Status and future trends of ICA in wastewater treatment – a European perspective

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Abstract The status of instrumentation, control and automation (ICA) within the European wastewater community is reviewed and some major incentives and bottlenecks are defined. Future trends of ICA are also discussed. The information is based on a COST 624 workshop and a non-exhaustive survey with regard to ICA carried out in 13 European countries during March 2001. The level of instrumentation (type of sensors, usage frequency, etc.) and how these instruments are used for on-line control purposes are presented for each individual country (Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Netherlands, Romania, Slovenia, Spain, Sweden and Switzerland). The most common types of applied real-time control in wastewater treatment plants are given. One conclusion of the paper is that sensors no longer represent the main bottleneck for on-line control, rather the lack of plant flexibility is more troublesome. Moreover, the current transitional phase of the wastewater industry in Europe represents a unique opportunity to apply ICA on a large scale. The driving forces are simply too strong to ignore.

Keywords Automation; control; COST 624; ICA; instrumentation; sensors; status report; wastewater

Introduction

The public view concerning wastewater treatment within Europe (and the European Union in particular) is fairly positive. It is generally believed that effluent regulations are imposed, the quality of the receiving water bodies is improving and that authorities are taking the necessary steps to handle the problems. Unfortunately, this is not always the case. The EU Urban Water Directive (91/271/EC) adopted ten years ago, together with the newly adopted EU Water Framework Directive (2000/60/EC), define stringent requirements for urban wastewater treatment and a time frame for the step-wise implementation by the member countries. However, at a recent seminar the EU Environmental Commissioner evaluated the progress by the end of 1998 (http://europa.eu.int). It was stated that only two countries – Austria and Denmark – were almost in conformity with Directive 91/271/EC (with regard to compliance for agglomerations concerned by sensitive areas) at that time. Finland, Ireland and Sweden were in the conformity region of 50–75%; Italy, Luxembourg and Netherlands showed 25–50% conformity; Belgium, Greece, Portugal, Spain and UK below 25% conformity; France and Germany had not supplied sufficient information to allow for classification. Moreover, 37 major cities (>150,000 inhabitants) that had practically no wastewater treatment by the end of 1998 were identified. The “name-and-shame” list included cities such as Brussels, Cadiz, Dover, Dundalk, Hastings, Milan, Porto and Portsmouth. Consequently, a great deal remains to be done in the field of wastewater treatment, not only in Eastern Europe but also within the EU.

Similar conclusions with regard to the situation in the EU member states can be drawn from Figure 1, where the percentage of wastewater treated in 1990 is shown (Dornan, 1999). The situations in Canada, Japan, Norway, Switzerland, Turkey and USA are also indicated for comparison.

With regard to the situation indicated above, more extensive use of instrumentation, control and automation (ICA) in wastewater treatment (WWT) may offer an investment-friendly solution to many of the existing problems. Moreover, it will be shown that countries with the highest level of applied ICA are more or less the same as those that are highly ranked in Figure 1. To verify such a statement and to provide a more complete view of the ICA situation, this paper reviews the status of ICA within the European WWT community and defines some major incentives and bottlenecks. Future possibilities and trends within ICA are also discussed. The major part of the information presented here has been adopted from a COST Action 624 Working Group No 1 meeting in Vienna, Austria (May, 2000). COST is the European CO-operation in the field of Scientific and Technical research (http://www.belspo.be/cost) and information on COST Action 624 can be found at http://www.ensic.u-nancy.fr/COSTWWTP. A supplementary survey among the group members was also conducted during March 2001. Consequently, the information has been recently gathered by national experts with insights of local conditions and with access to the most up-to-date information. The paper includes contributions from nine EU countries and four non-EU countries, of which three are candidate states (see Table 1). Note that Southern Europe is not well represented in this investigation.

Constraints and driving forces for ICA

The primary purpose of ICA is to allow for efficient WWTP operation in terms of fulfilling effluent standards while maintaining operational (and capital) costs as low as possible. Although the main bottlenecks for implementing ICA technology within the WWT community vary between different countries, most of them are related to one of the following (partly from Olsson, 1993; Olsson *et al.*, 1998):

- poor legislation;
- inadequate education – training – understanding;
- lack of confidence and acceptance within the WWT industry;
- lack of collaboration between stakeholders/organisations;
- economy (and time to develop solutions in practice and making sure that they work);
- unreliable measuring devices;
- plant constraints and insufficient sewer systems;
- lack of transparency;
- lack of software and instrument standardisation.

New and sophisticated systems for ICA are often proposed in scientific journals but few are ever verified in full-scale applications. Here, the universities and research centres must

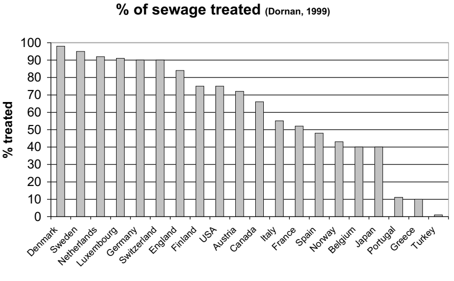

Figure 1 Percentage of sewage treated

Table 1 Contributing countries

Members of the EU	Non-members of the EU
Austria	*Candidate states*
Belgium (Flemish region)	Czech Republic
Denmark	Romania
Finland	Slovenia
France	
Germany	*Non-candidate states*
Netherlands	Switzerland
Spain	
Sweden	

play a much more active role in promoting their ideas and convincing the WWT industry of the benefits. Joint projects and closer collaboration could reduce the time lag from idea to implementation and prove beneficial to both parties.

Naturally, many of the listed constraints may be turned into driving forces given the right circumstances. The EU Water Directives represent an attempt to standardise and improve the legislation. Some economic factors are promoted in the new Directive, for example the "polluter-pays" principle and the aim to ensure that by 2010 water pricing policies provide adequate incentives for users to use water resources efficiently. Also, the new standard ISO 15839 will enhance comparisons of sensors and promote their standardisation (Nielsen, 2001). Otherwise, the main driving forces for ICA are most often related to:

- stricter effluent quality standards;
- demands for lower sludge production;
- economic incentives;
- reduce energy consumption and/or increase energy production;
- increased plant complexity (co-ordination of processes and loops, monitoring etc.) ;
- new treatment concepts, e.g. more compact plants, water reuse;
- new and cheaper technical solutions, e.g. computers, communications.

The EU Water Directives have created a drastic increase in the construction of new and upgrading of existing WWTPs in many European countries to meet stricter effluent quality standards. In fact, many persons found it troublesome to answer the survey because so many things regarding ICA and other aspects of WWT are changing so rapidly. This whole process of change will hopefully become an opportunity for ICA to prove its advantages on a larger scale. The main operational costs at a WWTP, which are only part of the total cost (including capital costs), are related to personnel, sludge production, consumption of chemicals and energy, and ICA has the potential of reducing all these costs. However, if operating cost savings alone must carry the investment costs of improving ICA, a cost–-benefit analysis will indicate only limited benefits. But if extra capacity is needed at a plant and it can be obtained by control instead of extension of reactor volumes, the economic benefit is enormous, often a factor of 5–20 compared to the conventional extension alternative (Nielsen, 2001). Herein lies the full potential of ICA.

A common perception is that sensors represent the weakest link for implementing on-line process control in WWTPs (Harremoës *et al.*, 1993). However, the performance and reliability of many on-line sensors (e.g. nutrient sensors, respirometers) have improved remarkably during the last decade (if maintained properly) and can today be used directly in many different control strategies (although on-line sensors are seldom accepted for effluent compliance verification). The possibility to apply estimation techniques and mathematical models to detect and compensate for faulty measurements, further enhances a more common use of such sensors. With on-line measurements the safety limits used in process design can be reduced and the efficiency and flexibility of plant operation can be improved. The probably most fundamental barrier for more widespread acceptance of new control strategies is that *existing WWTPs are not designed for real-time control*. This is clearly exemplified by the lack of flexible and controllable actuators. Moreover, initial plant designs guaranteeing high effluent quality without advanced control strategies have resulted in over-dimensioned plants. As effluent criteria become more stringent, increasing waste loads must be treated or sludge production must be reduced, use of ICA must be regarded as a valuable alternative to increased reactor volumes or other types of structural modifications. This would best be accomplished by involving competent ICA staff already in the design phase of new WWTPs as well as in planning any expansions of existing plants (i.e. control structure integrated design).

As stricter effluent quality standards are imposed, complexity of WWTPs tends to increase to meet these standards. However, when plant complexity increases, the need for ICA becomes more prominent and promotes use of ICA systems. However, an important incentive for ICA is also related to the time frame over which quality standards must be complied with. If standards are based on two-hour grab samples (e.g. in France and Germany), then WWTPs require more flexible operation in terms of disturbance rejection and handling dynamics (for which ICA is intended) than if standards are based on monthly or even yearly averages (as is the case in most other countries). In a few European countries (e.g. Belgium and Denmark) new economic incentives have been implemented during the last decade to promote better effluent quality (i.e. the plants pay a fee for every kg of organic material and nutrients released into the environment rather than simply paying for the amounts that are above certain limit values). Such systems would certainly promote ICA, since the payback time on ICA investments could be significantly reduced.

Many countries in Central and Eastern Europe are candidates to become full members of the EU within the near future and must then comply with EU environmental standards. In this case, the political process will be an incentive and most likely lead to significant investments in wastewater treatment in the future, although financing remains a problem. Czech Republic represents a particularly interesting case since most of the national water companies have been privatised and are now operated by large companies from the EU (i.e. Vivendi (France), Lyonnaise (France) and Anglian Water (UK)). The future will show whether or not this is the best way to proceed.

Status of ICA in Europe

Obviously, the use of ICA in Europe differs significantly between countries. Within the EU it is a fair generalisation to state that most WWTPs (>10000 p.e.) are equipped with SCADA (Supervisory Control And Data Acquisition) systems, although these may often be more used for data acquisition than for control. In Table 2, the level of instrumentation for the 13 surveyed European countries is shown (table format partly adopted from Köhne (1995)). The participants were asked to identify the variables that are “continuously” measured at WWTPs larger than 50000 p.e. in their respective countries and also indicate for what purpose the measurements are done. Note that the information presented below is not based on an exhaustive survey of national WWTPs but rather on estimates by a limited number of national experts.

The results in Table 2 demonstrate that the access to more traditional in-line devices (i.e. sensors placed directly in or in a side stream of the process and naturally providing on-line data) is fairly good in most countries, although their use for control purposes is quite limited for example in Czech Republic and Romania. The most common on an overall basis are sensors for temperature, water level, water flow and dissolved oxygen, but also sensors for pH, air flow and suspended solids are common. For on-line sensors the differences between the countries are more distinctive and their general use is still quite limited (a single + in Table 2 indicates that a sensor is either being tested or used in fairly uncommon types of processes). Denmark, Finland, Germany, Netherlands, Sweden and Switzerland appear to be the countries where sophisticated on-line sensors have gained the most frequent use. The most commonly used on-line sensors are nutrient sensors for ammonia and nitrate. There are several examples in Table 2 where expensive and maintenance-intensive on-line sensors are used only for monitoring. This may indicate insufficient use of sensors for relevant and money-saving control strategies, i.e. the sensors only cost money and report problems. Such instruments should be used for more elaborate purposes. The use of feed-forward control is also limited and primarily based on water flow measurements (i.e. controlling the return activated sludge flow rate proportional to the influent flow rate). In the opinion of the authors this implies that there is a significant margin to further improve

Table 2 Level of instrumentation at WWTPs (>50,000 p.e.) in Europe and the main purpose of the measurements, continued on next page (*usage:* +++ = normally used, i.e. standard, ++ = frequently used, + = seldom used; *used for:* M = monitoring, B = feedback control, F = feed-forward control)

	Austria		**Belgium**		**Czech Republic**		**Denmark**	
In-line sensors	Usage	Used for	Usage	Used for	Usage	Used for	Usage	Used for
Temperature	+++	M	+++	M	+++	M	+++	M
Conductivity	+++	M	+	M	+		+	M
pH	+++	M	++	M	++	M	++	M
Redox potential	+	M, (B)	+	M, B	+++	M, (B)	+	M, B
Air pressure	++		+	M	+		++	M, B
Water level	+++	M	+++	M, B	++		+++	M, B
Water flow	+++	M, B	+++	M, F	+++	M, (B)	+++	M, B, F
Air flow	++	M, B	++	M	++	M, (B)	++	M, B
Dissolved oxygen	+++	M, B	+++	M, B	+++	M, B, (F)	+++	M, B
Turbidity	+	M, (B)	+	M	+	M	++	M, B
Total suspended solids	+	M, B	+	M, B, F	++	M	+++	M, B
Sludge blanket level	+++	M, (B)	+	M, B	+	(M)	+	M, B
On-line sensors	Usage	Used for	Usage	Used for	Usage	Used for	Usage	Used for
BOD			+	M	+			
COD					+		+	M, B
TOC			+	M, B, F	+			
Ammonia	++	M, B	+	M	+	(M)	+++	M, B, F
Nitrate	+	M, (B)	+	M, B	+	(M)	+++	M, B, F
Total nitrogen					+		+	
Phosphate	+	M, (B)	+	M, B	+		+++	M, B
Total phosphorus					+	(M)	+	M, B
Respiration, activity	+++	M, B			+		+	M, B
Toxicity			++	M, F	+		+	M
Sludge volume index			+	M, F	+		+	M, B

(Table 2 continued)	**Finland**		**France**		**Germany**		**Netherlands**		**Romania**	
In-line sensors	Usage	Used for	Usage	Used for	Usage	Used for	Usage	Used for	Usage	Used for
Temperature	+++	M	+++	M	+++	M	+++	M	+++	M
Conductivity	+++				+++	M	+	M		
pH	+++	M, B	++	M	+++	M, B	++	M, B	+++	M
Redox potential	+++	M	++	M, B	++	M, B	+	M		
Air pressure			+++	M	+++	B	+			
Water level	+++	M, B	+++	M	+++	M, B	++	M, B	+++	M
Water flow	+++	M, F	+++	M, F	+++	M, F	+++	M, F	+++	M
Air flow	+	M, B	+++	M	+++	M, B	+++	M, B		
Dissolved oxygen	+++	M, B	++	M, B	+++	M, B	+++	M, B, F	+++	M, (B)
Turbidity	++	M	+	M	++	M	++	M		
Total suspended solids	+++	M	++	M	++	M, (B)	++	M, B	+++	M
Sludge blanket level	++	M, B	++	M	+	M, (B)	+	M, B	++	M
On-line sensors	Usage	Used for	Usage	Used for	Usage	Used for	Usage	Used for	Usage	Used for
BOD	+++	M			++	M, (F)	+	M, (F)		
COD	+	M			+	M	+	M, (F)		
TOC					++	M	+	M, (F)		
Ammonia	++	M, B	+	M	++	M, B, (F)	+++	M, B		
Nitrate	++	M, B			++	M, B	+++	M, B		
Total nitrogen					+	M	+	M		
Phosphate	+	M			++	M, B, (F)	+	M		
Total phosphorus	+++	M			+	M	+	M		
Respiration, activity			+	M	+	M	+	M, (B)		
Toxicity					+	M	+	M		
Sludge volume index	+++	M, B			+	M	+	M		

(Table 2 continued)	Slovenia		Spain		Sweden		Switzerland		Summary	
In-line sensors	Usage	Used for	Usage	Used for	Usage	Used for	Usage	Used for	Total	Average
Temperature	+++	M	+++	M	+++	M, B	+++		39+	3+
Conductivity			++	M	+++	M	+++	M	21+	1.6+
pH	++	M	+++	M	+++	M, B	+++	M	30+	2.3+
Redox potential			++	M	+	M	++		19+	1.5+
Air pressure	+	M, B	++	M	+++	M, B	+++	M, B	22+	1.7+
Water level	+++	M, B	++	M	+++	M, B	+++	M, B, F	36+	2.8+
Water flow	+++	M, F	+++	M, B, F	+++	M, B, F	+++	M, B, F	39+	3+
Air flow	++	M, B	+++	M, B	+++	M, B	++	M, B	28+	2.2+
Dissolved oxygen	++	M, B	+++	M, B	+++	M, B, F	+++	M, B	37+	2.8+
Turbidity			+++	M	++	M	+++	M	20+	1.5+
Total suspended solids			++	M	+++	M, B, F	+++	M, B	25+	1.9+
Sludge blanket level			+		+	M, (B)	+	M	17+	1.3+
On-line sensors	Usage	Used for	Usage	Used for	Usage	Used for	Usage	Used for	Total	Average
BOD			+	M	+	M	+	M	11+	0.8+
COD			+	M	+	M	+	M	8+	0.6+
TOC	+		+	M	+	M	+	M	9+	0.7+
Ammonia			+	M	+++	M, (B, F)	++	M, B	21+	1.6+
Nitrate			+	M	+++	M, B	++	M	19+	1.5+
Total nitrogen					+	M	+	M	5+	0.4+
Phosphate			+	M	++	M, B, F	++	M	15+	1.2+
Total phosphorus					++	M, (B)	+	M	10+	0.8+
Respiration, activity			+	M	+	M, B	+		11+	0.8+
Toxicity			+	M	+	M	+		9+	0.7+
Sludge volume index					+	M	+		9+	0.7+

the current control of WWTPs, as the potential benefits of feed-forward control are in many cases considerable compared to feedback control.

In Figure 2, the relative usage frequency of in-line and on-line sensors is shown together with the number of different types of on-line sensors used on a more regular basis (i.e. minimum ++ in Table 2) for individual countries. It is evident that a correlation exists between the number of sensors each country uses and the ranking of EU conformity and percentage of sewage treated (see Figure 1). Naturally, the correlation is not simply a result of applied ICA but rather a reflection of national policies, economic factors, public awareness, etc. However, the amount of ICA applied may certainly be used as a possible indicator for the general status of WWT on a national level. It is also a strong indication that when plant complexity reaches a certain level (e.g. primary, secondary and tertiary treatment combined), ICA becomes more inherent.

Based on the conducted survey it can be concluded that the by far most common type of applied real-time control (RTC) is controlling the oxygen concentration in the aerobic reactors based on DO measurements (feedback). The second most common involves

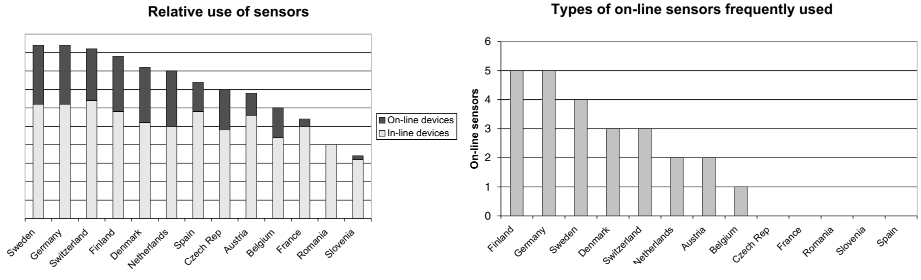

Figure 2 Relative usage frequency of in-line and on-line sensors (left) and the number of different types of on-line sensors used on a fairly regular basis (right) for individual countries

various types of flow-rate control. Various RTCs are summarised in Table 3. Note that the majority of large nitrogen-removal plants in Europe are based on recycling principles applying pre-denitrification. The exception is Denmark, where most of the large plants are alternating (Nielsen, 2001). Differences between countries are significant and Table 3 should be interpreted together with Table 2, i.e. if a country does not frequently use the required type of sensor then the indicated type of control does not apply.

Classification of control actions can be done according to several principles and Table 3 represents one attempt. Various measurements are sometimes combined, for example flow and concentration to calculate load, and controllers may use that information instead. Frequently, several control loops are applied simultaneously and are (hopefully) supervised by some overlaying rule-based system. The most common controller types are time

Table 3 Most common types of real-time control applied in large European WWTPs

Aeration by measuring	**Control handle**	**Comment and (usage, type of control)**
Dissolved oxygen (one or more sensors)	Air flow and/or pressure	Constant set point (+++, B)
Air pressure in common rail	Air flow and/or pressure	General air demand set point (+++, B)
Dissolved oxygen (multiple sensors)	Air flow and/or pressure	DO profile control (++, B)
Redox potential	Air flow and/or pressure	Primarily in SBR plants (++, B)
Respiration	Air flow and/or pressure	Standard in Austria (+, B)
Nitrification by measuring		
Ammonia at end of aerobic part	Dissolved oxygen set point	Also intermittent aeration, on/off (+, B)
Ammonia at head of aerobic part	Dissolved oxygen profile	Adjust to ammonia load (+, F)
Denitrification by measuring		
Influent flow rate	Internal recirculation flow	(++, F)
Nitrate at end of reactor	Internal recirculation flow	Use denitrification capacity (++, B)
Nitrate in anoxic part	Internal recirculation flow	Use denitrification capacity (+, B or F)
Nitrate in anoxic part	External carbon flow	Enhance denitrification (+, B or F)
Sludge inventory by measuring		
Influent flow rate	Return sludge flow	Ratio control (+++, F)
Suspended solids in reactor	Return sludge flow	Often constant MLSS (++, B)
Suspended solids in reactor	Waste sludge flow	Often constant MLSS (++, B)
Sludge blanket level	Return sludge flow	Standard in Finland (+, B)
Sludge age (indirectly)	Waste sludge flow	Normally manually (+, B)
Chemical additions by measuring		
Flow rate	Coagulants, polymers, P-precipitants	(++, F)
Phosphate	P-precipitants	Based on load (+, B or F)
Suspended solids	P-precipitants	(+, F)
pH	Lime addition	Mainly anaerobic digestion (++, B or F)
Others by measuring		
Influent flow rate	Internal flow distribution	Step-feed approaches (+, F)
Flow, levels, rain measurements	Influent buffering, storm tanks etc.	Including sewers, equalise influent (+, F)
Phosphate	Flow rates, acetate addition etc.	In bio-P processes (+, B or F)

based or variations of PIDs, however, the use of more advanced algorithms is increasing, e.g. fuzzy, neural-net and model-predictive control. Examples of plant-wide or integrated control (including sewer networks) are still scarce.

Future trends of ICA in Europe

For WWT in general in Europe the main focus in many countries during the next decade will be related to construction of new and upgrading of existing WWTPs to include N and P removal. Consequently, control of nutrient removing processes will remain an important issue. Apart from this, the main concern appears to concern sludge issues. Minimising sludge production (indicated by 8 countries in the survey) and treating the excess sludge in an effective and environmentally friendly way (e.g. recovery of phosphorus) will be a major field of research. Energy issues (5 countries) and previously not monitored low-concentration substances in water and sludge (e.g. micro-pollutants, endocrine substances, pathogens and new types of heavy metals; 4 countries) are other important topics (as well as minimising CSOs, water reuse and decentralised treatment). Regarding new process technologies, the highest expectations are directed towards membrane processes.

Based on the survey it can be concluded that there are still significant expectations for cheaper and more robust on-line sensors, particularly for nutrient measurements. The need for instrument redundancy and sensors with integrated data quality verification and fault-detection systems is significant. This is especially important to gain acceptance for ICA from plant staff. In addition to the more common types of sensors presented in Table 2 there is also a fairly rapid development towards new sensor technologies for water and wastewater applications (e.g. software sensors, combined on-chip sensors, on-line image analysis, quartz crystal micro-balance sensors, laser- and ultrasound based sensors, titration-based sensors, fluorescent DNA, antibody probes and other types of biosensors). Some of these sensors may allow more information to be gained about conditions within the biomass itself, rather than indirectly estimating such properties from measurements of oxygen, COD, nutrients, etc.

Within the field of control and automation there is a slow but steady trend towards more sophisticated tools for control (e.g. model-predictive control, fuzzy logic, neural networks, multivariate statistical analysis, on-line simulation). Which of these will gain more general acceptance is more difficult to predict. Software-based monitoring and detection are other areas of increasing importance. It is also a reasonable conclusion that WWT control is moving towards more use of multiple-input control. Moreover, ten countries replied that supervisory, process-wide, plant-wide and integrated control principles would be the main focus of ICA in 2010. The need for good local control (unit process control) is obvious but the problem of harmful sub-optimisation must be avoided. Consequently, the whole WWTP (if possible together with the sewer system and the recipient – indeed the entire urban water system) should be considered as one “unit”. However, ICA complexity is not a goal and it is important to realise that fairly simple yet creative control strategies (on-off or PID algorithms linking carefully selected sensors and actuators together and being supervised by an overlaying rule-base) are more easy to understand for an operator (transparency) and may well be what we will see in practise. As the use of ICA increases so does the need for operator understanding and information support systems. With regard to this there is another trend related to the possibilities of telemetry and high-speed digital communication. An increasing number of smaller WWTPs allow for remote monitoring and control, i.e. no (or limited) staff are required at the plant. Instead a group of experts may control the behaviour of many plants from one operations centre.

There exists a significant need for objective evaluation of different control strategies. The performances of strategies proposed in the literature are often demonstrated either by means of simulation or by real experiments in pilot- or full-scale plants. However, the results are in many cases troublesome to compare as they have been achieved using different mathematical models, different plant configurations, a variety of influent wastewater characteristics, etc. Consequently, it is often impossible to determine whether presented results are primarily due to local factors or if the control strategy is generally applicable. To remedy this – and simultaneously take advantage of sophisticated mathematical models, available computer power and the Internet – benchmarking is increasing in popularity. By defining a simulation environment including plant models, plant layouts, influent wastewater characteristics, evaluation criteria, test procedures, etc. and making it generally accessible, it is possible to set up a consistent and unbiased methodology and create a database for evaluation of control strategies (Spanjers *et al.*, 1998; Pons *et al.*, 1999; Copp, 2000). The importance of these and other software tools is likely to increase in the future.

A final conclusion from the survey is that ICA has an important role to play in future WWT. To the question “How do you judge the current use of ICA in WWT in your country?” seven responded “Much more could be gained” and six replied “More could be gained”. Moreover, ten responded “Strongly agree” and three “Mildly agree” to the statement “ICA will gain importance at WWTPs in my country in the next 5–10 years”.

Conclusions

Based on a (non-exhaustive) survey of 13 European countries, combined with the opinions of the authors, some conclusions regarding ICA in WWT in Europe are drawn and summarised below.

- *New and more reliable on-line sensors* are available and sensors are no longer the main bottleneck for ICA in practice. Instead the *lack of plant flexibility and controllability* may prove troublesome.
- Sophisticated sensors are available at many WWTPs but not used to their full potential (i.e. for control).
- *Economic demands* in combination with *stricter environmental regulations* will force plants to operate closer to their constraints, thus promoting use of ICA.
- *Increasing plant complexity* including many processes and loops inherently requires more ICA and in particular more need for integrated and plant-wide control.
- Countries applying the most ICA are identical to the ones with the highest degree of WWT in general.
- 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 regard to ICA is imminent!

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