CLEEN MMEA wp 4.1
Petri Nieminen

Automatic monitoring in wastewater treatment plants and reclaim of sludge

1. INTRODUCTION

One of the most significant challenges in wastewater management is the handling of sewage sludge (hereafter sludge). Sludge is a residue which is produced in wastewater treatment processes where solids are being separated from the water. Water is later on discharged to aqueous environment, while solids are removed for further treatment and final disposal (Fytili & Zabanitou 2008). Solids produced in waste water treatment plants include grit, screenings and sludge, latest being by far the largest in volume of the three. For example in Finland, 160 000 tonnes of dry matter (DM) sludge is being formed annually (Pöyry Environment 2007). It may be regarded both as a threat to the environment and as a resource which should be recycled in a proper way. Sludge contains nutrients (e.g. phosphorus and nitrogen) and organic and inorganic compounds which can be reused in agriculture, energy production and in building materials, for instance (Rantanen *et al.* 2008). But on the other hand, it contains harmful substances such as heavy metals, organic pollutants and pathogens which limit the possibilities of its use (Rantanen *et al.* 2008). Therefore, sustainable sludge handling has to meet the requirements of efficient recycling of resources, and also prevent the dispersal of harmful substances to the environment. Due to its nature, the handling and disposal methods of sludge are a matter of concern and its usage is regulated in the European Union.

The institutional system of EU is formed by three main institutions: the Council of the European Union, the European Parliament and the European Commission. The Parliament and the Council share the power to legislate (e.g. Directives), whereas the Commission has the task to promote and propose draft legislation, for example on environmental issues. Since 1971, Environment Action Programs have given direction to the work of the European Commission in environmental issues. The present, 6th Environment Action Program (2002-2012) has set out key objectives to be achieved in four priority areas: climate change, nature & biodiversity, environment & health and natural resources & waste. 7th Environment Action Program is currently in discussion.

EU Directives should be applied and implemented in the member countries, and in many cases their requirements are made stricter in national legislation (Gómez Palacios *et al.* 2002, Rantanen *et al.* 2008). The Directives provide a framework for national regulations, and the member states can have their own way in achieving their objectives. For example for the wastewater effluent quality, the member states have had the right to decide their own parameters and reduction limits (Kattainen 2012), as long as the outcome of the actions is such that the EU Directives demand. The Urban Waste Water Treatment Directive (91/271/EC) together with the Water Framework Directive (2000/60/EC), define the main requirements for urban wastewater treatment in the European Union (Table 1). By creating stricter effluent quality standards, EU Directives have caused an increase in the construction of new and upgrading of the existing wastewater treatment plants in many European countries during the past few decades (Jeppson *et al.* 2002). In the EU countries, the most common parameter to be measured during the waste water treatment processes is biological oxygen demand (BOD), but limits for phosphorus, nitrogen and total suspended solids (TSS) are also rather common in legislation (Kattainen 2012). Depending on the country, these limits are given by national legislation; national recommendations; or regional/county/municipal orders (Kattainen 2012). According to Industrial Emissions Directive (2010/75/EC) (Table 1), industrial wastewater emissions and industrial sludge (e.g. pulp and paper industry) should be treated with best available techniques (BAT) in order to minimise the pollution.

Table 1. Different EU directives concerning waste water management. Table modified from the one presented by Kattainen (2012).

Directive	**Objectives**
91/271/EEC Urban Waste Water Directive	To protect the environment from the adverse effects of wastewater discharges
2000/60/EC Water Framework Directive (WFD)	To achieve 'good status' in water bodies by 2015.
2006/118/EC Groundwater Daughter Directive to WFD	To prevent and control groundwater pollution.
2008/105/EC Directive on Environmental Quality Standards	To limit the presence of certain substances/pollutants in surface waters.
2010/75/EC Industrial Emissions Directive (IED)	To minimise pollution from various industrial sources.
80/68/EEC Groundwater Directive dangerous substances	To prevent the pollution of groundwater by certain substances/pollutants.

The main article concerning sludge in the Urban Waste Water Treatment Directive is Article 14, where it is declared that ‘‘sludge arising from the wastewater treatment shall be re-used whenever appropriate’ (Fytili & Zabanitou 2008). This Article is in line with the main objectives of fundamental EU Directives concerning waste management, such as the Waste Framework Directive (2008/98/EC) and the Landfill Directive (1999/31/EC). Their main objectives are: 1) reduction of waste generation, 2) increase of material recycling and recovery, 3) energy recovery, and 4) reduction of direct disposal of organic waste. Consequently, the EU waste management policy can be summarized in few key principles (Gómez Palacios *et al.* 2002):

- *“Prevention principle”*: production should be minimised whenever possible.
- *“Producer responsibility & polluter pays principle”*
- *“Precautionary principle”*: Prediction of possible problems.
- *“Proximity principle”*: Waste treatment and disposal should be near to its generation site.

The Sewage Sludge Directive (86/278/EEC) (Table 2) regulates the agricultural use of sewage sludge in the EU. According to this Directive, sludge must be treated before its agricultural use. It sets limit values for the concentration of seven different heavy metals (cadmium, copper, nickel, lead, zinc, mercury and chromium) in sludge and soil. However, after 20 years of its adoption, the Directive is rather outdated. As scientific knowledge in the effects of sludge use on land has increased, many member states have implemented much stricter limit values for heavy metals as well as for contaminants which are not addressed in the Directive (Rantanen *et al.* 2008). Update for this Directive has been in consideration for several years.

Table 2. Different EU directives concerning sludge usage and disposal. Table modified from the one presented by Rantanen *et al.* (2008).

Directive	**Objectives**
86/278/EEC Sewage Sludge Directive	To regulate the use of sewage sludge in agriculture in a way that prevents harmful effects on soil, vegetation, animals and man.
91/271/EEC Urban Wastewater Directive	To protect the environment from the adverse effects of waste water discharges
91/676/EEC Nitrate Directive	To prevent and reduce water pollution caused or induced by nitrates from agricultural sources
1999/31/EC Landfill Directive	To prevent and reduce negative effects on the environment from the landfilling of waste.
2000/76/EC Waste Incineration Directive	To prevent and reduce air, water and soil pollution caused by the incineration of waste.
2008/98/EC Waste framework directive	The framework for the collection, transport, recovery and disposal of waste

The main demands of the EU directives are being supported by European standards which are developed in the European Committee for Standardization (CEN). European standards should be included to the collection of national standards without change and should be taken into use in member countries within the time limit that has been set for them. At the same time, contradictory national standards should be removed (Kattainen 2012). The actual work of CEN is carried out in technical committees. For example, CEN technical committee 308 works with wastewater sludge issues and has released codes of good practice for different use and disposal routes of sludge as well as standards for the analytical characterization of sludge (Table 3).

Table 3. Some relevant CEN Standards and Technical reports (Technical Committee 308) concerning wastewater sludge (Gómez Palacios *et al.* 2002).

Doc. Number	Title
EN 5667-13	Sampling of sludges
EN 12176	Determination of pH-value of sludges
EN 12879	Determination of the loss on ignition of dry mass
EN 12880	Determination of dry residue and water content
EN 13342	Determination of Kjeldahl nitrogen
EN 13346	Aqua regia extraction for determination of trace elements (h. metals)
EN 12832	Terminology and sludge types
CR 13097	Good practice for sludge use in agriculture
CR 13714	Good practice for sludge production in relation to use or disposal

2. AUTOMATIC MONITORING IN WASTE WATER TREATMENT PLANTS

Wastewater treatment may be divided into three main stages: primary, secondary and tertiary treatment (Ren 2004). Primary treatment refers to the removal of insoluble matters such as grit, grease and scum from water by screening and/or sedimentation. Secondary treatment removes oxygen-demanding organic matter, usually by the action of microorganisms. Tertiary treatment further removes suspended solids and dissolved organic and/or inorganic materials from the effluent of secondary wastewater treatment (Ren 2004). The most applied secondary wastewater treatment method is the activated sludge process (Gernaeu *et al.* 2004). Activated sludge refers to biological treatment processes where bacterial biomass suspension is responsible of lowering down BOD and the removal of nitrogen, phosphorus and suspended solids. In an activated sludge system, a proper balance between the amount of food (organic matter), organisms (activated sludge) and oxygen (dissolved oxygen) must be maintained in order to obtain desired level of performance. Hence, operation of the activated sludge process requires operator control: the operator must adjust aeration, return rates and waste rates to maintain the balance of food, organisms and oxygen. There are several factors that can affect the performance of an activated sludge treatment system. These include for instance: temperature, return rates, amount of oxygen available, amount of organic matter available, pH, waste rates, aeration time and wastewater toxicity. Instrumentation, control and automation (ICA) may help to achieve optimal performance of the processes in a plant (Jeppson *et al.* 2002).

Although the technology in waste water treatment has developed during the last decades, demands on the water quality have become more stringent at the same time. Wastewater quality is today usually measured with parameters such as BOD, chemical oxygen demand (COD), total organic carbon (TOC), total suspended solids (TSS), and by the amount of nitrogen and phosphorus compounds (Bourgeois *et al.* 2001). Values for these parameters have to be lower than the limits that have been set by the legislation and/or environmental permit. Traditional monitoring procedures for these parameters involve sampling, storage and laboratory analysis, which is time taking and increases the risk of errors due to handling. In order to comply with the regulations of certain parameters on a permanent basis, and because of the spatial and time dependent variability of wastewater characteristics, on-line monitoring of these parameters can be very useful (Jeppson *et al.* 2002). It can reduce the need for sample handlings and offer fast and accurate devices which are able to monitor a range of parameters by direct measurements. During the past few decades, the performance and reliability of many on-line sensors have improved greatly and can nowadays be used in many different control strategies (Jeppsson *et al.* 2002). On-line monitoring can offer tools to measure physical (e.g. turbidity, suspended solids), chemical (e.g. nitrate and phosphate, dissolved metals), and biological properties (e.g. BOD, bacteria) of the water (Table 4). Several different principles have found application in on-line monitoring; optical measurement, biosensors, ultrasound, spectroscopy and fluorescence, for example (Bourgeois *et al.* 2001, Vanrolleghem & Lee 2003).

Vanrolleghem & Lee (2003) classified the monitoring and control in wastewater treatment plants in four different units: 1) proper process model (which gives insight into the process); 2) on-line data providing sensors; 3) proper monitoring and control strategies, and 4) controlling elements that implement the controller output. Furthermore, they concluded that sensors can be used in three different purposes: 1) for monitoring; 2) in automatic control systems, and 3) as tools for plant auditing/optimisation/modelling. Consequently, sensors used in waste water treatment plants can be classified in two basic types (Vanrolleghem & Lee 2003):

- reliable, simple and low maintenance sensors for day-today monitoring and control
- advanced, higher maintenance sensors used in model calibration and process optimisation

Table 4. State of the art of on-line monitoring equipment for wastewater treatment processes as given by Vanrolleghem & Lee (2003).

Physical measurements			**Physico-chemical measurements**			**(Bio-) chemical measurements**		
Variable	**Process**	**Range**	**Variable**	**Process**	**Range**	**Variable**	**Process**	**Range**
Temperature	G	∀	pH	G	∀	Respirometry	2, 3	∀
Pressure	G	∀	Conductivity	G	∀	Toxicity	2, 3	∀
Liquid level	G	∀	Oxygen concentration	2, 3	∀	BOD_{st}	2, 3	∀
Flow rates	G	∀	Fluorescence	2, 3	∃	COD	1, 2, 3	O
Suspended solids	G	∃	Redox	1, 3	∀	TOC	1, 2, 3	∀
Sludge blanket	4	∃	NH_4^+ (ISE)	3	∀	NH_4^+	3	∀
Sludge volume	4	∃	NO_3^- (ISE)	3	∃	NO_3^-	3	∀
Settling velocity	4	O	Digester gas	1	∃	Micro-scale NOx	3	∀
Sludge morphology	G	O	(CH_4, H_2S, H_2) CO_2	1, 2, 3	∀	PO_4^{3-}	3	∃
Calorimetry	1, 2, 3	O				Bicarbonate alkalinity	1, 3	∃
UV absorption	G	∃				VFA	1, 3	O

Process: Unit process in wastewater treatment plants where the sensor can be implemented 1: Anaerobic Digestion; 2: Activated Sludge; 3: Nutrient Removal; 4: Sedimentation; G: All processes. Applicability Range: ∀: State of the Technology; ∃: Application in certain cases; O: Requires development work

In Europe, traditional in-line devices (i.e. sensors placed in or in a side stream of a process and providing on-line data) are widely used to measure temperature, water level, water flow and dissolved oxygen. Sensors for pH, air flow and suspended solids are also common (Jeppson *et al.* 2002) (Table 5). Vanrolleghem & Lee (2003) mention in their review that: "probably the most important variable in wastewater treatment processes is the suspended solids concentration". According to Jeppson *et al.* (2002), the most commonly used on-line sensors in Europe are nutrient sensors for ammonia and nitrate (Table 5). The differences in the usage of on-line sensors between countries is rather distinctive and their use has been quite limited in general (Table 5). The countries with most frequent use of on-line sensors include Denmark, Finland, Germany, Netherlands, Sweden and Switzerland (Jeppson *et al.* 2002).

Table 5. Level of instrumentation in waste water treatment plants (> 50000 p.e) in 13 different European countries and the main purpose of the measurements, as given by Jeppson *et al.* (2002) (usage: +++ = 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

	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 5. Continues.

	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+

3. SLUDGE USAGE IN EUROPE

Before disposal, sludge has to be treated in several ways. Handling may include mechanical (e.g. dewatering), chemical (e.g. lime addition), biological (e.g. anaerobic digestion, composting) and thermal (e.g. drying) processes. Fytili & Zabanitou (2008) summarize a typical process as described in Table 6.

Table 6. Typical processes of sludge treatment before disposal (Fytili & Zabanitou 2008).

Process	**Methods**
preliminary treatment	screening, comminuting
primary thickening	gravity, flotation, drainage, belt, centrifuges
liquid sludge stabilization	anaerobic digestion (-> biogas production), aerobic digestion, lime addition
secondary thickening	gravity, flotation, drainage, belt, centrifuges
conditioning	elutriation, chemical, thermal
dewatering	plate press, belt press, centrifuge, drying bed
final treatment	composting, drying, lime addition, incineration, wet oxidation, pyrolysis, disinfection
storage	liquid sludge, dry sludge, compost, ash
transportation	road, pipeline, sea
final destination	landfill, agriculture/horticulture, forest, reclaimed land, land building, other uses

Possible options for final usage of sludge may be categorized as: reuse (e.g. agriculture, landscaping), energy recovery (e.g. biogas, incineration) or no use (disposal to landfill). In Europe, the framework for the usage of sludge is given by the EU Directives, as mentioned earlier. However, the national legislation between countries differs from each other. Generally, the producer of the sludge has the responsibility for its proper disposal, and needs a permit for it which is given by national, county or local authority (Rantanen *et al.* 2008). The main usage for sludge in Europe is in landscaping, agriculture or incineration (Table 7). Dumping to landfill is fairly uncommon, except in Greece.

Table 7. Final disposal of sludge in different EU countries. Modified from Rantanen *et al.* (2008).

Country	**Sludge usage**
Great Britain	65% agriculture or landscaping 35 % incinerated or dumped to landfill
Germany	Agriculture Incineration
Greece	To landfill
Norway	Agriculture Landscaping
France	60-62 % agriculture and landscaping 16 % incineration 2 % other usage 20 % landfill
Holland	47 % incineration 34 % thermic drying + concrete manufacturing 14 % landscaping 5 % taken abroad
Italy	Dispersal to soil Composting Landfill
Belgium	45 % thermic drying + incineration 29 % incineration 14 % landscaping 12 % agriculture
Austria	Agriculture Landscaping drying + composting incineration + landfill
Estonia	40 % landscaping 35 % agriculture 10 % gardening 10 % recultivation 5 % landfill
Finland	80 % landscaping 12 % agriculture 6 % landfill

As mentioned earlier, EU directive 278/86 determines the levels for heavy metals in sludge. However, most of the European countries have stricter levels for the heavy metals in their national legislation. In the USA, the legislation for the heavy metal amounts in the reclaimed sludge is not as strict as in the EU directive, having 1.75 times higher levels on average than in EU directive (Rantanen *et al.* 2008). The amount of pathogens in sludge (viruses, bacteria, parasites) is being limited in many countries, too. For example, bacteria from the family 'Enterobacteriaceae', such as *Salmonella* and *Escherichia Coli,* are being monitored quite commonly (Rantanen *et al.* 2008). The limits for organic pollutants (e.g. PAH, AOX, LAS, DEHP, NPE, PCB etc.) are still rather rare in Europe with only few countries having limits for them (Rantanen *et al.* 2008). Also pharmaceutical compounds may end up in sludge. Significant amount of these compounds, either original or metabolized substances, are excreted via urine or faeces to wastewater treatment plants. Removal of these compounds from the wastewater differs greatly between process conditions and individual pharmaceuticals (Beausse 2004). They can either be eliminated by sorption to sludge or biodegradation, but many compounds which show neither of these two options or biodegrade only partly, are discharged into receiving water. At present, there is not enough scientific knowledge concerning pharmaceutical compounds in waste water and sludge, and thus, there yet exists no limits for their concentrations.

According to the enquiry made to European sludge experts by Rantanen *et al.* (2008), the following factors have an effect on the final disposal of sludge in Europe:

- limits in legislation concerning heavy metals, organic pollutants and pathogens
- economical factors such as transport, production and investments
- origin of the sludge
- general opinion of consumers, farmers and food industry
- administrative factors
- proximity of incineration facilities
- BAT of the disposal of sludge
- regional prohibitions
- prohibitions on deposition of organic waste to landfill
- possibilities of dispersal
- seasonal usage in agriculture

The most common reasons why sludge is not utilised/reused in agriculture in Europe are: high amounts of heavy metals, pathogens, organic contaminants, too high nitrogen concentration, costs, and public prejudice for its usage. Moreover, logistics with long transportation distances can be a problem (Rantanen *et al.* 2008.)

Industrial sludge produced by the paper and pulp industry differs considerably by its composition and quality from the sewage sludge. It contains more wood-originated substances such as lignin, cellulose, carbohydrates and ash. Industrial sludge is usually incinerated in the boilers of the producing facility with bark, woodchips and -dust after mechanical dewatering (belt filter press and screw press) procedure (Ojanen 2001). The quality and amount of industrial sludge is rather mill-specific, and therefore different technologies in incineration are used, depending on the mill. Other options for the industrial sludge use are anaerobic digestion (biogas), composting, landscaping, or disposal to landfill (Ojanen 2001).

4. FUTURE

Traditional, manual standards/methods in sample taking and monitoring of waste waters and sludge are often favoured in the legislation and regulations. Therefore, it seems that automatic monitoring technology has not removed the need for traditional sample taking and laboratory analyses. However, accurate and fast on-line monitoring of pollutants may be very cost-effective, giving economic gain to corporations. Hence, technological advances may reduce the need for rather expensive and slow laboratory analysis in the future, if legislation changes. EU regulations are likely to become stricter in the future, which may promote the use of automatic monitoring as the need for real-time, rapid monitoring of emissions increases. Polluters must be more and more aware of the quality of their emissions as they have the burden of proof to show that they are not releasing any substances which are prohibited or being under regulations. While the heavy metal content in the wastewater sludge in Europe is regulated by the sewage sludge Directive, the concentration of the organic toxic substances in the sludge has been left to the consideration of the members of the European Union at the moment. Therefore, limits for those parameters do not exist or vary significantly in different countries. Update for the old sludge Directive has been under debate for several years, and it is likely to promote new parameters to be measured, for example organic pollutants and certain pathogens. It most probably also brings stricter limits for heavy metals, even though most European countries already have stricter national legislation concerning them than given by the Directive.

Industrial markets for environmental technology are likely to be increasing, promoting the use of new devices. Environmental and impact analyses may be done by applying new techniques and be more economical than earlier. As mentioned, the biggest challenge concerning on-line monitoring is probably the present legislation, which generally favours the traditional monitoring methods/laboratory analysis. Also the maintenance of the sensors in the harsh conditions of wastewater treatment plant can be a problem, even though robust sensors have been developed and different cleaning strategies are available. For example the pH sensors immersed in sludge can be maintained by hydraulic (water spray), mechanical (brush), chemical (rinsing with cleaning agent) or ultrasonic cleaning (Vanrolleghem & Lee 2003).

Jeppson *et al.* (2002) concluded that the main driving forces for instrumentation, control and automation (ICA) in waste water plants are most often related to:

- stricter effluent quality standards
- demands for lower sludge production
- economic incentives
- reduction in energy consumption and/or increase in energy production
- increased plant complexity
- new treatment concepts,
- new and cheaper technical solutions

However, majority of the existing wastewater treatment plants have not been designed for the use of real-time control systems, which is probably the most fundamental barrier for the widespread acceptance of new sensors (Jeppson *et al.* 2002).

Sludge issues are likely to remain as important issues in the future. Methods for minimising sludge production and for treating the excess sludge in an effective and environmentally friendly way (e.g. recovery of phosphorus) are major fields of research. Rantanen *et al.* (2008) conclude that rather recent research topics concerning sludge handling and disposal have dealt with: digestion, energy utilization, composting, worm composting, reduction of the amount of sludge, physical properties of the sludge, pathogens in sludge, potentially harmful substances in sludge, and risk assessments concerning sludge. In the future, previously not monitored low-concentration substances in water and sludge (e.g. endocrine substances, pharmaceuticals) are also important topics (Jeppson *et al.* 2002). Based on the survey made by Jeppson *et al.* (2002), it can be summed up that expectations for cheaper and more robust on-line sensors exist, particularly for nutrient measurements.

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