many unit processes have been developed. Commercial *simulators* are available to condense the knowledge of plant dynamics;
- *Operators and process engineers* are often educated in instrumentation, computers and control ideas. However, there is still a great need for better education in these areas.
- There are obvious *incentives* for ICA, not the least from an economic point of view. Plants are also becoming increasingly complex which necessitates automation and control.

Today the main obstacle for more ICA is the lack of process flexibility. Plant design and operation still have to be integrated in a systematic way.

## 4. Instrumentation and Monitoring

To measure is to know. Developments during the last two decades have contributed that instrumentation is not the main obstacle for ICA (Olsson & Newell, 1999; Vanrolleghem & Lee, 2003; Olsson et al., 2005). The increased confidence in instrumentation is now driven by the fact that clear definitions of performance characteristics and standardized tests for instrumentation have become available (ISO 15839:2003).

To track the process operational state via the instrumentation is called *monitoring*. For the clean water supply on-line monitoring will be required throughout the system including at the tap. The availability of low cost instrumentation will encourage better leakage detection and water quality monitoring. In wastewater treatment systems the use of ICA has proven to significantly reduce the costs for operation. However, even reliable instrumentation can fail during operation, which can have serious consequences if the instrumentation is used in closed loop control. Therefore real time data validation is needed before using measurements for control purposes (Lynggaard-Jensen & Frey, 2002). If confidence in a measurement decreases, it might be possible (on a short-term basis) to use an estimated value, but eventually control must be set to a default scheme until confidence in the measurement has been restored.

In a sophisticated treatment plant there is a huge data flow from the process. More instrumentation will further provide more data. Unlike humans, computers are infinitely attentive and can detect abnormal patterns in plant data. The capability of computers to extract patterns (useful information) is rarely utilized beyond simple graphing. Information technology is not commonly used to encapsulate process knowledge, i.e. knowledge about how the process works and how to best operate it. Process knowledge is typically built up from the experience of operators and engineers but all too often disappears with them when they leave. If process knowledge can be encapsulated, then not only is it retained but the computer can also assist decision-making in plant operation (Rosen et al., 2004). The potential of substantial operator support for diagnosis and for corrective actions is there and has been demonstrated, but it needs to be adopted by the water and wastewater industry.

## 5. Control Applications in Wastewater Treatment

The fundamental principle of control is feedback. The process (for example, an aerator, a chemical dosage system, or an anaerobic reactor) is all the time subject to disturbances. The current state of the process has to be measured by some sensor and this is the basis for a decision. In order to make a decision the goal or purpose of has to be expressed. Having made the decision it has to be implemented via an actuator, which is typically a motor, a pump, a valve or a compressor. In other words: *control is about how to operate the plant or process towards a defined goal, despite disturbances* (Olsson & Newell, 1999).

The traditional WWTP control is still unit process oriented to a great extent. Some examples of state-of-the-art control are mentioned here (Olsson et al., 2005) :

- DO control with a constant or a variable setpoint as part of the aerator unit process operation;
- Aeration phase length control in alternating plants is based on nutrient sensors, but still locally;
- Nitrate recirculation control in a pre-denitrification plant can be based on nitrate and DO measurements in the aerator and in the anoxic zone (Ingildsen, 2002);
- Advanced sludge retention time control is based on local measurements of effluent ammonia concentration and of estimates of nitrification capacity;
- Return sludge control can be based on sludge blanket measurements in the settler;
- Aeration tank settling (ATS) is one way of temporarily increasing the plant capacity at storm conditions (Nielsen et al., 1996, Gernaey et al., 2004);
- The control of anaerobic processes aims at regulating the biogas flow, at stabilizing the process and at maximizing its productivity. Still current state-of-the-art focuses on the unit process operation;
- Successful chemical precipitation control can be based on local measurements of phosphate concentration.

In water supply systems leakage detection has been successfully applied for many different operating conditions. Leakages can appear as sudden bursts or slow and gradual leakages. They will take place in both single water transmission lines and in water distribution networks. Many interesting methods have been developed to cope with leakages, and some interesting examples are shown in Misiunas (2005a, 2005b) that contain further references.

## 6. Energy and Water

Energy and water are closely related, which is seldom considered. Here we will briefly discuss the consumption of electrical energy and the production of biogas energy.

### *6.1. Electrical Energy*

Treatment and transmission of water and wastewater requires large amounts of energy. In a country like Sweden water and wastewater operations use about 1% of the total national electrical energy supply. The demand on electrical energy will have an environmental impact, which means that the sustainability issue is critical also from an energy perspective. Clean water requires electrical energy; for pumping of drinking water and of sewage, for mixing and for aeration of wastewater, for chemicals, and for transportation of sludge. Desalination for water supply is rapidly increasing. In the Mediterranean area there is an 18% annual increase and in Saudi Arabia a 17% increase every year. Impressive efforts are in place in Korea. This just demonstrates that the energy issue will require a lot more attention.

As long as the cost of electrical energy has been quite low the energy aspect has not been given much attention. However, as prices are raising the interest in various energy savings has been increasing. Many different assessments can be defined for energy requirement, such as *kWh/person/year* or *kWh/kg N removed* etc. Here we will not elaborate on various methods to estimate the energy use. Instead we will point at some important factors where control and automation can bring down the electrical energy requirement.

Dissolved oxygen control will save a lot of electrical energy compared to no control at all. A time varying setpoint of the DO concentration will further reduce the energy consumption (Olsson & Newell 1999, Olsson et al., 2005). Large pumps, primarily for the influent water, are often the most energy demanding equipment in a plant. Too often the pumping equipment has not been designed for the adequate flow rates. Aeration by compressors ought to be continuously variable. To control airflow by closing airflow valves will cause a lot of energy losses. Instead, variable speed compressors will save energy significantly.

A wastewater treatment plant in fact should be considered a recovery plant for both nutrients and energy. If we consider the energy potential in anaerobic digestion there is a huge unused potential in most places. We can illustrate this with one good example (the Rya WWTP in Göteborg, Sweden): the plant uses 41 *kWh/person/year* of electrical energy. At the same time the plant produces biogas corresponding to *72 kWh/person/year*. The heat content of the effluent water is taken care of in heat pumps. Here the production potential is 336 *kWh/person/year*. The plant is in fact an important energy producer.

### *6.2. Biogas Production*

Recent data show that anaerobic digestion (AD) uses only some 20% of the energy content of the sewage. In addition, costs of sludge transportation and disposal, which currently place a major burden on the industry, could be reduced. The nature of the influent characteristics involves dynamic variation in both flow rate and composition (Batstone et al., 2002). Handling of these disturbances by attenuation or rejection is thus important for stable operation. Many anaerobic bioreactors are still being operated without close monitoring and control. This is not only due to the fact that the anaerobic process involves a complicated mechanism of degradation steps, but it is also due to the lack of proper analytical devices. In fact, sensor technology is the weakest part of the process chain (Liu, 2003; Olsson et al., 2005).

Close monitoring and control makes it possible to enhance the operational stability, to attenuate and reject disturbances and to allow the treatment of waste and biogas production at a higher specific rate (Liu et al., 2004). The activity of the different microbial groups involved in the AD process can be measured indirectly by monitoring the metabolites. In general, it is now possible to analyse pH, alkalinity, biogas flow and composition, VFAs, biodegradable organic matter, dissolved hydrogen, and toxicity on-line by less expensive sensors and instruments. Usually the feed rate is the control variable. Another interesting approach reported in recent years is the probing control strategy based on analysing the effect of disturbances added on purpose to the influent flow rate (Steyer et al., 1999).

## 7. Concluding Remarks

*Disturbances* are everywhere and are the main reason for control. *Uncertainty* in the process or in its environment makes automation both an opportunity and a great challenge. Application of automation in water operations can be said to have two primary functions: information acquisition and process control. For the former function, the level of automation is relatively high. Often many thousands of variables are gathered on-line in the SCADA systems of treatment plants and more or less sophisticated data analyses are standard components of the treatment operation. The latter function, process control, is less developed and often limited to a few unit process control loops. Future development will be exploiting the enormous capacity of data distribution that is possible today. Many SCADA systems are also applying the technology from the Internet, which gives an almost unlimited potential for remote data evaluation and decision. The distributed control room is already here. There is a limit of how much expertise a treatment plant can afford. However, given that plant data can be made available anywhere it is possible to utilize specialist competencies wherever they are located.

The increasing incorporation of ICA in water treatment operation is not only driven by the impressive technical development of instrumentation and computer technology, modelling and control, and the progress in automation. It is motivated by economy and environmental obligations and turns out to be a necessary and worthwhile investment. It is already proven in several installations that ICA investments have paid off quickly and we will see that ICA will become an increasing part of the total investments.

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