NSERC Industrial Research Chair Agreement

between

THE GOVERNING COUNCIL OF THE UNIVERSITY OF TORONTO
having an office at Research Services, Simcoe Hall, Rm. 133-S,
27 King's College Circle, Toronto, Ontario M5S 1A1
(the **"University"**)

-and -

YORK REGION
having an office at 17250 Yonge Street
Newmarket, ON L3Y 6Z1
(**"York"**)

WHEREAS York (the "**Sponsor**") wishes to support the research project described in the Research Program entitled "NSERC Senior Industrial Chair in Source Water Quality Monitoring and Advanced/Emerging Technologies for Drinking Water Treatment" and attached as Appendix "A" (the **"Project"**), to be conducted under the direction of Professor Robert Andrews of the University (the **"Researcher"**);

NOW THEREFORE the parties agree as follows:

1. **Definitions.** In this Agreement:

(a) **"Confidential Information"** means all information disclosed by one party to another party that is clearly marked "confidential" or is so reduced to writing within ten (10) days thereafter by the disclosing party, but does not include information that: (i) is already known to the party to which it is disclosed; (ii) is or becomes part of the public domain without breach of this Agreement; or, (iii) is obtained from a third party that has no obligation to keep confidential to the parties to this Agreement.

(b) **"Intellectual Property"** means all intellectual property, including without limitation technical information, know-how, copyrights, models, drawings, specifications, prototypes, inventions and software, whether or not patentable, that is discovered, created or reduced to practice in performance of the Project.

(c) **"Effective Date"** means September 1st, 2008.

2. **Contributions. T**he Sponsor will make financial and in-kind contributions to the Project in the amounts set out in Appendix "B". Upon receipt of invoices, cash payments shall be made by cheque payable to the University of Toronto and addressed to the Executive Director, Research Program Funding. The first payment shall be due within 30 days of the Effective Date. Subsequent payments as set out in Appendix "B" shall be made on or before April 1 for each year of the Project. Annual payments may be dependent on a Sponsor's internal annual budget approval.

3. **Reports.** The University shall meet annually to describe the progress of the Project to the Sponsor and shall provide a final report upon completion of the Project.

4. **Confidential Information.** The parties may disclose Confidential Information one to another to facilitate performance of this Agreement. Each party will safeguard and not disclose Confidential Information received from the other party, except to those of the receiving party's personnel who have a need to know and an obligation to protect it.

5. **Ownership of Intellectual Property.** Intellectual Property created solely by the personnel of a party will be owned solely by that party. Intellectual Property created jointly by the personnel of both parties will be owned jointly by the parties.

6. **Research and Teaching Use.** Notwithstanding anything contained herein, the University will retain the right to use Intellectual Property for research, educational and administrative purposes, without cost and in perpetuity.

7. **Publications.** The University may publish or disclose the results of the research arising from performance of the Project and will acknowledge the Sponsor's support in all such publications. The University will provide a copy of the manuscript or proposed disclosure to the Sponsor at least thirty (30) days prior to submission for publication or presentation. At a Sponsor's written request received within thirty (30) days of the Sponsor's receipt of the proposed disclosure, the University will:

   (a) remove identifiable references to Confidential Information provided by the Sponsor from the proposed disclosure; and/or,

8. **Term and Termination.** This Agreement shall enter into force as of the Effective Date and shall terminate on March 31, 2012, unless sooner terminated:

   (a) upon written notice by the University if NSERC discontinues or withholds funding for the Project; or,

   (b) upon the written agreement of the parties.

9. **Limitation of Liability.** The University shall not be liable for any delays in the performance of its obligations under this Agreement resulting from circumstances or causes beyond the University's control, and in no case shall the University be liable for loss of business or profit or other indirect or consequential damage.

10. **No Use of Names.** Neither party will use the name of the other party, or of any member of the other party's personnel, in any advertising or publicity without the prior written approval of the other party's authorized representative. However, both parties may make the following information a matter of public record: names of Chair Holder; Chair Holder's department; University's name; Sponsor's name; Project title; Project duration; and, contract value.

11. **Independent Parties.** The parties are independent parties and nothing in this Agreement shall constitute either party as the employer, principal or partner of or joint venturer with the other party. Neither party has any authority to assume or create any obligation or liability, either express or implied, on behalf of the other.

12. **No Assignment.** No party may sell, assign, encumber, licence or otherwise transfer any of its rights, duties or obligations under this Agreement without the prior written consent of the other parties, which consent may not be unreasonably withheld.

13. **Successors.** This Agreement shall bind and enure to the benefit of the parties and their respective heirs, successors and assigns.

14. **Governing Law.** This Agreement will be governed by and construed in accordance with the laws of Canada and the laws of the Province of Ontario applicable therein.

15. **Entire Agreement.** This Agreement is the entire agreement of the parties and no change or modification shall be valid unless it is in writing and signed by both parties.

IN WITNESS WHEREOF, the authorised representatives of the parties have executed this agreement in two original counterparts effective the last date of signature below.

THE GOVERNING COUNCIL OF THE UNIVERSITY OF TORONTO

Name: Judith Chadwick
Title: Executive Director, Research Program Funding

Date:

YORK REGION

Name:
Title:

Date:

Acknowledged by **RESEARCHER**:

Name: Robert Andrews
Title: Professor, Department of Civil Engineering

Date

DIVISIONAL APPROVAL:

Name: Brenda McCabe
Title: Chair, Department of Civil Engineering

Date

APPENDIX "A"

RESEARCH PROGRAM
(2008-2012)

NSERC Senior Industrial Research Chair in Source Water Quality Monitoring and Advanced/Emerging Technologies for Drinking Water Treatment

Department of Civil Engineering, University of Toronto

NSERC Senior Industrial Research Chair in Source Water Quality Monitoring and Advanced/Emerging Technologies for Drinking Water Treatment

CHAIR RATIONALE

Canadians enjoy tap water that is both safe and inexpensive, but there are still many opportunities for improvement. Public health studies show that even incremental changes in tap water quality may have enormous public health benefits to communities as a whole. Economically, the global drinking water industry is worth over $400-billion a year, so breakthroughs in treatment technology and its optimization have major industrial repercussions in both public and private sectors.

The NSERC Industrial Research Chair (IRC) at the University of Toronto takes advantage of its existing strong drinking water research infrastructure and that of nearby analytical facilities and municipalities. Focal to this infrastructure are a dedicated drinking water laboratory (wet lab) and a Level 2 Biosafety certified microbiology lab, analytical equipment including a GC/MS/MS, GC-ECD, AOX analyzer, TOC, IC, AA, UV-VIS spectrophotometer, an environmental chamber, and various experimental equipment to support research. There is also ongoing access to other facilities at the University of Toronto including an industry-sponsored analytical chemistry facility (ANALEST), and transmission electron spectroscopy (Faculty of Medicine). In addition, the location of an IRC at the University of Toronto optimizes collaboration with both academic colleagues and municipal and industrial partners by facilitating travel (when necessary) to/from its central location.

The University of Toronto and all of the Chair partners recognize that they will realize significant and direct benefits through their participation and have made strong long-term commitments. They understand that the Chair program involves developing sustainable research activities that will generate results of scientific and industrial relevance, enhance training, and stimulate academic collaborations and industrial interactions. The University has recently made a major commitment to focus on urban infrastructure as one of five major research initiatives. The Department of Civil Engineering has also adopted Urban Engineering as its predominant theme in its most recent strategic plan. The IRC, by examining issues related to urban water treatment, plays a flagship role within this Departmental research initiative. It also serves as a highly valued resource for drinking water utilities in the Greater Toronto Area and beyond, Canadian manufacturers and technology developers that support research and development of new products which are distributed nationally and internationally and government agencies that appreciate a targeted focus on public health. The Department of Civil Engineering has committed resources to the Chair program in recognition of its strategic importance to the Department as a whole. In return, it is anticipated that the Chair will help the Department to reach its stated goal as becoming one of the leading Civil Engineering departments in the world.

There are both general and specific benefits for each of the partners. Knowledge and technology transfer is facilitated through professional development via regular meetings that bring together students, public utilities, government organizations and industry. Strategically, the Chair also provides each partner with the following:

Benefits to industrial and utility partners:

- The research benefits Pathogen Detection Systems Inc. and Hydromantis Inc. by demonstrating their technologies to utilities and regulators and by developing new methods of integrating these technologies together and within the operational constraints of existing treatment facilities.

- Calgon Carbon, the leader in activated carbon production and application and a major manufacturer of ultraviolet technology, gains through the development of improved evaluation methods for their carbon products, thereby enabling better customer support. There is also the potential for increasing their market share of GAC and UV-related installations resulting from the research to be completed on taste and odour and contaminant removal, and increasing regulatory confidence concerning UV-based methods for contaminant destruction during drinking water treatment.
- Benefits to Zenon Environmental, at the forefront of membrane technology, include advanced product development and evaluation, information to promote new market areas, and increased confidence of regulators for the use of membrane technologies to control emerging drinking water contaminants.
- The utility partners, including the City of Toronto, the Region of Halton (Greater Toronto Area), the City of Peterborough (ON), the Lake Huron and Elgin Area Primary Water Supply Systems (London, ON), the Region of Durham, and York Region benefit in their efforts to be proactive in providing optimized treatment to address emerging contaminants and pathogens in drinking water. The total population represented by these utilities is approaching 5 million.

Benefits to the University of Toronto:

- The addition of a new faculty position in drinking water (Prof. Ron Hofmann) and two non-faculty positions (Carole Baxter, Microbiologist; Ella Ye, Research Chemist). The significantly enhanced research infrastructure provided by the Chair results in an increase in the number of high quality students entering the workforce with backgrounds enabling them to take positions of leadership, more industry-university partnerships to help with technology transfer, and a stronger network of drinking water-related collaborations across campus.
- The Chair also greatly enhances the Department's profile both within Ontario and internationally, with collateral benefits expected across the Environmental Engineering program.

This network of collaborators has excellent resources that have been committed to the Chair, and represents a critical mass that will yield major innovation.

SENIOR CHAIRHOLDER EXPERIENCE:

The NSERC Senior Industrial Research Chair is held by Dr. Robert C. Andrews, a senior professor and former Associate Chair of Research in the Department of Civil Engineering at the University of Toronto. As part of Dr. Andrews' position as Chairholder, he receives a 50% release from teaching.

Dr. Andrews has over 20 years of experience in the field of drinking water treatment, both as an academic researcher as well as an industrial researcher and consultant, having worked as a Senior Research Engineer conducting pilot studies for the City of Edmonton as well as a senior Process Design Engineer for Stantec, prior to entering academia. He regularly collaborates with researchers at universities across Canada, the United States, France and Singapore in multidisciplinary studies. In 2008 he was elected to serve on the Board of Directors of the Canadian Water Network (CWN). He is a past co-recipient of the NSERC Synergy Award for University-Industry Partnerships. His leadership and management skills are evidenced by his ability to serve as principle investigator on major American Water Works Association Research Foundation (AWWARF) and CWN projects, and by his service as the 2006 Chair for both the NSERC Civil Engineering Grant Selection Committee and the CFI Water/Wastewater Expert Committee. Dr. Andrews is also an appointed member of the Ontario Ministry of the Environment Advisory Council on Water Quality and Testing Standards, and the Walkerton Clean Water Centre Research Advisory Committee. Additional past commitments include serving on American and Ontario Water Works Association technical committees, and on the Great Lakes International Joint Commission Council of Research Managers. Two of his previous doctoral students now hold academic appointments, with the majority of his past Masters students being employed by consultants who serve the drinking water industry.

NSERC INDUSTRIAL RESEARCH CHAIR IMPACT

The Chair yields many benefits to its partners, the University and the broader national and international drinking water community:

- **Provision of safer tap water.** The ultimate goal of the Chair's research is to enhance public health through contributions to the provision of safer drinking water. Our exploration of new technologies and new methods to monitor source water quality and optimize treatment processes represent significant contributions.
- **Delivery of major innovation to the Chair partners.** Ongoing research provides numerous areas of opportunity for our network of industrial, utility, and government partners. Our research is designed to directly improve market opportunities for activated carbon, UV, membranes, biosensor, and computer technologies, benefiting both providers of those technologies and industry receptors. Our research is also producing advances in water quality monitoring and general process optimization that will allow our utility partners to provide safer water more cost-effectively.
- **Dissemination of new ideas to the global water industry.** The Chair's research results in refereed publications and conference presentations that contribute significantly to the state-of-the-art in drinking water treatment. Dr. Andrews's research group regularly disseminates research results in the top journals (*e.g*. Water Research) as well as at the largest conferences worldwide (*e*.g. American Water Works Association ACE and WQTC). The research group has also created an information booth that is displayed at conferences to present ongoing research programs, distribute research summary information, and attract potential new collaborators and students. The booth has been recently expanded to distinctly highlight the IRC's partners and major research thrusts.

SECTION II –RESEARCH PROGRAM

OVERVIEW

The primary research areas for the NSERC Senior Industrial Research Chair are:

A) Linking Source Water Quality to Process Selection and Control

We are critically assessing the feasibility of using new technologies developed by our Chair partners to monitor source water quality in near real-time, with the information used to trigger immediate responses in treatment. It is our hypothesis that the resulting improvements in treatment will lead to safer drinking water and cost savings.

B) Advanced and Emerging Technologies for Water Treatment

- *Membrane applications in drinking water treatment*

The Chair is examining methods to improve the removal of emerging source water contaminants (including endocrine disrupting compounds, EDCs, and pharmaceutically active compounds, PhACs), and disinfection by-product (DBP) precursors by investigating various membrane pre-treatment methods, including the use of alternative coagulants and PAC. Treatment facilities that use membranes primarily for microbial and particulate removal may potentially expand their range of expectations concerning treatment effectiveness.

- *Novel treatments using UV/H_2O_2*

A major research effort is being directed towards developing tools that allow engineers to design UV/H_2O_2 systems for taste and odour control. A second objective consists of determining the ability to use UV/H_2O_2 for the destruction of emerging micropollutants, including EDCs, PhACs, algal toxins, and others.

- *Improved methods of granular activated carbon (GAC) filter-adsorption*

The Chair is developing tools to improve the characterization of GAC in terms of adsorptive capacity and expected bed life, such that personnel involved with the operation and supply of product to treatment facilities can make more precise and knowledgeable judgements concerning carbon applications. The Chair will also be developing a method for testing partially exhausted GAC to predict when it should be replaced, prior to exhaustion.

- *Computer applications for improved treatment process optimization*

Research is focusing on the application of artificial neural networks to predict filter cycle length, and on using computational fluid dynamics (CFD) modeling as an online option to optimize disinfection processes. The goals of this work are to remove much of the guesswork in day-to-day treatment optimization, improve process efficiency and raise the bar on finished water quality expectations.

DETAILED RESEARCH APPROACH

A. LINKING SOURCE WATER QUALITY TO PROCESS SELECTION AND CONTROL

Background

There is currently a debate in the water industry regarding how measurements of the microbial quality of source waters can and should be linked to water treatment process selection and control. In many cases, there are challenges to direct quantification of pathogens in source waters (e.g. *Cryptosporidium*, *Giardia*, viruses) due to temporal and spatial variations in concentrations (Dorner et al. 2004). As well, pathogens are typically present in low concentrations (Haas 1983) and require large sample volumes to be analyzed by time-consuming, expensive detection methods (Allen et al. 2000; Medema et al. 2003a). However, regulations and guidance manuals prepared by the United States Environmental Protection Agency (USEPA) and developed over the last two decades have recommended linking microbial source water quality monitoring to treatment objectives (USEPA 1989, 1999, 2006).

The U.S. Surface Water Treatment Rule first introduced the requirements for a minimum 3-log/4-log *Giardia*/virus reduction when treating surface waters in the late 1980s (USEPA 1989). These 3-log/4-log reduction requirements were based on risk analyses that calculated the log reduction required to provide safe drinking water given the measured ambient concentrations of the organisms in a survey of pristine watersheds in the environment (Haas 1983; Rose and Gerba 1991). The regulation went on to recommend that when the source waters were not "pristine", the required log reductions should be increased beyond the 3-log/4-log level to maintain the same level of public health protection. Unfortunately, the difficulty in routinely monitoring *Giardia* and viruses in source water led, in practice, to the minimum 3-log/4-log reduction requirements being adopted by many treatment plants regardless of source water quality.

Quantitative Microbial Risk Assessment (QMRA) encompasses the traditionally applied four steps of risk assessment, namely hazard identification (e.g. the concentration of various pathogens in the water supply), dose-response analysis (e.g. the probability of infection due to waterborne pathogens), exposure assessment (e.g. volume of water and number of pathogens ingested by the consumer), and risk characterisation (e.g. calculation of the number of resulting infections among consumers). This approach therefore attempts to calculate precise health consequences from what is known or can be inferred about the concentrations of particular pathogens in the water supply and the infectivity of those pathogens to humans (Hunter et al. 2003).

Research Plan

QMRA has the potential to be extremely useful as a water treatment design and decision making tool within a larger risk management strategy. Health Canada is currently in the process of developing a QMRA model for this purpose and the NSERC Chair at U of T is helping to test the model by applying it at our utility partners. The model is a valuable tool to evaluate treatment performance and identify critical processes. Ultimately, it enables quantification of risk associated with consuming treated water from a given water treatment plant.

The QMRA model is being applied to fulfill the following specific objectives:

1. Calculate treatment effectiveness and benchmark current performance.
2. Determine critical processes by identifying the process which poses the greatest risk in case of failure, and determine the relative effectiveness of physical removal vs. chemical inactivation at each plant.
3. Calculate the potential risk to public health from consuming treated water and determine the health effects of altering treatment parameters.
4. Determine the effect of changing source water quality on health risk and use of QMRA to identify any potential need for additional treatment based on source water quality.

Another aspect of this component of the Chair research is to evaluate whether near real-time monitoring of microbial source water quality can be used to determine treatment needs and adjust treatment operations accordingly. Such an approach would then be compared in terms of overall public health exposure risk versus the more common treatment strategy that is based on fixed treatment goals (i.e. independent of temporal variability in microbial source water quality).

A portion of this research will be conducted at pilot-scale at our participating utilities (Peterborough, Toronto, Halton), with two parallel trains designed to simulate an actual full-scale conventional treatment plant. One pilot train will operate with treatment variables being adjusted continuously based on real-time source water quality monitoring (i.e. *E. coli*), as per the method described in USEPA (1999). Instrumentation provided by Pathogen Detection Systems Inc. (PDS) will transmit raw water *E. coli* data to a computer-based disinfection evaluation and management system (provided by Hydromantis Inc.) which will be installed as part of the pilot plant SCADA system. The software will allow continual calculation of disinfectant residuals and required corresponding dosages to meet disinfection targets. Those dosages will be continually updated, with the resulting water quality monitored. In contrast, the second train will operate according to fixed operating parameters that will be based on the USEPA LT2ESWTR *Cryptosporidium* bin classification approach (USEPA 2006). Historical *Cryptosporidium* data will be used to classify the source water, or in cases where no previous data exist, an initial *Cryptosporidium* sampling program will be conducted. Treatment operating parameters (e.g. chlorine dosages) for the second train will then be set to meet the prescribed levels of microbial inactivation via this bin classification method and will not change over the course of the pilot trials, simulating current actual practice. A comparison between the treated water quality of the two trains will therefore indicate the advantages, if any, of adjusting treatment practices based on a continuous reassessment of raw water microbial quality.

B. ADVANCED AND EMERGING TECHNOLOGIES FOR WATER TREATMENT

The second major research focus of the Chair is on emerging technologies or advances in the application of conventional technologies. Specifically, these include: novel treatments using UV/hydrogen peroxide (H_2O_2), membrane optimization, improved methods of granular activated carbon (GAC) filter adsorption, and the application of computational methods for treatment process optimization.

MEMBRANE APPLICATIONS

Background

An increased demand for water quality and quantity combined with decreasing membrane costs have resulted in the growth of membrane applications in drinking water treatment. In Canada, the demand for high quality water and stringent regulations are the main drivers for the use of membranes as an alternative to conventional treatment processes. In addition, the detection of organic micropollutants, such as endocrine-disrupting compounds (EDCs) and pharmaceutically active compounds (PhACs) in wastewater effluents (Ternes et al. 1999; Baronti et al. 2000), source waters (Kolpin et al. 2002; Stackelberg et al. 2004) and drinking water (Kuch and Ballschmiter 2001) in various parts of the world has brought increasing concern over their potential adverse ecological and human impacts. This information enhances the need to investigate the ability of advanced treatment processes to remove emerging contaminants, such as EDCs and PhACs, as well as other low molecular weight contaminants.

Research Plan

This research examines the removal of organic micropollutants, including, but not limited to EDCs, PhACs and taste and odour compounds geosmin and 2-methylisoborneol (MIB), by membrane treatment processes as a function of compound properties, membrane properties and feed water characteristics. Recent improvements in analytical methods allow for studies to be conducted at realistic environmental concentrations (ng/L range) (Reddersen and Heberer 2003; Kimura et al. 2004; Spring 2004). In addition, the removal of these compounds is being investigated in the presence of natural organic matter, which may act as an adsorbent for the EDC/PhAC compounds or may compete for membrane adsorption sites and alter membrane surface properties. Specific research objectives include:

1) Examine the mechanisms associated with the removal of low molecular weight organic micropollutants by membrane filtration.
2) Examine the impact of natural organic matter on the removal efficiency and mechanisms of low molecular weight organic micropollutants by membrane filtration .
3) Evaluate the ability of a combined powdered activated carbon and ultrafiltration (PAC-UF) system to remove organic matter, organic micropollutants, and taste and odour compounds.

A bench-scale membrane testing apparatus is being used initially to investigate objectives 1 and 2. The membrane apparatus consists of a steel cross-flow membrane filtration unit, which uses flat sheet membrane coupons. All contacting surfaces are made of stainless steel to minimize any potential loss of compounds on non-membrane components of the system. A flow meter and a balance connected to a computer is used to continuously measure and record the permeate flow from the membrane cell, allowing the determination of flux decline (i.e. fouling) throughout an experimental run. This experimental set-up is the most common method for cross-flow membrane bench-scale testing (Lee et al. 2004; Kimura et al. 2004). For the PAC-UF experiments, PAC is added as a continuous dose to the membrane feed tank, as described in Basar et al. (2004) and Mozia et al. (2005). Analyses of EDCs and PhACs are conducted at the University of Toronto using a recently acquired GC/MS/MS.

Membranes are characterized for each experimental condition by determining the pure water permeability (PWP); (Yoon et al. 2004), zeta potential (indicator of surface charge); (Childress and Elimelech 1996), contact angle (indicator of hydrophobicity/hydrophilicity); (Cho et al. 2000; Shäfer et al. 2003), and membrane surface functional groups (Lee et al. 2004). In addition, the organic matter present in the feed water (present naturally or added) is being characterized in terms of molecular weight distribution (Chin et al. 1994), humic content (Edzwald et al. 1985; Cho et al. 2000), and organic matter fractionation (Cho et al. 2000; Lee et al. 2004). The fouled membrane specimens are also characterized by infrared spectroscopy (FTIR); (Lee et al. 2004).

Removal of low-molecular weight organic micropollutants by membranes (UF, NF, RO) is being examined as a function of compound properties, membrane properties and feed water characteristics through bench-scale trials using water obtained from the partner utilities. Bench-scale testing is being used to assess UF, NF, and RO membranes (objectives 1 and 2) and the combined PAC-UF system (objective 3). To increase potential background concentrations, water is spiked with emerging compounds such as EDCs/PhACs (including caffeine, bisphenol A, sulfamethoxazole, estrone and 17β-estradiol) and geosmin and MIB at a dose of approximately 100 ng/L, representative of levels measured in natural waters (Kolpin et al. 2002; Stackelberg et al. 2004). Pilot facilities will be available in Peterborough (2008), Toronto (2009), and Halton (2010), during which time ultrafiltration membranes will be incorporated on-line to compare results obtained at the bench-scale level. The impact of PAC addition to a UF system on contaminant removal and fouling will be examined through bench-scale experiments prior to moving to pilot scale. Throughout the pilot trials, selected DBPs (including THMs and HAA_9) is being monitored (following chlorine or chloramine addition) to also examine the impact of PAC addition as a pre-treatment alternative for DBP minimization.

The research will benefit Provincial and Federal regulatory agencies who are currently considering the appropriate maximum acceptable concentration limits for HAAs, and potentially EDCs/PhACs in drinking water and which technologies should be recommended for effective treatment. The research will also directly involve and benefit membrane and activated carbon supplier partners (e.g. Zenon Environmental Inc., Calgon Carbon Corporation) by demonstrating whether these treatment methods provide effective control of these contaminants. In addition, the research will benefit our utility partners who seek to optimize their treatment processes.

TREATMENTS USING UV/H_2O_2 ADVANCED OXIDATION

Background

Advanced oxidation processes are relatively well established in the fields of groundwater and soil remediation, however they have not yet become widespread in the drinking water industry. This may change because of the recent increase in popularity of UV for disinfection. The rationale is that plants that are already installing UV for primary disinfection may also consider installing hydrogen peroxide (H_2O_2), so that UV and H_2O_2 may be used together when needed for advanced oxidation (for example, for periodic taste and odour control). This flexibility to use UV routinely for disinfection and UV/H_2O_2 on an as-needed basis for advanced oxidation has led to a growth of interest in AOPs for drinking water in general.

Despite the promise of AOPs, research for drinking water applications has been limited. The majority of the research to-date has explored the effectiveness of AOPs when treating various micropollutants such as pesticides, nitrosamines, and other potentially toxic compounds (e.g. Hill et al. 1997; Soroushian et al. 2001; Linden et al. 2004). A major area where research is lacking is in the use of UV/H_2O_2 to control taste and odour. The proponents of the Chair, along with our industrial partner, Calgon, believe that taste and odour control may be the first widespread application of advanced oxidation in drinking water treatment. Studies to-date have established that common taste and odour-causing compounds can be destroyed using UV/H_2O_2 under laboratory conditions, with the reaction kinetics now fairly well established (Bhatkhande et al. 2001). The main difficulty, however, is in scaling up these bench-scale results for full-scale treatment system design. Complications include non-ideal UV reactor hydraulics, complex UV light intensity fields and competition kinetics with other compounds in the water. At present, there is no known methodology for using data generated at bench-scale concerning UV/H_2O_2 treatability of water samples to design a full-scale system. This leads to a lack of confidence in the application of UV/H_2O_2 systems. Until this obstacle is overcome, it is likely that engineers and customers will remain reluctant to commit to UV/H_2O_2 treatment for taste and odour control.

A second major opportunity for the use of UV/H_2O_2 is in the destruction of EDCs, PhACs, and algal toxins. There has already been considerable research on the destruction kinetics of many of these micropollutants when applying AOPs, however many compounds remain untested due to a requirement for complex laboratory methods and capabilities. Furthermore, the use of UV/H_2O_2 as an advanced oxidant may yield different destruction kinetics than other AOPs, such as Fenton-based processes, due to the impact of direct UV photolysis. There is therefore still a large gap in our understanding of the control of these micropollutants using UV/H_2O_2.

Research Plan

There are three major research initiatives related to the use of UV/H_2O_2 treatment.

1) Taste and odour control,
2) Control of emerging micropollutants, including EDC, PhACs, and algal toxins,
3) Exploration of potential treatment side-effects.

Taste and odour control. The Chair's research is building on preliminary work that has determined the reaction kinetics of a number of common T&O-causing compounds with hydroxyl radicals (*e.g.* Rosenfeldt et al. 2005). The research challenge lies in developing tools that bridge the gap between such fundamental knowledge, and being able to predict the performance of a specific UV/H_2O_2 system for a given water quality. At present, the only technique available to verify UV/H_2O_2 performance for T&O control is to conduct full-scale trials.

The required tools include a computer model that combines hydraulic modelling within the UV reactor, a UV light intensity field, and water chemistry, to ultimately predict the amount of hydroxyl radicals that will be generated and will react with the target contaminants. The Chair and partner Calgon, have already conducted considerable research on computational fluid dynamic modelling of UV reactors (Templeton et al. 2006), and UV light intensity models have been developed by others (e.g. Blatchley et al. 1998; Janex et al. 1998). The major initial research component will be to combine these models with an advanced oxidation chemistry model, followed by validation of the combined model using bench-scale and pilot-scale data. To our knowledge this will be the first such model developed for UV advanced oxidation systems, although similar models for other oxidation systems (e.g. ozonation) have been produced in the past (e.g. Ta and Hague 2004). The main challenges with this model will be to account for the complex photochemistry associated with different UV emission and absorption spectra associated with different lamp types and water matrices.

In parallel with the model development, the Chair will also be conducting bench- and pilot-scale research on UV/H_2O_2 performance for T&O control. We will work with our utility partners to install UV reactors onsite, and to test their performance at controlling a wide range of T&O compounds, including geosmin and MIB under real operating conditions. We will then compare the measured performance against the performance predicted by our modelling. The combination of modelling and a comprehensive empirical database will give us an excellent understanding of how UV/H_2O_2 systems may best be applied to treat taste and odour-causing compounds.

Control of emerging micropollutants. The Chair will broaden our knowledge of the ability of UV-based advanced oxidation processes to destroy EDCs, PhACs, and algal toxins; emerging contaminants of concern in the water supply field. The Chair's research program builds on an existing database to include compounds not yet studied (e.g. antibiotics such as lasaloid A, meclocycline, and sulfadiazine), as well as to consider not only reaction between the micropollutants and hydroxyl radicals, but also the effect of direct UV photolysis that would occur in a UV/H_2O_2 system.

Testing is scheduled to be concurrent with that for T&O control (2008-2009 bench-scale, 2010-2012 pilot-scale). Analyses of EDCs and PhACs (including selected antibiotics, analgesic compounds, and reproductive hormones) will be conducted using a new GC/MS/MS in our research group. In addition, waters treated using UV/H_2O_2 will also be analyzed in terms of potential toxic/genotoxic effects, using tests such as the Ames fluctuation, SOS, Microtox, and YES tests. These bacteria-based (geno)toxicity tests will provide an initial indication of potential harmful side effects of by-products of UV/H_2O_2 that may be formed during the destruction of target organic micropollutants.

Exploration of potential treatment side-effects. There are very few drinking water UV/H_2O_2 systems installed in the world. As such, there is little experience concerning possible side-effects associated with this type of treatment. Members of the Chair have conducted preliminary research on such side-effects in a recent study (CWN 2006), and indications are that by changing the properties of natural organic matter, UV/H_2O_2 may affect several important water quality parameters in both positive and negative ways. To build on this work, the Chair is exploring the following phenomena:

The effect of UV/H_2O_2 on

- biodegradable organic carbon formation (BDOC)
- subsequent chlor(am)ination DBP formation
- subsequent chlor(am)ine stability

The Chair research will include a comprehensive survey of different water types and conditions (e.g. pH, temperature, bromide concentration) to identify possible trends in these phenomena. The goal of the research is to identify conditions that impact positively and negatively on overall water quality when applying UV/H_2O_2, such that treatment strategies can be designed to provide the best possible water.

These experiments will be conducted first at bench-scale (2008-2009). Both low and medium pressure UV collimated beam reactors will irradiate different water samples containing different amounts of H_2O_2. The irradiated water will then be analysed for BDOC, and parallel samples will also be exposed to different concentrations of chlorine and monochloramine to explore DBP formation and chlor(am)ine stability. DBPs will include both currently regulated compounds (THMs and HAAs) and emerging DBPs (e.g. AOX, haloacetaldehydes, halonitromethanes, etc.). During 2010 it is proposed that the biostability of UV/H_2O_2 treated water will also be examined using annular reactors (ARs) – devices designed to examine biofilm formation in a simulated distribution system environment (Gagnon et al. 1997; Gagnon et al. 2000; Chauret et al. 2005).

IMPROVED METHODS OF GRANULAR ACTIVATED CARBON FILTER-ADSORPTION

Background

Granular activated carbon (GAC) is commonly applied to remove organic contaminants, such as those that cause health effects (e.g. pesticides) and taste and odour (e.g. geosmin, methylisoborneol) (Roberts and Summers 1982; Chen et al. 1997; MacKenzie et al. 2005). GAC functions by adsorbing organics and therefore has a finite service life (Crittenden et al. 1993). In many cases, a GAC filter bed will be effective for only 1-2 years before it needs to be replaced or regenerated (Bond and DiGiano 2004), either of which can be expensive.

One challenge associated with GAC as a water treatment technology is a lack of understanding by users and engineers about how to select an appropriate carbon. In practice, carbons are most commonly selected based on iodine number. The iodine number, however, provides no information about how well a particular carbon will adsorb a particular contaminant in a water containing a unique suite of compounds that will compete for adsorption sites. The American Water Works Association has recently added a second test, the Trace Capacity Number (TCN) test, to its Granular Activated Carbon Standard. This test adds greatly to the ability of treatment professionals to properly characterize the adsorptive capacity of carbon, however it is cumbersome and requires specialized equipment. The Chair, together with its partner, Calgon, will introduce a third method, the Trace Capacity Number Gas-Phase (TCNG) test, which promises to provide a simple method of characterization that utilities and consultants may use to ensure that the carbon they select will meet their needs. The drinking water treatment industry at present is extremely poorly educated when it comes to carbon selection, and such research will clearly demonstrate in a concrete and quantifiable manner the benefit, in terms of cost and performance, of using more rigorous carbon characterization methods.

A second important challenge for the application of GAC for periodic taste and odour control is an inability to accurately estimate the remaining life of an existing bed. During periods when there are no taste and odour compounds present in the water that can be actively monitored, there is no indication of whether a bed of GAC is exhausted. Utilities at present must either replace their carbon on a very conservative schedule to avoid reaching exhaustion, or else they must be resigned to replacing the carbon after breakthrough is observed. Ideally, a method would exist that would allow a sample of carbon to be removed from a bed and tested in a way that would allow its remaining life to be estimated. The carbon could then be replaced on a schedule that is not overly conservative and expensive, yet ensures the maintenance of acceptable water quality.

One of the Chair partners, Calgon, has developed an in-house Accelerated Column Test (ACT) that may serve as the foundation for such a test. The ACT is a very small-scale column containing pulverized carbon that could, in theory, be sampled from an existing GAC bed. This test can give results within hours to days on GAC adsorption kinetics and thermodynamics. It is similar to the existing Rapid Small-Scale Column Test (Crittenden et al. 1986), except it is several orders of magnitude faster and much simpler. One major research challenge in applying this test for the purpose of predicting remaining service life of a carbon bed is to establish a method for pulverizing the GAC sampled from the plant in such a way that it doesn't interfere with test results. A second challenge will be to determine whether the test requires use of the exact analyte of interest (e.g. geosmin or MIB), or whether a more convenient surrogate can be used. These issues will be explored as part of the Chair's research.

Research Plan

The research has begun with the completion of a review of methods used by previous researchers to assess GAC bed life and adsorption capacity, development of a detailed experimental design for bench-scale, and any required method development and optimization for analysis of taste and odour-causing compounds (e.g. geosmin and MIB). The Chair is now undertaking a series of bench-scale testing to be followed by pilot-scale and full-scale investigations.

Carbon selection criteria. The Chair, in partnership with Calgon, is working to develop a gas-phase TCN test (TCNG) that promises to be quick, easy, and together with the iodine number, will greatly help in carbon characterization for engineering design (2008). The TCNG test has already been developed as a prototype by Calgon, so the Chair activities consist largely of refining the method as required, and then demonstrating its usefulness compared to the iodine number alone. The testing will consist of a series of bench-scale and pilot-scale studies (2008-2009 and 2010-2012, respectively) in which the absorptive capacities for taste and odour-causing substances (e.g. geosmin, MIB) will be assessed for several different carbons with identical iodine numbers. Our research hypothesis is that despite similar iodine numbers, the carbons will exhibit different absorption kinetics and thermodynamics. We will also measure the TCN and TCNG parameters for these carbons, with the goal of demonstrating that while iodine number alone is not a good descriptor of carbon capacity, the use of iodine number together with the TCN and/or TCNG parameters will allow for a confident prediction of the carbon performance in terms of taste and odour control.

Pilot-scale studies for this part of the project will employ GAC filter columns with empty bed contact times consistent with actual practice. Bench-scale studies will use both RSSCT and ACT methods to test carbons over much shorter time periods and allow comparisons to pilot-scale results.

Assessing Remaining GAC capacity. The Chair will conduct research to develop a simple test to predict remaining service life of a GAC bed (2008-2010). We will base this test on the Accelerated Column Test (ACT) developed by our partner, Calgon. The goal of this research is to modify the existing ACT in such a way that representative carbon samples can be collected from existing GAC beds, and then tested using the ACT apparatus to determine the remaining bed life for taste and odour control. Conceptually, the main challenges with this approach will be to develop a method for sampling carbon from an existing bed and pulverizing it for the ACT test in such a way that results can be extrapolated back to the bed. The research also involves developing a mathematical model to equate a full-scale GAC system to the carbon in the ACT test. Experiments at bench-, pilot-, and ultimately full-scale will be conducted to validate the approach and determine practical limits for the mathematical model.

COMPUTER APPLICATIONS FOR TREATMENT PROCESS OPTIMIZATION

Background

The drinking water industry is arguably “low-tech” when compared to other process-oriented industries. There is, however, massive opportunity for the implementation of computer applications. Two particular types of computational methods – artificial neural networks and computational fluid dynamics – are the focus of NSERC Chair research in this area.

Artificial neural networks (ANNs) are used to establish correlations in systems where the variables are too complex to understand mechanistically or through simple regression techniques (Rodriguez et al. 1997; Haas 2004). ANNs have many possible applications in water treatment such as prediction of optimal coagulant doses (Maier et al. 2004), predicting inactivation of microorganisms by free chlorine (Haas 2004), modeling chlorine decay in distribution systems (Rodriguez et al. 1997; Rodriguez and Serodes 1999), improving membrane performance (Delgrange-Vincent et al. 2000; Teodosiu 2000; Cabassud et al. 2002; Shetty et al. 2003), modeling bromate formation during ozonation (Legube et al. 2004), and modeling adsorption onto activated carbon (Brasquet and Le Cloirec 1999). One particularly promising application of ANNs that is yet to be investigated in detail is predicting filter breakthrough and filter run length based on water quality characteristics (pH, temperature, TOC), efficiency of upstream processes (e.g. coagulation), and filter characteristics (filter depth, media type, backwash frequency),

Computational fluid dynamics (CFD) modeling has been applied to various water and wastewater processes (Brouckaert and Buckley 1999; Do-Quang et al. 1999), including activated sludge reactors (Karama et al. 1999), UV disinfection reactors (Blatchley et al. 1998; Janex et al. 1998), storage reservoirs (Hannoun et al. 1998; Ta and Brignal 1998), chlorine contact chambers (Crozes et al. 1999), and ozone disinfection processes (Ta and Hague 2004). A novel evolution of the use of CFD in treatment process optimization would be to use CFD models either online, or results from modeling previously conducted, to optimize treatment in real time. For example, the primary disinfection process is governed by CT values whereby disinfectant doses (C) must be adjusted based on contact times (T). In current practice, the determination of contact times is very rudimentary and overly conservative, leading to routine overdosing of disinfectant, which in turn may form unnecessarily high concentrations of disinfection by-products. The use of CFD online to calculate contact times with great precision may allow plants to optimize their disinfectant doses to reduce DBP formation while maintaining adequate pathogen control.

Research Plan

Artificial neural networks (ANNs) appear to be ideally suited to describe filtration performance, where particle breakthrough and length of filter cycle are a complex function of a number of interconnected factors (e.g. influent water quality parameters, time since last backwash, filter loading rate, etc.). The goal of the Chair's research will be to develop ANNs during 2008-2009 to identify opportunities for improvement in filtration operations. Following this period, the ANN models that are developed will be ready for validation. Experiments will be conducted at pilot-scale, using filter columns with media depths and column diameters that are representative of full-scale treatment (Harrington et al. 2003). Traditional input variables to the ANN that are being used include filter loading rate, elapsed time since the last backwash, media depth and type, headloss across each media layer, and influent turbidity, particles counts, temperature, and pH, among others. Filter effluent variables to be monitored include turbidity, headloss, and particle counts. The resulting ANN model predictions will be compared with experimental data via linear correlation analysis (R^2) as in previous ANN modeling studies (e.g. Brasquet and Le Cloirec 1999; Maier et al. 2004). The ultimate goal of this research is to determine whether ANN models describing filter performance can be used with confidence as tools to modify and improve filter operations.

The Chair is also examining the opportunity to use information from computational fluid dynamics modelling (CFD) to optimize primary disinfection in real time. Regulations govern primary disinfection using CT values, where T is a measure of contact time and C is disinfectant concentration. Values for C can be easily measured (e.g. with a chlorine residual analyzer), but at present, there is no online instrument that can measure T directly. Instead, flow rates are monitored and values for T are conservatively estimated using tank volumes and assumed baffle factors to account for non-ideal hydraulics. This conservative approach may result in routine overdosing of disinfectant, which in turn leads to increased costs and disinfection by-products. The Chair's research will explore the benefits of installing real-time CT monitors that will continuously calculate CT based on measured disinfectant concentrations and CFD modelling results of contact time. Our industrial partner, Hydromantis, produces software called WatPro that will serve as the basis for online CT calculations. The research element is to integrate CFD predictions of contact time into WatPro. The ultimate goal would be to bundle a CFD model with WatPro which would allow estimates of contact time to be updated continuously. However, at present, the technology is lagging in terms of CFD modelling speed, so our initial approach will be to model flow scenarios offline, and then create a database of contact times representing the complete range of flow conditions (flow rates, water level in tanks, temperature, etc.) that may be encountered for a given plant.

The research in this area will include both model development, as described above, as well as full-scale validation of the approach at one or more of the participating utilities. The ultimate goal of the project will be to report on the benefits of adopting a computational method for improving CT calculations. It is our hypothesis that by calculating CT accurately, rather than relying on arbitrary and typically overly conservative baffle factors, more consistent pathogen control can be maintained while also allowing disinfection by-product formation to be minimized.

RESEARCH MANAGEMENT

Meetings with partners will be scheduled on a regular basis and to meet specific project needs. A "Technology Transfer" day will be held in Toronto once a year to bring all partners together and highlight research completed over the past year. In addition, specialty events will be held to highlight specific or emerging technologies.

Each project within the broader Chair research program will be assigned a Project Manager. The Project Manager may be one of the Professors, Research Associates, Senior Graduate Students, or potentially an individual from one of the Chair partners. He/she will be responsible for the day to day operations of the research team with our partner for that project. Each project will be organized using MS-Project software to formalize tasks, deliverables, schedules, budget, etc.

VALUE OF THE RESEARCH AND BENEFITS TO CANADA

A discussion of the value of the research and benefits to Canada has been provided within many of the preceding sections. A summary of the highlights include:

- Providing a research engine to serve the direct and immediate needs of the Chair partners, resulting in improved treatment technologies, and improved methods to apply those technologies.
- Developing a research infrastructure that can respond to the technical needs of the industry as represented by the Chair partners, and the industry in general, that may view the Chair as a valuable resource that can be consulted as needed.
- Enhancing the position of the University of Toronto as an international leader in drinking water treatment technology, ensuring that it remains a self-sustaining centre of excellence in the field.
- Building upon the existing research infrastructure already in place at the University of Toronto, resulting in excellent added value for the investment in the Chair.
- Disseminating information to utility and engineering consumers on how best to apply emerging technologies, thereby expanding the market opportunities for our Chair partners and ensuring that new technologies are applied appropriately.
- Providing information on how to optimize treatment in such a way as to reduce costs and enhance public health protection.
- Stimulating an environment of excellence among municipal utilities Canada-wide, by highlighting the proactive approach of our flagship utility partners.
- Fostering increased public awareness in drinking water issues by working with our utility partners to communicate their research activities to their City, Town and Regional Councils and to their general customers.
- Advancing of the state of the art in drinking water science, through dissemination of research results to the world-wide scientific community.
- Improving the ability to inform regulators and policy-makers about emerging issues and research through the Chair's involvement on committees and task forces at the regulatory level.
- Ultimately improving the quality and safety of Canada's drinking water.

APPENDIX "B"

Contributions

For York:	Year 1-2008	Year 2-2009	Year 3-2010	Year 4-2011
Direct costs	$20,833	$41,667	$41,667	$41,667
Indirect costs (20%)	$4,167	$8,333	$8,333	$8,333
Total	$25,000	$50,000	$50,000	$50,000
In-Kind contributions	-	-	-	-