A glance view of

ICA – Instrumentation, Control and Automation

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ICA is a key technology to keep a plant or a process working as efficiently as possible despite disturbances. This includes saving energy and resources. Bioprocess Control AB is an esteemed provider to the ICA domain by supplying advanced instrumentation.

ICA includes all information that is generated and used in a system. All processes can be controlled to perform better. It is the process knowledge, the sensor technology and the way the plants have been designed and built that may limit what can be achieved. Wastewater treatment and sludge or organic wastes handling processes have some unique features compared to other process industries: the flow rates, feedstock disturbances, concentration and composition variations, the microorganisms, the separation, and the fact that all the “raw material” must be accepted and treated. The critical issues are the attitudes and incentives. Of course, the attitudes often depend on the incentives. Today there are clear incentives to invest in ICA and we can use many of the results from other process industries that introduced ICA earlier.

A key motivation for all control is the presence of disturbances. The load to a wastewater or a biogas plant is hardly ever constant in terms of quality and quantity. The flow rate, the concentrations and the composition of the influent feed are changing all the time. With all these disturbances it is impossible to operate any plant with constant settings of pumps, motors, compressors, valves and other actuators.

Feedback – a fundamental principle

Feedback control is a powerful tool. It makes it possible to reduce the effect of disturbances and process variations. It can change poorly performing components into good systems and it can stabilize unstable systems. Biological systems make use of feedback in an extraordinary number of ways, on scales ranging from molecules to cells to organisms and further on to ecosystems. We use feedback more or less conscientiously every minute of our life. Information from our feet and our balancing sensors is processed via our brains to our muscles to keep us walking or standing. Oxygen levels in the blood stream are fed back to our respiratory system to keep us going. Driving a car requires a lot of feedback. Sensory information from our eyes, ears, and balancing system are processed in the brain and forwarded to the “actuators”, our muscles, to steer the car, keep the speed or avoid unexpected obstacles.

The term *control* is defined here as the technique to get a system or a plant to behave in a desired manner despite disturbances. This is typically achieved by using feedback. A feedback controller senses the operation of a system, compares it against a desired response, computes corrective actions - sometimes based on a model of the system’s response to external inputs - and actuates the system to effect the desired change. This basic *feedback loop* of sensing, computation, decision and actuation is the central concept in control, as illustrated in Figure 1.

In wastewater and organic waste or sludge treatment operations such as biogas production, the motivation for all feedback control is the presence of disturbances. The load to a wastewater treatment plant or an anaerobic digester is hardly ever constant. The flow rate or feed rate, the concentrations and the composition of the influent flow or feed are changing all the time. Many disturbances are created internally, within the plant, because of the operation. Due to all the disturbances, it is impossible to operate any plant successfully with constant settings of pumps, compressors, valves and other actuators.

ICA is often considered a hidden technology. It is not noticed as long as it works. Still it is becoming ubiquitous in most water, wastewater and solid waste handling systems. ICA was recognized already in the early 1970s as an important technology to improve both water, wastewater treatment and transport operations and to satisfy both quality of the effluent and resource efficiency (Olsson, 2012; Olsson *et al*., 2014). At the basic level ICA is applied to keep the plant running by automatically manipulating the actuators - pumps, valves and compressors - to keep physical variables, such as flow rates, levels and pressures around the desired values. Once this is guaranteed, on the second level, the effluent or "product" quality requirements must be satisfied.

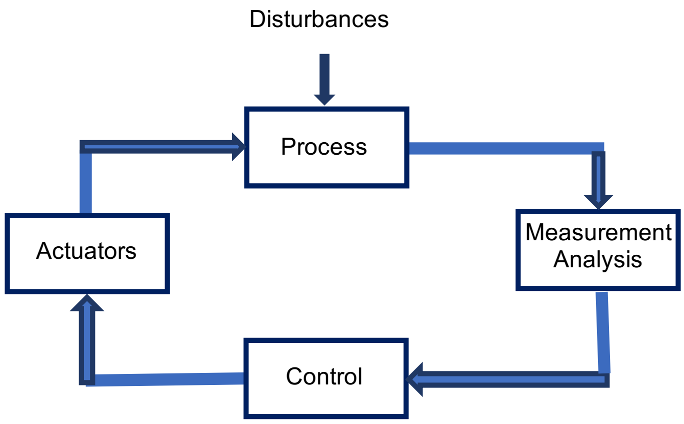

Figure 1. Illustration of the feedback principle.

Measurements matter – to measure is to know

During the last decades there has been an important development of advanced sensors. This includes automated laboratory analysers and *in situ* sensors that can be placed directly in the liquid to be monitored.

No plant can be operated, and no process control application can perform better than the quality of the measurements. Still today, many biogas plants are operated "blindly", indicating that there are no measurements supporting the operation. Not analysing the biodegradability and the biogas potential of the feedstock means that the "fuel" of the plant is unknown. Consequently, it is impossible to predict or guarantee the resulting gas flow and gas composition.

Outlet gas flow and sometimes gas composition are measured in many plants. This information is useful, but only to a limited extent. The operator can notice if the gas flow is decreasing and may be able to change the mass flow of the feed accordingly. However, information about the gas is late information. As a result, any correction of the feed flow will come as a much-delayed action on the information from the outlet gas.

Feedstock analysis

Knowing the composition and the biodegradability of the feedstock is a crucial measurement for biogas operations, definitely the most important measurement in an anaerobic process operation. Traditionally this analysis has been made manually. This is a time-consuming laboratory work that requires a high skill of the personnel performing the analysis. In order to obtain believable results, any repeated analysis of a certain feed should be reproducible with good accuracy.

Today analysis of feedstock can be made automatically with high precision and high accuracy. In most plants the composition and biogas potential of the feedstock is not constant but is varying dynamically. Naturally, this asks for repeated analysis. Having an automatic methane potential analysis equipment is extremely important to achieve a stable operation of an anaerobic digester. With this analysis the biogas production can also be increased without sacrificing stability of the plant operation. The device, being automatic, will of course save personnel time. Furthermore, it does not require the same analysis skill as required for the manual analysis. Still the accuracy of the result is very good. The automatic feedstock biodegradability analysers offered by Bioprocess Control (such as *Gas Endeavour* and *AMPTS II*) will not only provide the methane potential of the feed but will also make it possible to compose the best achievable feed from various sources to maximize the biogas output and to keep the operation stable.

Feedstock analysis is not only part of a qualified operation but should also be used as a tool for the biogas project feasibility study and design the best process flow and configuration for the given biomass.

With information of the feedstock properties and effluent gas flow and composition the operator has a significantly better condition for good operation. Knowledge of the feedstock is like knowing that there is adequate and right “fuel” in a car. Similarly, observing the result of the operation, the effluent gas, is like seeing the direction of the operation.

Measurements in the reactor

The operation can be further improved if information about the process can be obtained as early as possible. Early information is good information and make it easier for better corrections. By measuring key parameters in the biological reactor more adequate information can be obtained about the direction of the process, any formation and accumulation of metabolic and their influence on process stability and efficiency. Some key variables are pH, alkalinity, volatile fatty acids (VFA) and dissolved hydrogen concentration. These measurements can provide an early warning of imbalances in the microbial system, such as if the process is approaching a stability limit. For example, if the VFA concentration is allowed to increase too much there is a great risk for process failure as a result of decreasing pH. Naturally, a warning system for process failure is a crucial component for good and stable operation.

Measurements in wastewater treatment

In wastewater treatment there are many sensors that are well proven, such as sensors for pH, temperatures, levels, pressures, flow rates, dissolved oxygen, turbidity and mixed liquor suspended solids. Sensors measuring chemical oxygen demand (COD), nutrient concentrations, such as ammonia-nitrogen, nitrate-nitrogen or phosphate, include more advanced automated analysis. As a result, instrumentation – including sensors, analysers and other measuring instruments - is no longer a bottleneck for wastewater system control. However, it should be kept in mind that the measurements all the time must be tested before being used. Still there is no general standard how to check on-line sensors, and it is important to realize that a control loop depends on every single value from the sensors.

Screening and analysis of data

The data quality of any measurement must always be checked. Consequently, measurements must be combined with adequate data screening, measurement processing and more or less sophisticated feature extraction from the measurements.

Almost all measurements are affected by some glitches or imperfections like missing values, noise or outliers. It is always important to screen sensor data for high-frequency noise, missing data, values out of range, or trends from drifting sensors. Corrupted measurements must be found and corrected, so that false conclusions based on the measurements are avoided. To track the current process operational state via the screened measurements is called *monitoring*.

Monitoring

Monitoring the process means to ensure that the process is not operating outside the desired operating range. Furthermore, any online or offline sensors and laboratory analysis can be combined with human observations. A human can see, hear and smell and these observations should be combined with the physical/chemical/biological measurements. All this information serves as operator support for detection of process problems. Further analysis of measurement information should lead to a decision about control, in other words manipulating some variable to keep the process “on track”.

In a sophisticated plant there is a huge data flow from the process. More instrumentation will provide even more data. Unlike humans, computers are infinitely attentive and can detect abnormal patterns in plant data. Wastewater and sludge treatment systems are relatively slow systems. Still, when disturbances appear in the plant it may be quite difficult to dampen their effect. Therefore, early warning systems are asked for. There has been a significant increase in the interest of detection and isolation of disturbances.

Actuators

It is fundamentally important that it should be possible to manipulate (control) any biogas or wastewater treatment plant. Otherwise, it is like having a car without a steering wheel.

The mass transfer rate of the feedstock is a key control variable. If the feed rate cannot be manipulated, then the plant is not controllable, and cannot compensate for dynamical disturbances. Furthermore, if there are different sources of the feedstock, it should be possible to readily change the composition of the feedstock by controlling the feed from different sources. Similarly, it should be possible to control the discharge from the reactor.

Usually a digester is operated at a certain temperature, for example at mesophilic or thermophilic conditions. The temperature should be kept close to its setpoint value, which will require some means to control the temperature.

The actuators are the “muscles” of the plant. They are motors and valves that are used to change flow rates or the amount of mixing. Today variable speed drive technology is well-proven and affordable and allows smooth operation, as opposed to on/off control of the devices. As noted above a feedback control loop depends not only on reliable measurement data but also on adequate actuators, like compressors, pumps and valves. A poor actuator performance can destroy the outcome of any good control method. It was recognized early that actuators may limit the ability of control, for example by having a too small controllability span. This is probably the most fundamental barrier for more widespread acceptance of new control strategies, and many existing plants are not designed for real time control. The ability to adjust the control handles in a continuous way is also of paramount importance to get a satisfactory control. A striking example is a digester where we found that the feed rate had to be constant or shut down.

Control

As remarked, in “traditional” biogas plant operation the operator has limited information. Naturally, the operator does not wish to risk any process failure. Therefore, such a plant is often controlled with large safety margins with price on efficiency and profitability. This results in a gas production that is much lower than possible, sometimes even approaching zero.

Given adequate information about the feed composition, outlet gas and internal variables there is a huge potential for improvements of gas production and of process stability with available analyzers and sensors technologies. Control theory has had a truly extraordinary development during the last four decades. There are adequate control methods for practically all kinds of biological processes.

The understanding of the biological and related physico-chemical phenomena responsible for removal of organic carbon, nitrogen and phosphorus compounds as well as biogas generation have been documented in internationally recognized models, such as the Activated Sludge Models, and the Anaerobic Digestion Model, developed by task groups in IWA (The International Water Association). The impact has been remarkable.

Still many plants experience unsatisfactory control. The reason is not that the control is difficult or that the sensors are not sufficiently robust. Many implementers and equipment providers do not have enough knowledge of the process dynamics or do not efficiently communicate their knowledge. Sensors are located at wrong positions, data analysis is not adequate, sampling frequencies are often unrealistic (mostly too fast), actuators are not designed for control, or the controller settings are not adequate.

Plant wide control

To maximize the efficiency, it is often necessary to undertake a plant wide perspective. The sludge production in the liquid train of a wastewater treatment plant is intimately coupled to the biogas production capacity of the anaerobic digestion process. If co-digestion is applied, then there is a challenge to obtain information about the feed composition so that it is possible to calculate the biogas potential of the feed. Electrical energy consumption in the plant should be minimized and this requires that the coupling between the processes is considered. Organic carbon in the influent wastewater should be used wisely throughout the plant to produce energy via biogas: making sure that there is enough carbon for denitrification and at the same time maximize the amount or organic carbon that can be used for anaerobic digestion. To give a consistent and clear order to control goals is a truly multi-criteria decision problem and is the overall challenge of ICA.

Integrated control is expected to not only deliver benefits in terms of treatment efficiency and costs, but also enhance the ability of a plant in coping with increased loading; thus, deferring plant upgrading. A plant-wide perspective must be applied to achieve the highest possible efficiency in the operation. The operation of the primary settler will influence the treatment both in the activated sludge unit and the anaerobic treatment of the sludge. Chemical precipitation can be performed by dosing before or after the biological reactors or in the reactor itself. The many recycles make the complex couplings obvious, such as the return sludge, nitrate recycle or the recycling of the supernatant from the anaerobic digester to the influent of the wastewater treatment plant.

It has been experienced several times that it is not enough to control each unit process in isolation. The decomposition of complex systems is a convenient way of designing and operating control systems. Eventually, however, we must step back and take a helicopter view of the whole plant, or even a larger system. We may talk about plant-wide, system-wide or integrated control when not only the various unit processes of a wastewater or a sludge treatment plant but also the sewer and sometimes the receiving water are included. Whatever size of the system we have to define its boundaries, so that we can define external and internal events. Depending on the system size we will have different degrees of freedom and each system definition will determine what we can manipulate.

A plant-wide control system will assume that all the different unit processes are controlled locally. The interaction between different parts of the plant is considered by the computation of suitable setpoints for the local controllers.

The goal of integrated control is not to build up increasingly complex ICA systems. Quite the opposite: an ICA system has to be composed in a systematic way so as to deal with the intricate couplings of a complex process. These couplings appear between competing biological processes, between unit processes, between fast and slow reactions, between sewer systems, solid waste handling and treatment plants and between the treatment plants and the receiving water. Integrated control is still in its infancy. The necessary condition of having a plant-wide computer information system is often satisfied. Now operation and control should take advantage of the system-wide information and integrate the operation of one unit with other interacting system units.

Summary

ICA is no longer a supplementary profession to the water, wastewater or biogas industries but has become main-stream. The key message is:

- Measure and analyse more – there are already advanced sensors and analysers available;
- Important sensors and analysers are: methane potential, gas flow and gas composition, pH, alkalinity;
- Early warning systems from measurements and analysis are even more important in slow processes like anaerobic digestion;
- Good instrumentation is the basis for operator guidance;
- Today there is an impressive process knowledge available. It is crucial to look for implementers with the adequate knowledge of the complex biological processes;
- Control theory and engineering can offer all necessary methods. However, a good control also requires adequate process knowledge;

ICA applications are common in urban wastewater systems with significant benefits reported. The primary applications of ICA have focused on the control of various process units in water and wastewater treatment plants, leading to improved performance, reduced energy and other operational costs and increased capacity of the plants. Future research and development should focus on integrated control of urban water systems. Through properly recognising the connections and interactions between various units in a plant, and between various sub-systems, ICA will play more significant roles in more efficient use of existing urban water infrastructure, leading to system-wide optimisation. The use of ICA can allow us to get more out of existing assets, deferring capital-intensive upgrading that would otherwise be needed.

More to read

The development of ICA in water and wastewater systems is published in a personal review:

Olsson G. (2012). ICA and me – a subjective review. *Water Research,* **46**(6), 1585-1624.

Another overview of ICA development during 40 years in found in:

Olsson G., Carlsson B., Comas J., Copp J., Gernaey K.V., Ingildsen P., Jeppsson U., Kim C., Rieger L., Rodríguez-Roda I., Steyer J.-P., Takács I., Vanrolleghem P.A., Vargas Casillas A., Yuan Z. and Åmand L. (2014). Instrumentation, Control and Automation in wastewater– from London 1973 to Narbonne 2013. *Water Science and Technology,* **69**(7), 1373-1385. doi: 10.2166/wst.2014.057

The whole idea of combining instrumentation, data analysis, monitoring and control is explained for the non-specialist in the book:

Ingildsen P. and Olsson G. (2016). *Smart water utilities*. IWA Publications, London.

There is a close coupling between water and energy, nowadays called by the buzzword the “water-energy nexus”. This is described in detail in the book:

Olsson G. (2015). *Water and energy. Threats and opportunities*, 2nd Ed., IWA Publishing, London.