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Process automation in Wastewater Treatment Plants: the Finnish experience

Abstract The degree and importance of automation at municipal wastewater treatment plants (WWTPs) have increased with the development of technology and tightening of treatment requirements. The objective of this paper is to assess and document the current status of process automation at WWTPs in Finland to determine successful practices and the needs of plant operators. Renewing ammonia or organic content removal processes to total nitrogen removal processes has also increased the need of Instrumentation, Control and Automation (ICA). The survey has quantified that the reliability and accuracy of the on-line sensor measurement has improved recently, which makes the use of on-line measurements in control more applicable. The use of nutrient sensors in control is apparently still rare at Finnish WWTPs even though their use for monitoring purposes is common.
Keywords Automation, control, Finland, instrumentation, sensors, survey, wastewater

1. INTRODUCTION

The importance of process automation at municipal WWTPs has increased as treatment requirements have tightened and the processes have therefore become more complicated. Since the implementation of the European Directive 91/271/CEE regarding urban wastewater treatment, environmental water protection has gained increasing public awareness among European Union Countries. The treatment requirements for the WWTPs are determined together with national legislation based on the implementation of the European Directives, depending on the sensitivity of the receiving water body in terms of eutrophication, especially for nitrogen removal requirements. For instance, a special concern is shown at the Baltic Sea, which is designated as a “Particularly Sensitive Sea Area” by the United Nations’ International Maritime Organisation (IMO). In the Baltic Sea Action Plan annual nutrient reduction targets are allocated for each of the nine Baltic coastal nations (Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden) based on the nutrient reduction needs compared to the loads during the period 1997–2003. In particular, the phosphorus and nitrogen load reductions allocated for Finland are 150 and 1 200 tons per year respectively [7]. A significant share of the total nutrient load to water systems caused by human activities originates from municipalities. Here, the shares of phosphorus and nitrogen loads from municipalities were, respectively, 5.0% and 15.1% of the total nutrient loads caused by human activities in 2005 [17].

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The necessity of cost-efficient and reliable treatment processes has considerably increased in order to meet the continuously more stringent level of environmental regulations and, on a larger scale, to achieve the challenging national targets for nutrient load reduction into water bodies. As a result of these regulations, major upgrading and new construction works have taken place, in particular for more efficient nutrient removal. Implementing more advanced Instrumentation, Control and Automation (ICA) system represents the right way of renovating a WWTP, leading to the more optimal use of the unit processes. Moreover, on-line measurements and controls based on them are essential in the flexible and cost-effective operation of modern nutrient removal plants.

State-of-the-art surveys on ICA at WWTPs have been performed over the years with the perspective of different countries. Starting with one of the first overviews of ICA in the Scandinavian countries [14] and at the same time in the United States [4], interest in the implementation of automation in WWTPs has been progressively growing. An international survey was provided by Ingildsen [9], giving an interesting picture of the actual utilization of sensors and controls in the plants based on key performance indicators. Jeppsson *et al.* [10] took the point of view of European country conditions, where the focus was on the level of instrumentation used in plants larger than 50 000 p.e. for on-line control. Also, ICA surveys of the water sector on a national level have been conducted, e.g. in the Republic of Korea [12]. Lately, the international ICA situation has been summarized and updated by Olsson *et al.* [15], whose main conclusions were that a well-established level of automation based on the physical variables and basic control of dissolved oxygen (DO) has been reached, while control based on more advanced sensors is still in its initial stages.

In a similar attempt, the aim of this paper is to review the current status of ICA in municipal WWTPs in Finland, also as part of a technical report [5]. The method of investigation was based on a questionnaire including key elements regarding plant design, operation and utilization of ICA, and operator's opinion which was sent to large, medium-sized and small WWTPs. The paper is organized as follows. In the next section, the basic concepts of modelling and control are briefly reviewed. The research methodology is described in detail in Section 3.1. Then, the present operational conditions of the investigated Finnish plants are reported in Section 3.2 and the status of ICA is assessed in Section 3.3. Finally, Section 4 provides some general conclusions.

2. GENERAL OVERVIEW ON MODELLING AND CONTROL OF WWTP

The aim of this section is to provide a general overview on process modelling and control, with particular emphasis on their application to wastewater treatment processes.

The typical components of a simple single-input and single-output (SISO) feedback control loop are presented in Figure 1. Overall control system performance depends on the proper choice of each component of a control loop.

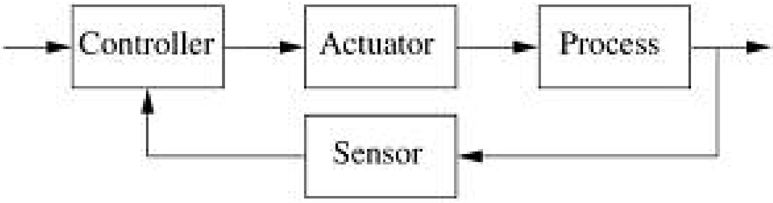


Figure 1. The typical components of a SISO feedback control loop.

The formal representation of the *process* has been done via a mathematical model, which attempts to find analytical solutions enabling the prediction of the behaviour of the system from a set of parameters and initial conditions. Modelling techniques include statistical methods, computer simulation, system identification, and sensitivity analysis; however, each one of these is as important as the ability to understand the underlying dynamics of a complex system.

With respect to the biological processes in a WWTP, the development in the family proposed by the International Water Association (IWA) represents a major contribution. The models of the ASM family (ASM1, ASM2, ASM2d, ASM3) [8] are used in most of the modelling and simulation studies, and also in the commercial simulation platforms. In an international activated sludge modelling survey 80% of the respondents used ASM models for various purposes [6]. In today's practice, Takács' model [20] is the most widely used mathematical representation of the clarifiers. Also models for anaerobic sludge digestion (e.g., ADM1 [1]) exist and interfaces for wastewater and sludge treatment process models have been developed in order to enable plant-wide modelling and optimizing [13]. In simulations the mathematical equations of a process model are solved and the dynamic behaviour is given as the result.

The knowledge of the process through its mathematical representation constitutes the first steps for *model-based process control*. Generally speaking, the objective of a control system is to make the process output behave in a desired way by manipulating the plant inputs by actuators such as valves and pumps. This leads to favourable process conditions for the demanded results and cost-effective process operation. In modern WWTPs processes such as aeration, chemical feeds and sludge pumping are usually controlled by on-line sensor measurements.

Two types of algorithms predominate in WWTPs, and in the process industry in general, the on-off and the Proportional-Integral-Derivative (PID) algorithms. *On-off controllers* provide simple, inexpensive feedback control in which a controller switches an actuator between two stages according to sensor measurements and a control law. Thus, the controlled variable is kept within certain limits. The control of the pumps in the return and excess sludge flow control loops are typical examples of on-off controllers in wastewater treatment. The *PID control* algorithm is a feedback control method in which the controller output is proportional to the error (P), its time history (I), and the rate at which it is changing (D). Although many advanced control systems have been proposed, conventional PID control algorithms are the most popular in WWTPs.

A feedback controller does not take corrective actions until after the disturbance has upset the process and generated an error signal. Sometime, if the influent characteristics and flow rate (disturbances) are measured and it is possible to calculate the required change in airflow (manipulated variable) supplied to an activated sludge process to maintain constant DO concentration (controlled variable), a *feedforward control* can be implemented. In practical application, feedforward control is normally used in combination with feedback control; this combination can provide a more responsive, stable and reliable control system. Combined feedforward and PI control has been proposed, e.g., for external carbon flow control [18] and DO concentration control [22] in activated sludge processes.

An alternative approach to feedback control, that can significantly improve the dynamic response to disturbances, employs secondary measurement points and a secondary feedback control. The secondary measurement point is located so that it recognises the upset condition sooner than the controlled variable, but the disturbance is not necessary measured. This approach is called *cascade control*: one feedback controller, identified as the *primary loop*, is used to calculate the set-point of another feedback controller that represents the *secondary loop*. A cascade controller has been used for instance to regulate the effluent nitrate concentration in the pre-denitrifying process by manipulating the external carbon dosage [2].

Advanced control strategies are found in WWTPs, for instance, *model predictive control* (MPC) based on choosing future adjustments of the manipulated variables, is used in effluent nitrogen concentration control [19] and DO control [3]. *Fuzzy logic* has been applied, e.g., for controlling the sludge blanket level in the secondary clarifier [21], nitrate recirculation flow rate and external carbon addition in an activated sludge process [16], and for optimizing volume distribution in each stage of a step-feed process [23]. The control is made in terms of a rule base that performs operations on the fuzzy sets and interference. Eventually, *artificial neural networks* (ANN), information-processing paradigm inspired by the way biological nervous systems process information, have great potential in control of wastewater treatment processes in general and anaerobic sludge digestion in particular [15].

Process control needs *sensors* and *analysers* for continuous on-line implementation. Common sensors are reported in Table 1, their increasing usage in WWTPs gives rise to an important improvement in operating safety and better operational economy [15]. In particular, the traditional nutrient sensor technology is based on automated laboratory methods, it requires sample flow without suspended solids (SS) which represents to some extend the weakness in the on-line measurement: the sampling, filtering and possible pre-treatment of the sample stream. The latest reagent- and sampling-free technology for measuring ammonia and nitrate concentrations is based on ion-selective electrodes and photometry respectively. When needed measurements are not available on-line, in a successful manner, they can be estimated with a *soft-sensor*, which represents a combination of robust hard-sensors and a mathematical model defined to reconstruct the time evolution of the unmeasured states. Such tools can also be used for helping the operator or a supervision system to take the appropriate actions to maintain the process in good operating conditions, diagnose possible process failures or prevent accidents.

Table 1. Commonly used measurements in WWTPs [15].

Flow	Sludge concentration
Level and pressure	Sludge blanket level
Temperature	Nutrients (NH_4-N, NO_3-N, PO_4-P)
pH	Total N and P
Redox potential	Organic matter with UV absorbance
Conductivity	Fluorescence
Oxygen	Biogas (CH_4, CO_2, volume)
Turbidity	

Finally, in the control loop *actuators* such as valves, pumps and compressors are operated according to controller outputs in order to keep the controlled variable at its set-point. The flow rates of gases, liquids, sludges and solids are controlled with the actuators. The control valves are fully or partially opened or closed in response to the signals received from controllers. Valves may be controlled manually, electrically, pneumatically, mechanically, hydraulically, or by combinations of two or more of these methods. Especially the following factors require consideration when selecting valves for wastewater treatment applications: pressure drop, maximum flow rate, rangeability, sensitivity, linearity, and hysteresis. The efficiency and flexibility of compressors, pumps and valves are crucial aspects in order to have proper control of the process.

3. RESEARCH METHODS

3.1 Methodology

The method of investigation was based on a questionnaire carefully prepared in co-operation with Finnish wastewater treatment experts and by utilizing the information of an extensive WWTP survey previously conducted in Finland [11]. In the questionnaire, key aspects regarding plant design, operation, and a more specific part on ICA were included. Questions that arose concerning ICA were, for instance, about sensors, automatic analyzers and their use for on-line control, type and usability of different controls, advanced controllers and process modelling, as well as the plant operators' attitude towards ICA. The questions also concerned the configuration and operation, removal requirements, the share of industrial wastewater, wastewater temperature, chemical use and electricity consumption. Further, the major problems and future expectations for WWTPs were queried. Altogether there were questions on thirty-one topics in the questionnaire, some of which were divided into several sub-questions. The answers to the questionnaire concerned either year 2006 or 2007. Altogether 24 of the investigated large (> 100 000 p.e.), medium-sized (30 000 – 100 000 p.e.) and small (< 30 000 p.e.) plants answered the questionnaire, establishing a response rate of 70%, and nine of those were visited. Nine plants were chosen as a representative group of Finnish municipal WWTPs of different scales, and *in-situ* investigations were organized. During the visits further details and observations on treatment processes and ICA technology were obtained. Altogether 11% of the questions in the returned questionnaires were left unanswered, the majority of them being open questions.

3.2 WWTPs in Finland

The design of the plant has consequences for the plant efficiency and performances, and for this reason, plant design questions were investigated first. All except one of the WWTPs considered in the survey consist of activated sludge processes, with different configurations and basin shapes, where the main objective is total nitrogen removal (in 13 plants), ammonia removal (in five plants) and organic matter removal (in six plants). Phosphorus removal is considered as another important objective for the operation of all the WWTPs. It is typically carried out by chemical precipitation; only at two of the plants enhanced biological phosphorus removal is used. The WWTPs studied have been in operation from 7 to 54 years; however, all the plants excluding the newest one were renovated during the 2000s.

Typically, the wastewater treatment line of a Finnish WWTP consists of screens, a sand trap, primary clarifiers, activated sludge basins and secondary clarifiers. Moreover, some of the plants have a tertiary treatment, and an equalization basin or a middle clarifier. Flotation is the most common tertiary treatment unit in use at four of the WWTPs included in this study, while post-filters are used as a tertiary treatment process at two plants. Further, in one of the WWTPs considered there is a carrier process. The biological treatment process configuration varies in the different plants as shown in Table 2. The total quantity of the processes in the table does not match the main objectives of the plants given in the beginning of this section because several respondents selected more than one of the given process options.

Table 2. Number of different nitrogen removal processes.

Type of treatment process	Number
Pre-denitrification	6
Simultaneous nitrification / denitrification	6
Post-denitrification	2
Alternate nitrification / denitrification	3
Only nitrification	4

The average design flow rate at the WWTPs is 38 300 m^3/d and the average maximum design flow rate is 71 600 m^3/d. The average current flow rate at the WWTPs considered is 29 200 m^3/d; however, the flow rates of the plants differ substantially with the range of average flow rates from 2 150 to 260 000 m^3/d. In addition, the proportion of current flow rate to design flow rate varies from 35 to 104%, the average being 69%. The key figures (average, median, minimum, maximum) relating to operation of the WWTPs and quality of wastewater are presented in Appendix A.

As key performance number for the ratio of the sludge production as dry solids and the influent BOD_7 load was calculated. The result was 1.2 kg TS/kg BOD_7 on an average and the standard deviation being 0.53 kg TS/kg BOD_7. The dry solids content of sludge varies from 6 to 32% while the average value is 24%. The results for sludge productions (tn/a) as dry solids and flow rates at WWTPs are presented in Figure 2. The high sludge production given for plant No. 4 can be explained by the remarkable amount of the excess sludge of the small treatment plants, and septic tank and cesspit sludges treated at the central WWTP considered. The mean sludge age used in plant operation during wintertime is 13.5 d and during summertime 9.5 d. Additionally, 10 of the plants are operated according to target sludge age and 11 according to target sludge concentration in the activated sludge basins. Regarding the share of industrial wastewater (e.g. from food, paper, chemical and textile industries) 10.5% of the influent flow rate and 19.8% of the influent load were found to be average values in the considered plants. The average concentrations of influent wastewater at 16 of the studied WWTPs are presented in Table 3; the influent concentrations of eight plants are missing because they were not delivered with the questionnaire. The average COD/N ratio of the influent is 11.9, which is considered low for a denitrification process without the use of an external carbon source.

Table 3. Average concentrations of influent wastewater.

Substance	BOD_7	COD_{Cr}	Tot. N	NH_4-N	Tot. P	SS
Concentration [mg/l]	248	582	48.0	35.0	8.3	297

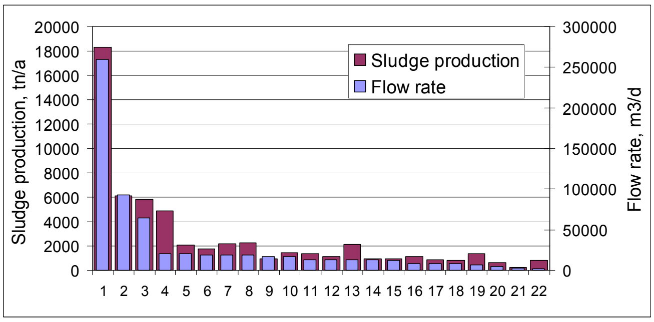


Figure 2. Sludge productions and flow rates at WWTPs.

Low temperature of municipal wastewater is typical in Finland: the mean wastewater temperature is 12.3°C and the average time, when the temperature of wastewater is above 12°C, is 6.2 months during a year. The usual problematic conditions at Finnish WWTPs are snowmelt and heavy rain; in such a situation, the influent flow rate is often too high, and for that reason also bypasses controlled manually by the plants operators are common. In fact, at eight of the investigated plants the biological part of the treatment process was bypassed at some time during last year, whereas the whole process was bypassed at 10 plants, and only at six of the WWTPs were no bypasses done. The removal requirements of 20 WWTPs were always fulfilled during the year of the survey, while the regulations of three plants were violated. One of the WWTPs did not answer the question about fulfilling the requirements.

The operation of the plant is associated with various costs, such as chemical and energy consumption. The consumption of precipitation and alkalinity chemicals as well as external carbon source varies from plant to plant. The average dosages of the most used chemicals at the investigated plants are presented in Figure 3a. The most commonly used precipitation chemical in Finnish WWTPs is ferrous sulphate, which is in use at 14 of the plants with an average dosage of 128 g/m^3, whilst ferric sulphate is used in nine plants. In addition to the precipitation chemicals shown in Figure 3a, also polymer is used for precipitation at four plants and aluminium chloride at two plants. Polymers are fed into secondary clarifiers and used together with ferrous or ferric sulphate.

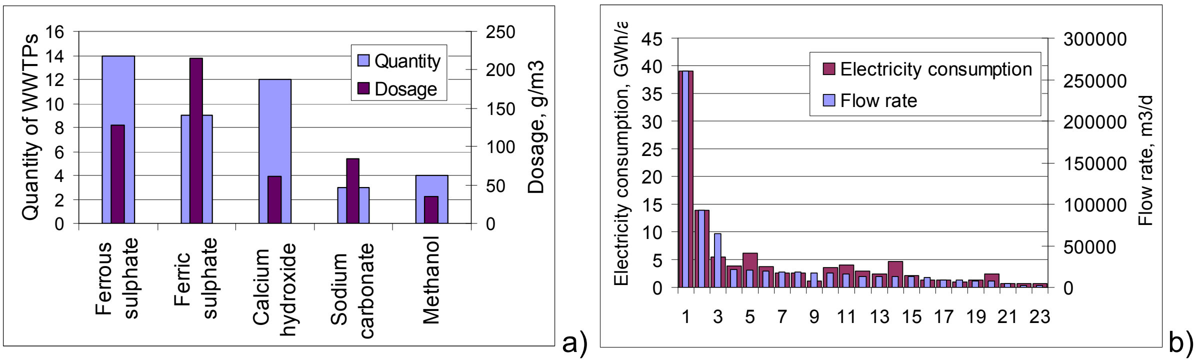


Figure 3. Quantity of WWTPs using different chemicals and average dosages of the chemicals (a). Electricity consumptions and flow rates at WWTPs (b).

From Figure 3a, it can be seen that calcium hydroxide is the most used alkalinity chemical (12 plants); sodium carbonate is used at three of the plants; methanol is used as an external carbon source at four of the WWTPs. At most of the plants with a total nitrogen removal process an external carbon source is not used; several of the plants are able to utilize carbon-rich industrial wastewaters from, e.g. breweries or dairies as a carbon source for denitrification. The range of methanol dosage is 23 – 56 g MeOH/m^3 the average dosage being 35 g MeOH/m^3.

The electricity consumption per influent flow rate ranges from 0.17 to 1.00 kWh/m^3. Additionally, seven of the WWTPs were able to specify the amount of electricity consumed by aeration, with the average share being 43.1% of the total electricity consumption. Furthermore, the average electricity consumption of the biological part of the plant is 54.6% of the total electricity consumption at five plants able to define the number. The average consumption of sludge treatment of the total electricity consumption at eight of the plants is 5.8%. Six of the plants also produce electricity on-site using biogas derived from sludge digestion; on average they produce 34.8% of the electricity consumed at the WWTP. The highest electricity production rate among the plants considered is 49% of the electricity consumed. The answers for electricity consumption and flow rates at WWTPs considered are presented in Figure 3b. It can be seen that there are a few plants with substantially different electricity consumption. The reasons for this are various; e.g. plant No. 3 in Figure 3b is the largest plant considered with only an ammonia removal requirement, plant No. 9 is a simple process with no nitrogen or ammonia removal requirement, and plant No. 14 is a carrier process, the configuration and operation of which differ from normal activated sludge plants.

3.3 Status of ICA in Finland

In this section, the results of the survey regarding the present condition of modelling, monitoring and control at the Finnish WWTPs are reported and analysed.

Sensors

A sensor inventory was given in the distributed questionnaire and the plants were asked to identify the variables continuously measured and monitored. Altogether 18 different wastewater characteristics are measured on-line at the 24 WWTPs considered. The number of WWTPs at which sensors and on-line analyzers are used and the number at which those are used for control are presented in Figure 4a. DO, SS, temperature, pH and level sensors are established technology at WWTPs; the operators consider them to function well apart from the SS and pH sensors (Figure 4b). Presumably the reason for this is the use of SS and pH sensors in activated sludge basins in which there is a high concentration of solid matter. SS measurements are used, e.g. for return sludge pumping control. During the plant visits it was pointed out that optical DO sensors have become more common at Finnish WWTPs and the plant operators find them more reliable and easier to maintain than galvanic and polarographic DO sensors.

Fourteen out of 24 plants use nutrient on-line analyzers (NH_4-N, NO_3-N and PO_4-P), but their usage in control is not common even though the operators generally consider the sensors to function properly (Figure 4b). The nutrient sensors are mainly in use at the plants that have a total nitrogen removal requirement. Moreover, the most modern on-line nutrient analyzers at the WWTPs visited are calibrated automatically. The usual locations for nutrient analyzers are the activated sludge basins and effluent, but NH_4-N analyzers are also used in other parts of the process, e.g. primary clarifiers and influent at some of the plants.

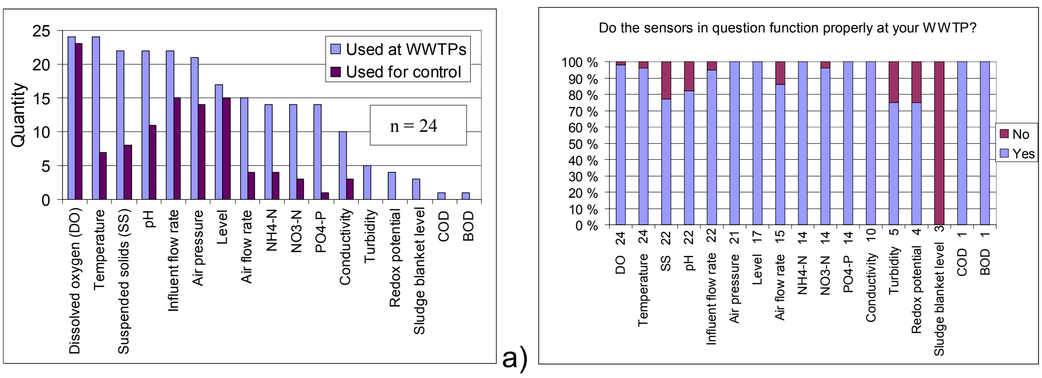


Figure 4. Number of WWTPs using sensors and on-line analyzers and their use for control (a). Functionality, number and type of sensors and on-line analyzers (b).

Air flow rate and air pressure sensors are common technology at WWTPs; measurements of both sensor types are used in aeration control. Conductivity sensors are in use at 10 plants; they are used, e.g. for monitoring industrial wastewaters and, at one of the plants, for predicting the nitrogen load coming to the activated sludge basins. Turbidity, sludge blanket level and Redox potential sensors are used in a small number of the WWTPs considered. Even so, none of the operators at the three WWTPs at which sludge blanket level sensors are used consider them to function properly.

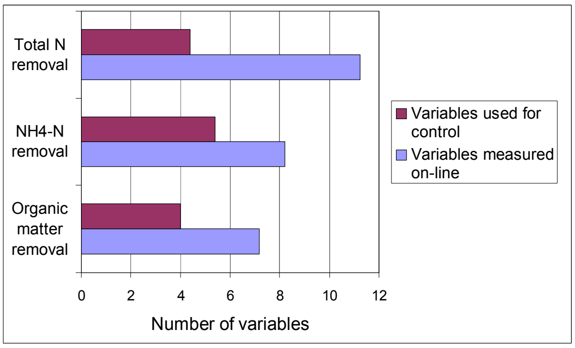


Figure 5. Average number of variables measured on-line and variables used for control at WWTPs with different treatment requirements.

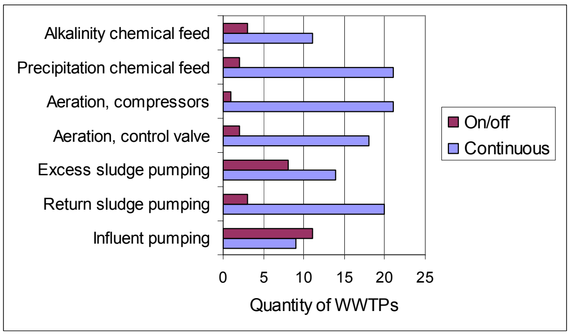
Average numbers of the variables measured continuously on-line and the variables used for control at WWTPs with different nitrogen compound treatment regulations are presented in Figure 5. At the plants with total nitrogen removal process 11.2 variables on average are measured continuously; furthermore, 4.4 of the on-line measurements of the variables are used for control. The average number of continuously measured variables at the WWTPs with ammonia removal requirements and organic matter removal requirements (no nitrogen or ammonia removal requirements) are 8.2 and 7.2, respectively. The on-line measured variables used for control at the plants with ammonia removal requirements and organic matter removal requirements are 5.4 and 4.0 on average. Uncertainty for the unexpected situation in which more continuously measured variables are used for control at the ammonia removal processes compared with the total nitrogen removal processes is caused by the difference in the numbers of the two processes considered, that is five and 13 respectively.

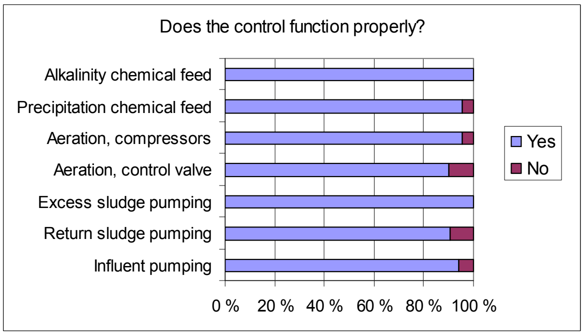
Control

The most applied method of aeration control is DO profile control, which is used at 18 of the plants. In the DO profile control, the aeration basin is divided into several zones in which the DO set-points differ and several sensors are used for the DO concentration on-line measurements. At five of the WWTPs, aeration control is based on one on-line DO measurement, whereas at one plant also automatic NH_4-N measurements are used for aeration control. At two of the large plants, the quantity of aerated and non-aerated zones is automatically defined. The average DO set-point at the nine WWTPs that were visited was 2.6 mg/l.

The plant operators were asked about the control types (on/off or continuous control), the range of the controls and the functioning of the controls. The answers are reported in Figure 6a, while

Figure 6b summarizes the functioning conditions of the controllers used. Apart from influent wastewater and excess sludge pumping, the majority of the controls are continuous. Also a pair of other controls not shown in the figure (polymer feed, methanol feed, neutralizing influent wastewater) is mentioned in a few replies. The plant operators consider the control ranges for most of the controls to be suitable even if, according to their opinion, the most common problem with the control range is the precipitation chemical feed.



a)


b)

Figure 6. Number of on/off and continuous control (a). Functioning of the controls at WWTPs (b).

The major part of the control at the WWTPs is implemented by using basic feedback controllers, the tuning being done from the control room by the operators. Advanced controllers, such as adaptive controller, fuzzy logic controller and model predictive controller, are in use at six plants for different purposes such as air flow control in aeration, mass flow rate control of return sludge, centrifugal sludge dewatering, methanol feed, and precipitation chemical feed. Fuzzy logic is also used in predicting the nitrogen load entering the activated sludge basins at one WWTP.

The alarm management was investigated and as a result it was found that different levels of alarms are taken into account, for instance indicating faults in the process equipment. Usually at modern Finnish plants the treatment process can be monitored and controlled remotely, e.g. on weekends, especially for alarm handling.

Modelling

Process modelling and simulation have been used at five of the plants; three of these have their own license for commercial software (being, GPS-X™ by Hydromantis the most popular). Three of the operators answered that modelling is also used to assist the process control; at one plant there is an expert system integrated into the process automation system and at the other two modelling is used off-line for creating control strategies. The operators mentioned studying different process operating possibilities, process design and supporting the start-up of the process as benefits of modelling software, whereas using modelling for dynamic set-point setting is considered one possible application in plant operation in the future. The plant operators found accurate model calibration rather challenging, which limits the use of models. In addition, the possibilities of using model predictive controllers have not yet been taken into account.

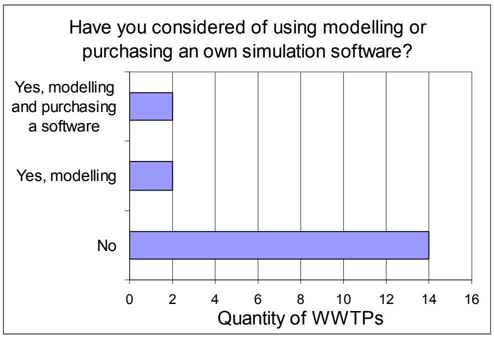


Figure 7. Opinions on using modelling and purchasing own simulation software at the WWTPs not working with modelling so far.

Figure 7 reports plant operator opinions on the usage of modelling and simulation software at the WWTPs, which have not yet been modelled. The majority of them have not so far considered using mathematical models representing their WWTPs.

5. CONCLUSIONS

An extensive survey on ICA conditions at large, medium-sized and small Finnish municipal WWTPs was carried out and the following conclusions were drawn: 13 of the plants consider that it would be possible to gain more from the current ICA equipment in use. From their opinions on the best way to make the plant more efficient the following stand out: (1) prediction of wastewater flow rate and load in real-time, (2) utilization of automatic on-line analysers in control, (3) better aeration control, and (4) more reliable on-line measurements. Infiltration into the sewage network, heavy rainfalls and snowmelts are named as the most important bottlenecks for improving the operation of the plant in four of the answers. Additionally, the maintenance of automation equipment and reliability of measurements are mentioned often.

Since the results in the latest European survey on the status of ICA at WWTPs larger than 50 000 p.e. [10], no significant changes have taken place in Finland regarding instrumentation and control. However, the reliability and accuracy of on-line sensor measurement have improved since the execution of the European state-of-the-art survey, which makes use of on-line measurements in control more applicable. The use of nutrient sensors in control is apparently still rare at Finnish WWTPs even though their use for monitoring purposes is common. It seems that approximately the same number of continuously measured variables is typically used for control even if the treatment requirements differ. Also, the popularity of dynamic process modelling has increased during recent years. At new and renovated Finnish plants conventional ICA technology is relied upon, apart from a few exceptions. The controllers used are PID feedback controllers and more advanced controllers are not often implemented. Even though the full potential of sensors and other ICA technology is not taken advantage of at most of the plants, the general attitude of plant operators towards ICA is one of interest and its importance in the future is understood. Otherwise, there are considerable differences between the level of automation technology and the knowledge of ICA at the plants. In the near future, new large and medium-sized WWTPs will be built in Finland. The possibilities of ICA should be given special attention in the design of the plants in order to optimize the operational costs. In addition, when renovating the existing plants, automation and control should be taken into account since, e.g. the manufacturers of sensors and analyzers are doing continuous development work. Advanced control strategies for nitrogen removal would be beneficial to implement as well as to investigate the possibilities of soft sensors and dynamic modelling in plant operation.

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Appendix A. Key figures of the WWTP survey in Finland

	Median	Average	Min	Max
Design flow rate, m^3/d	21 500	38 300	2 500	260 000
Max. design flow rate, m^3/d	37 200	71 520	15 120	600 000
Current flow rate, m^3/d	13 250	29 200	2 150	260 000
Current flow rate / design flow rate, %	68	69	35	105
Sludge age during winter, total N or NH_4-N removal, d	14.5	15.0	6.0	30.0
Sludge age during summer, total N or NH_4-N removal, d	9.5	10.8	5.0	20.0
Sludge age during winter, only organic matter removal, d	5.0	8.6	3.0	20.0
Sludge age during summer, only organic matter removal, d	3.5	5.4	2.0	10.0
Average temperature of wastewater, °C	12.3	12.3	8.7	16.0
Min. temperature of wastewater, °C	7.0	6.8	3.3	10.1
Temperature of wastewater above 12°C, months per year	6.0	6.2	1.5	11.0
Share of industrial wastewater of the flow rate, %	10.0	10.5	0	30.0
Share of industrial wastewater of the load, %	15.5	19.8	0	60.0
Influent COD / total N	11.0	11.9	8.9	18.4
Sludge production, kg TS/kg BOD_7	1.10	1.19	0.54	2.48
Dry solids content of sludge, %	23.6	23.5	6.0	32.0
Energy consumption / influent flow rate, kWh/m^3	0.47	0.51	0.17	1.00
Set-point of dissolved oxygen concentration in aeration, mg/l	2.5	2.6	2.0	3.1
Number of full-time employees	6	9.8	2	50