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WATER TREATMENT BY ENHANCED COAGULATION
Operational status and optimization issues

Introduction

Most drinking water treatment plants in Europe are already built. Unfortunately, sub-optimum operation of water treatment facilities is a rather widespread phenomenon, thereby compromising water supply safety, sustainability, and cost-efficiency. Thus the main focus for most end-users is how to secure safe, sustainable, and cost-efficient operation of existing facilities. Retrofitting and up-grading of existing facilities are also important issues in order to meet new demands and regulations.

Natural organic matter (NOM) is a major raw water constituent that negatively affects water supply systems in a number of ways and therefore needs to be controlled. Unlike conventional coagulation processes where removal of turbidity was the main objective, enhanced coagulation processes designed for the removal of NOM (i.e. TOC, colour, UV-abs) involve elevated coagulant doses and strict control of coagulation pH. A number of studies on (enhanced) coagulation and filtration have demonstrated that NOM is the major determining factor with respect to process operation conditions. The great spatial and temporal variability in NOM concentration and composition and thus in water treatability makes NOM a key substance in any operation optimization activity.

Ozone reacts with NOM and converts part of it into biodegradable organic matter (BOM). This fraction of BOM as well as the background BOM present in raw water is then removed in a biofilter. There are no regulatory limits for the amount of BOM in drinking water and biofilter design and operation may therefore be arbitrary. Since biofiltration is a seemingly simple process, little thought is usually given for operational issues once the biofilters are in place. The microbial processes taking place in the filters are, however, extremely complicated. The environment is extreme for microbial growth including low substrate and nutrient concentrations, sometimes very low temperatures, complicated substrate interactions, etc. Therefore it is likely that the biofiltration process is not well understood and that the operation may not be optimal at many facilities.

In addition to the great influence on coagulation and biofiltration processes, NOM interact with disinfection processes; form disinfection by-products (DBPs); increase disinfectant demands; affects stability and removal of inorganic particles and micro organisms; fouls membranes and blocks GAC pores, thus also affecting the removal of algal toxins, taste and odour. Because of the major negative implications for processes like coagulation, media filtration, activated carbon adsorption, membrane filtration and disinfection, NOM controls performance and optimal operating conditions of most water treatment processes. Last, but not least, NOM affects corrosion, biostability and regrowth, i.e. water distribution systems and water quality during distribution.

Especially in Europe, there has been a trend towards avoidance of chlorination or use of reduced chlorine doses to avoid formation of chlorinated disinfection by-products and taste and odor problems. The required treatment barriers can be achieved by using alternative disinfectants like ozon and UV, or by extensive water treatment.

Also because of the effective parasite inactivation, UV disinfection has gained increased popularity over the last few years. As a result, many water works do not have residual disinfectant in their distribution network. Bacterial growth during distribution can be prevented by employing treatment processes that produce a biologically stable water quality. To achieve this, optimal operation performance of water treatment facilities with respect to BOM is of primary importance.

Importance

Identification of optimum operating conditions and implementation of best operation practices at existing drinking water treatment facilities are key challenges in order to secure water supply safety, sustainability and cost-efficiency. Because of the great impacts of NOM on operation of treatment and distribution systems, NOM characteristics, NOM biodegradability and NOM treatability has to be addressed as part of an optimization strategy.

With some exceptions (e.g. UK, Germany, Norway, Sweden, Finland, etc), NOM and NOM-related issues have not gained the same focus within regulations, operation issues, and tailored research activities in Europe when compared to countries like USA and Australia. This situation seems to persist, in spite of the fact that due to climate change and global warming a significant increase in NOM has been observed during the past 10-20 years in large parts of Northern Europe. The corresponding increase in seasonal and spatial variation of NOM will impose even more operational challenges.

BOM contains large amounts of various organic compounds, most of which are not yet identified. In simple terms it can be divided into "fast" and "slow" BOM depending on biodegradation rates. Review of removal efficiencies in biofilters show that they are not able to achieve complete removal of BOM. Probably they are able to remove the "fast" fraction of BOM only. One of the challenges of biofilter operation is to achieve good removal also of the "slow" BOM. Raw water quality, ozone dose and seasonal changes of NOM may affect this. One strategy is adjustment of ozone dose, since it has a major impact on the types of BOM formed. Doing this without compromising other ozonation objectives like disinfection may require careful optimization.

One of the major problems in biofilter operation is that there are no available methods for rapid analysis of the major parameter – biodegradable organic matter. The analytical methods for direct measuring of BOM are typically time consuming taking from days to weeks before result is ready. Many of them are expensive and require analytical experience which is not available in many (smaller) waterworks. Thus they cannot be used for process control. There is therefore a need for rapid and simple methods which could allow measurements of changing BOM concentrations in biofilter feed and/or effluents.

Other factors which may influence biofilter performance, although not very well studied and therefore poorly understood, include limiting phosphorus concentrations, oxygen supersaturation after ozonation, role and control of invertebrates, and control of the amount of microorganisms in the biofilter effluent.

Approach

The previous report/deliverable (D5.3.1) addressed state-of-the-art optimization needs and challenges at existing water treatment facilities employing: 1) Enhanced coagulation and filtration processes, and 2) Ozonation and biofiltration processes. A number of knowledge gaps and research needs were identified, suggesting further activities on: 1) NOM characterization and treatability interactions, including implications of climate change; 2) Improved practical linkage of NOM characteristics and seasonal variations to practical operation routines and actions, including identification of NOM fractions that are recalcitrant/not amendable to removal; 3) Refinement, development and verification of user-friendly optimization routines, as well as models that can be applied for the purpose of overall process optimization; and 4) Improved process control systems, and development of in-line sensors for treatment process and product control purposes.

This report presents preliminary results from optimisation investigations with the two treatment processes in laboratory, pilot and full-scale applications. In addition, selected methods for NOM characterization and biodegradability evaluations are tested and discussed in relation to treatability and operation issues.

Detailed optimization procedures for the two water treatment processes are suggested, and are now to be implemented, tested and verified at selected full-scale facilities in cooperation with end-users. Operation model candidates are also presented for further testing and verification.

New partners are included (S:can and IHE-Delft) to further strenghten the links between water characteristics and treatability. This will provide new treatment process control options (from in-line Delta UV probe measurements), and measurements of fluorescence excitation-emission matrix (EEM) and size-exclusion chromatography with dissolved organic carbon detection (SEC-DOC). EEM allows one to track humic-like NOM, effectively removed during coagulation, and protein-like NOM, amenable to removal by biofiltration. SEC-DOC allows one to track biopolymers, potentially removable by biofiltration, low molecular weight acids, significantly removable by biofiltration, and humic substances, effectively removed by coagulations. Both EEM and SEC-DOC can provide quantitative as well as qualitative information.

Results

NOM and biodegradability characterization. Literature data as well as fractionation and column-based biodegradability results obtained within this study show significant seasonal and spatial variability of NOM concentrations, nature and properties, and thus also in NOM treatability by enhanced coagulation as well as ozonation-biofiltration processes. Inter-laboratory comparisons tests (SINTEF, RTU and EAWAG) showed comparable results for TOC and NOM fractionation data.

Tests of batch and column-based BDOC methods generated similar results. However, the latter method is much faster, yielding results in 2 hours compared to 9-15 days for the batch method. A time period of about 6 hours is required for adaptation of BDOC columns to new samples/new substrates.

Enhanced coagulation. Pilot and full-scale investigations show that enhanced coagulation operation performance, i.e. treated water quality, coagulant demand, sludge production and filter run lenghts, is predominantly controlled by NOM rather than turbidity or other substances. Optimal operation is important also from a treatment barrier point-of-view, i.e. the removal of protozoan parasites like *Cryptosporidium* and *Giardia* is compromised by inadequate operation conditions like non-optimal pH and coagulant doses, and by operational disturbances from filter ripening, peaks in hydraulic load/filtration rates, improper management of return flows, early filter breakthroughs and inadequate filter backwash routines.

Laboratory investigations (jar tests) at Daugava WTP in Riga revealed optimization potentials related to pH and coagulant dose control. Today about 50-60 % DOC is removed by coagulation at Daugava WTP. Improved performance was obtained in the laboratory tests when pH was reduced from an existing range of 6.7-7.7 down to 5.5-6.0. Pre-ozonation did not seem to affect coagulation performance or NOM composition (rapid fractionation results) to any great extent. However, an increase in the hydrophilic charged fraction (CHA) concentration was observed. Great seasonal variation in raw water quality, i.e. NOM concentration and composition was detected at Daugava WTP, indicating significant challenges in treatment process operation and control. Both humic and non-humic fractions are present in the raw water (River Daugava). Treated water neutral hydrophilic fraction (NEU) concentration is high, thus representing a concern in terms of regrowth in the distribution system.

Pilot scale optimization experiments performed at VIVA WTP in Trondheim, Norway demonstrated the great significance of a strict pH and coagulant dose control on operation performance. Case studies on full-scale optimization efforts in Norway demonstrated the applicability of the proposed optimization procedure. In one case improved operation performance and improved treated water quality was obtained, while another case revealed significant optimization potentials in terms of resources use (chemicals and energy), less waste (sludge) produced and considerable cost savings (40 000 € per year for 30 000 m^3 per day production capacity). Results from NOM fractionation of raw and treated waters indicate that an increase in the NEU fraction during coagulation treatment may be taken as an indication of sub-optimum coagulant dose levels.

Ozonation-biofiltration. During pilot scale tests performed at Daugava WTP (3 pilot columns) on ozonated water a simple steady-state mathematical model (in Excel with Macros) for prediction of DOC removal though the column was developed. The input parameters for the model are filtration rate, temperature, BDOC in the inlet and ATP content in the upper part of the filter. The output factors are BDOC at inlet from the column. The model was verified in pilot scale and in lab-scale columns with different contact times.

Both in the pilot and full-scale plants, removal of DOC and BDOC was poor. AOC and MAP (phosphorus) removal was however close to 50 %. The positive effects of a temperature increase from a minimum of 5 °C in winter to about 20 °C in summer was reflected in the good correlation between ATP and temperature level. Preliminary NOM fractionation results showed that in well-operated biofilters the hydrophilic neutral (NEU) are effectively removed whereas the hydrophilic charged (CHA) fractions are increased. The results further showed that not only the total

BDOC value but rather the BDOC degradation rate is important in treatment of waters with high levels of humic substances. For this purpose a rapid, column-based method of measuring BDOC was developed as described above.

Preliminary results from ozonation-biofiltration pilot investigations at VIVA WTP, Trondheim showed removals of colour and UV-abs. in the range of 60-70 %, and DOC removal of 10-20 % with a DOC-specific ozone dose of close to 1 mg O_3 per mg DOC. The raw water quality at VIVA WTP (Lake Jonsvatnet) is far better and very constant compared to the Daugava River water quality. Further activities will include biodegradability and NOM fractionation studies, and optimization studies on optimum ozone dosage, EBCT, backwash procedures, etc. As a result of these efforts, removal efficiencies are expected to increase significantly.

Operation models. Unit process operation models are presented as optimization tools and possible inputs to the development of a treatment process simulator (WA5.4). To test, verify and calibrate operation model candidates, a number of case studies from water treatment facilities in Latvia and Norway will be included.

More information

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TKI Categorisation

Classification									
Supply Chain		Process Chain		Process Chain (cont'd)		Water Quality		Water Quantity (cont'd)	
Source		**Raw water storage**		**Sludge treatment**		**Legislation/regulation**		- Leakage	
- Catchment		- Supply reservoir		- Settlement		- Raw water (source)		- Recycle	
- Groundwater	x	- Bankside storage		- Thickening		- Treated water	x		
- Surface water	x	**Pretreatment**		- Dewatering		**Chemical**			
- Spring water		- Screening		- Disposal		- Organic compounds	x		
- Storm water		- Microstraining		**Chemical dosing**		- Inorganic compounds	x		
- Brackish/seawater		**Primary treatment**		- pH adjustment	x	- Disinfection by-products	x		
- Wastewater		- Sedimentation		- Coagulant	x	- Corrosion	x		
Raw water storage		- Rapid filtration		- Polyelectrolyte	x	- Scaling			
- Supply reservoir		- Slow sand filtration		- Disinfectant	x	- Chlorine decay			
- Bankside storage		- Bank filtration		- Lead/plumbosolvency		**Microbiological**			
Water treatment		- Dune infiltration		**Control/instrumentation**		- Viruses		Consumers / Risk	
- Pretreatment		**Secondary treatment**		- Flow	x	- Parasites	x		
- Primary treatment		- Coagulation/flocculation	x	- Pressure	x	- Bacteria	x	**Trust**	
- Secondary treatment	x	- Sedimentation	x	- pH	x	- Fungi		- In water safety/quality	x
- Sludge treatment		- Filtration	x	- Chlorine	x	**Aesthetic**		- In security of supply	
Treated water storage		- Dissolved air flotation(DAF)		- Dosing	x	- Hardness / alkalinity		- In suppliers	x
- Service reservoir		- Ion exchange		- Telemetry		- pH	x	- In regulations and regulators	x
Distribution		- Membrane treatment		**Analysis**		- Turbidity	x	**Willingness-to-pay/acceptance**	
- Pumps		- Adsorption		- Chemical	x	- Colour	x	- For safety	x
- Supply pipe / main		- Disinfection		- Microbiological	x	- Taste		- For improved taste/odour	
Tap (Customer)		- Dechlorination		- Physical	x	- Odour		- For infrastructure	
- Supply (service) pipe		**Treated water storage**						- For security of supply	

- Internal plumbing		- Service reservoir				**Water Quantity**		**Risk Communication**	
- Internal storage		**Distribution**						- Communication strategies	
		- Disinfection				**Source**		- Potential pitfalls	
		- Lead/plumbosolvency				- Source management		- Proven techniques	
		- Manganese control				- Alternative source(s)			
		- Biofilm control	x			**Management**			
		Tap (Customer)				- Water balance			
		- Point-of-entry (POE)				- Demand/supply trend(s)			
		- Point-of-use (POU)				- Demand reduction			

TKI Categorisation (continued)

Contains		**Constraints**		**Meta data**					
Report	x	Low cost		*Bjørnar Eikebrokk, Stein W. Østerhus, Esa Melin, SINTEF, and Talis Juhna, RTU*					
Database		Simple technology		*SINTEF and RTU*					
Spreadsheet		No/low skill requirement		*Bjornar Eikebrokk and Talis Juhna*					
Model	x	No/low energy requirement		*bjornar.eikebrokk@sintef.no; talisj@bf.rtv.lv*					
Research	x	No/low chemical requirement		*Sveinung Sægrov*					
Literature review	x	No/low sludge production		*SINTEF*					
Trend analysis		Rural location		Source					
Case study / demonstration	x	Developing world location		*Dec 2007*					
Financial / organisational				2007-12-31					
Methodology	x								
Legislation / regulation									
Benchmarking									