Renewing wastewater

Experienced engineer and chemical researcher **Dr Bruno Chabot** describes the device his lab has created to fight water contamination in Canada, and elucidates upon his professional history and how it has led him to pursue studies in this area

Can you shed some light on your research into pulp and paper effluents?

I started this research programme when I was hired as a new professor at the Chemical Engineering Department within the Université du Québec à Trois-Rivières. While in this position, the opportunity arose to work for a local paper mill as a research engineer for three years. I was subsequently involved in a project that aimed to introduce calcium carbonate fillers into the production of specialty papers using thermomechanical pulps. This involved extensive work on process waters and effluents, as well as a thorough study of water circulation around the mill. It made me realise the enormity of the volumes of water used to produce just a single tonne of paper.

Although paper mills have for a long time now implemented measures to reuse process waters, there is still room to improve water and energy savings potential – as well as corporate environmental performance – through further reduction of freshwater consumption and effluent volumes. I therefore initiated the long-term research programme in which we are now engaged, focusing on reducing the freshwater consumption of paper mills using innovative technologies. Our main objective is to develop alternative adsorption processes that could remove contaminants, in order to increase process water recirculation within the mill without affecting either product quality or machine operability. With Masters, PhD and postdoctoral students aiding us in our endeavours, we first developed a fluidised bed reactor using modified solid sorbents capable of removing contaminants from paper machine whitewater prior to recycling. More recently, we initiated a research project concentrating on the development of a multifunctional adsorbent filter using electrospun nanofibres as a material basis.

What are the main features of this adsorbent device, which can remove various contaminants from aqueous effluents? How does it operate?

The proposed device is part of an advanced process technology. It will be used for the purification of biologically treated wastewater that is discharged into receiving waters. The main feature of the device includes a non-woven filter media constructed of randomly laid nanofibres. These nanofibres form 3D porous mats that provide a physical, sized-based separation mechanism for the filtration of contaminants.

Are you testing the device for other types of wastewaters?

Up to now, we have mainly focused on pulp and paper mill effluents. However, the device could also be used to test other types of wastewaters, especially those from the mining industry, and shale gas fracturing operations. Both effluents contain high levels of various contaminants, including heavy metals that must be removed to avoid potential environmental risks. Removing them will also allow significant water recycling, which could help build an effective and economical wastewater management plan for operations.

What advantages are afforded by basing your research at the Department of Chemical Engineering at the Université du Québec à Trois-Rivières?

Impressive research facilities in both engineering and science are available at the Department, as well as at the Lignocellulosic Materials Research Centre, which is based on campus and to which I belong. The advantages are numerous and the facilities here allow me to conduct specific research and gain access to specialised technical resources, including well-instrumented laboratories and an important bank of analytical instruments that are vital to complete the analytical determinations required to conduct my research. Additionally, scientific collaborations with several research groups from other universities are in place that help me access grants and other funding sources. Finally, we have access to undergraduate students who are often involved in my research projects.

With whom are you collaborating to achieve your research goals? How important is a multidisciplinary approach to your work?

Strong research collaborations with leading groups and organisations is very important to the development of innovative projects. I have established research partnerships with several colleagues working in chemistry and biology departments within my home institution, alongside others, including the Université Laval in Quebec City. I also work with a college technology transfer centre, Innofibre, one of our partners based in Trois-Rivières, and hold a membership of two strategic clusters supported by the Government of Quebec: the Quebec Centre on Functional Materials and the Research Centre for Renewable Materials. Both clusters are gathering researchers from many disciplines with the overall objective of developing innovative materials for applications in various fields, including environmental science.

Pulp reality

A group of chemical engineers based at the **Université du Québec à Trois-Rivières** is developing a solution to the problem of water consumption and effluent output in paper mills that uses nanofibre mats as filtration devices

OVER THE COMING years, Canada is set to face a real problem as one of its most important and valuable natural resources is depleted. Demand for this commodity is so ubiquitous, and the growing economy so dependent upon a plentiful supply of it that the quantity available is intimately linked with the prosperity of the country; as the population continues to increase and the economy to thrive in the next few years, it seems inevitable that this vital reserve will undergo increasing stresses with serious consequences on its sustainability. The resource in question is not oil, wood or ores, but water. Canadians use more of it per capita than any other nation except the US, and consume more than twice as much as the average European.

Canada is often perceived as a water-rich country, and indeed, it is – at least proportionally. Twenty per cent of the world's freshwater reserves are held in Canada, which explains to some degree why the country – in both its people and industries – is so reliant upon it. However, with rapid urbanisation, the threat of climate change and the growth of population and dependent industries all putting pressure on the large but finite supply, the need for change is clear. Recent figures suggest that, as with many resource and pollution issues, it is not personal but commercial use of freshwater that drives unsustainable patterns. The food, chemical and petroleum and coal industries, for example, demand approximately 300 million cubic metres of water each per year according to Statistics Canada.

PAPER PRESSURE

Even this vast consumption pales in comparison to that of the prime culprit: the paper industry.

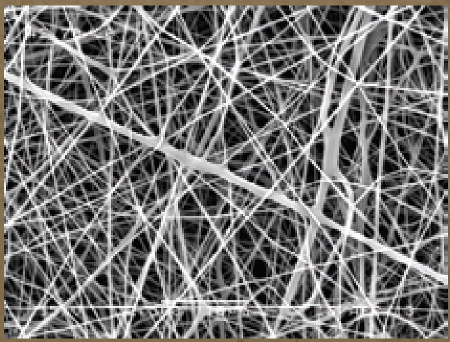
A PhD student determining copper ion concentration in effluent via titration after adsorption test with nanofibres.

Using an incredible 1.6 billion cubic metres per year, the amount of water used to make paper is comparable to that used by every other industry combined. Around 42 per cent of water withdrawal is down to paper mills – and the discharge of effluent stemming from this sector is even more disproportional at 45.2 per cent. As Canadian governing bodies at every level have already begun to conduct research into the issue of water sustainability, it seems likely these shocking figures will direct their attention in policy making towards stricter regulations surrounding water use, especially when it comes to paper-making.

The fact remains that sooner or later, innovative technology will be required to alter the manner in which paper mills operate – and one group of researchers at the Université du Québec à Trois-Rivières is working to ensure this technology is available sooner. Dr Bruno Chabot leads a team within the University's Lignocellulosic Materials Research Centre, dedicated to developing new solutions towards reducing the environmental impact of paper milling and encouraging water sustainability. The Canadian scientists have recently made most headway with their unique nanofibre-based filter product, which, through adsorption, is able to remove a high proportion of heavy metals from wastewater, thereby rendering it suitable for reuse.

THE MODEL MATERIAL

Since the 1980s, paper mills have been under pressure to reduce their water consumption and, to a substantial degree, have been successful. This progress has been largely due to previously promising methods including chemical precipitation, and more recently membrane separation and reverse osmosis. The problem, however, is that these practices are expensive, slow and comparatively inefficient. What is required is a material with high adsorption capacity and permeability, Chabot and his colleagues have determined, one with a minimal base weight and pore size, to affect optimal filtration. These features would overcome the problems associated with the current alternative solutions already being implemented. This left one prevailing question: how could such an ideal material be fabricated?



A scanning electron microscope (SEM) image of an electrospun nanofibre mat.

The answer lay in nanofibres. These tiny polymer threads, which can be as small as 3 nm in diameter, are not much to look at individually, but together can form a mat with a huge surface area and great permeability. Nanofibres are produced using a technique known as electrospinning, which is similar to electrospraying. Both methods entail the application of electrical current to the polymer in a liquid droplet form; this current causes the droplet to stretch into a cone shape, and then, at a specific voltage, deformation overcomes surface tension and a tiny jet of polymer is created. In the case of electrospraying, this jet forms a spray of tiny droplets, but in electrospinning, the continuous jet cools into a nanofibre.

CRACKING CHITOSAN

The kind of polymer used was also of crucial importance to the Quebec team; it would have to possess an ideal chelating capacity, allowing it to bind to heavy metals and trap them, but also be readily available and cheap to procure. The ideal solution appeared to be chitosan, a polymer derivative of the chitin that constitutes crustacean shells. When used as a filtration membrane, the polymer exhibited low permeability and poor volumetric properties – but, the Canadian engineers knew that once formed into a nonwoven mat these shortcomings would be overcome. As well as retaining desirable properties, chitosan is readily available at a very cheap cost, since it is essentially a waste product from the fishing and marine industries.

The answer lay in nanofibres. These tiny polymer threads together form a mat with a huge surface area and great permeability

Dr Bruno Chabot (**right**) and his two students in the lab.

However, there were still problems: in its liquid form, chitosan was too viscous, and its chemical structure to rigid, to be effectively used in the electrospinning process. As droplets of chitosan deforms past the limits of surface tension, they still produces a jet, but instead of being a continuous stream, the output of the viscous polymer is a plume of beads, as used in the electrospraying process. The team developed two solutions to this issue: firstly, to dissolve chitosan in a solvent such as strong acetic acid to weaken its surface tension and secondly, mixing it with a copolymer to reduce its viscosity. An additional benefit of the latter is that the porosity of chitosan nanofibres can be increased by blending it with copolymers such as polyethylene oxide.

Apparatus used to make nanofibres by electrospinning.

THE FINAL FILTER

Recently, Chabot and his colleagues tested the efficacy of their chitosan/polyethylene oxide nanofibre mat in removing copper (II) ions from aqueous solution under various conditions. The results were encouraging to say the least – with optimal conditions including a pH of 5.5, temperature of 55.7 °C and a copper concentration of 100 parts per million, the 75 mg nanofibre mat achieved an adsorption of 94.7 per cent over four hours. Although these results have yet to be published, they are sure to cause quite a stir among paper mills looking to reduce their water dependence.

In the future, further investigations on the nanofibre filter are necessary, including efforts to discover the optimal mass ratio of chitosan to polyethylene oxide, as well as to determine how the solution fares against other heavy metals such as nickel and iron. Chabot also plans to look into the possibility of using other biomaterials – starch, cellulose, cyclodextrins and keratin – in innovative, sustainable products to bolster the future of paper milling.

INTELLIGENCE

MULTIFUNCTIONAL ADSORBENT FILTER FOR THE TREATMENT OF PULP AND PAPER MILL EFFLUENTS

OBJECTIVES

- To investigate the development of an adsorbent device – using electrospinning to make nanofibres from polymer solutions – for the removal of various types of contaminants from aqueous effluents
- To investigate biopolymers as potential candidates for the production of electrospun nanofibres for applications in wastewater treatment, with further potential applications in mining industries and shale gas extraction

KEY COLLABORATORS

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BRUNO CHABOT has been Professor at the Department of Chemical Engineering, Université du Québec à Trois-Rivières since 1998. After completing a PhD at the University, he held a postdoctoral position at the Chemical Engineering Department, Auburn University, Auburn, USA, from 1996-98. He also worked for several years as a research engineer in paper mills. His main research interest covers process water recycling. His current research includes the development of an electrospun nanofibrous filtering media for the removal of contaminants from aqueous solutions.

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cqmf centre québécois sur les matériaux fonctionnels
UQTR ÉCOLE D'INGÉNIERIE Génie chimique
CENTRE DE RECHERCHE SUR LES MATÉRIAUX RENOUVELABLES