Industrial water treatment

Novel treatment solutions turns industrial wastewater into commodity

A novel industrial wastewater treatment technology developed with funding from the Water Research Commission (WRC) is offering South African industries a more sustainable solution for wastewater treatment.
Article by Sue Matthews.

When Ernest Shackleton and his polar exploration team were forced to abandon their ship in Antarctica in 1915, their survival hinged on two special properties of ice. Firstly, ice is unique in that it is less dense in its solid state than in its liquid state, which means it floats on water – so the stranded men were able to camp on drifting ice floes for over five months.

Secondly, as seawater freezes, the salt ions are rejected from the ice crystal lattice and become trapped in pockets of brine, before slowly leaching out into the seawater below under the effect of gravity. This natural tendency to reject impurities means sea ice that is several years old can be melted and used for drinking water – a key factor in keeping Shackleton's team alive until their rescue.

These special properties of ice are exploited in a new wastewater treatment technology based on research conducted at the University of Cape Town's Department of Chemical Engineering. Under the leadership of Prof Alison Lewis, the research team embarked on their journey of scientific discovery in much the same spirit of exploration that Shackleton showed a century ago – and at times needed a pinch of his perseverance!

In a TEDx talk presented in Cape Town in 2011, appropriately titled 'Be bold and mighty forces will come to your aid', Prof Lewis explained the nature of their research. "Imagine if we could deconstruct contaminated waters and form pure, usable water that we could put back into the water cycle, as well as take the contaminants and recover them in the form of something useful, like pure salts," she said.

"This concept of deconstructing contaminated water into useful products is what we've been doing in our lab. Basically, we're using a process called eutectic freeze crystallisation, which involves cooling the contaminated solution down to freezing point, so the water crystallises out as ice and the contaminants crystallise out as pure, usable salts."

Prof Alison Lewis, founder and Director of the Crystallisation and Precipitation Research Unit in the Department of Chemical Engineering at the University of Cape Town.

The contaminated waters being used in the research are hypersaline brines originating from mining operations, power stations and petrochemical refineries. Wastewater treatment for these sectors typically involves sequential membrane filtration incorporating, for example, ultrafiltration as a pre-treatment step followed by reverse osmosis. This produces water clean enough to re-use in the plant or release into the environment, but the contaminants are in the process concentrated into a highly saline brine.

One way of reducing the volume of such brines is to discharge them into evaporation ponds, but these require a large area of land set aside for the purpose, and risk contaminating groundwater if not properly lined. Alternatively, the brines can be passed through an evaporative crystallisation plant, which uses heat to transform them into a purified distillate and a dry salt waste. The disadvantages of this approach are the high energy costs for heating and the mixed composition of the salt waste, which necessitates either additional treatment or disposal in a landfill.

The beauty of EFC is that the energy required to separate the water as ice (involving a phase change from liquid to solid) is significantly less than that required to separate it by evaporation (liquid to gas). What's more, individual salts can be recovered, because each has its own unique temperature at which it will crystallise out in that particular mixture.

In one set of experiments, for example, the research team recovered calcium sulphate and sodium sulphate form a brine that had been produced by a reverse osmosis plant treating coal-mining wastewater. Calcium sulphate is more commonly known as gypsum, the material from which ceiling boards, drywall and plaster are made, but it is also used as a fertiliser in agriculture and as a filler in dentistry and orthopaedic surgery. Sodium sulphate is a key ingredient of soaps and detergents, but it is used in the production of paper, glass, textiles and a variety of other materials too.

The potential to sell these and other more valuable salts, combined with the operating-cost savings associated with the lower energy demand, should prove to be a major incentive in the adoption of this technology, although – being so new – the initial capital costs will still be very expensive.

Fortunately, two local stakeholder groups were willing to make the investment required to scale up the lab-based research into a real-world treatment facility. The Coaltech Research Association – made up of coal-mining and -processing companies as well as various research organisations, including the WRC – contracted Prentec to design and build a full-scale demonstration plant at the Optimum Colliery near Middelburg, which became operational in May last year.

In April of this year, Eskom commissioned a pilot plant, which was designed and built by Proxa, at its Research and Innovation Centre at Rosherville. The intention is to test whether the technology will be suitable for recycling water used in the electricity-generation process, and also for treating acid mine drainage so that it can be used at power stations. Eskom consumed almost 300 billion litres of water last year, but EFC could provide a way of reducing its water footprint while at the same time addressing one of South Africa's most pressing environmental problems.

"Students and staff from the Crystallisation and Precipitation Research Unit went up for the commissioning and spent a week on the plant," says Prof Lewis. "Our involvement there is to be kind of an academic sounding board – we were involved in trouble-shooting and problem-solving in getting the plant up and running, but also in identifying other issues for which we need to consider developing new research projects."

"For now, we're still busy with a big WRC project that started in 2013 and runs until the end of 2017, and we're doing that in collaboration with Eskom. We have our own research questions aimed at increasing our understanding of particular aspects so we can feed that back into the design, but the engineers at the pilot plant are also generating new questions. All the questions are a complex interaction between physical and chemical processes – and, of course, what happens at small scale and large scale are often quite different!"

The WRC has been supporting the team's research on EFC since it began in 2007. The initial project to establish fundamental principles used synthetic wastewaters typical of the effluents produced by major South African industries, but the follow-on project used real wastewaters from the coal-mining and platinum industries. Experiments were conducted to investigate aspects such as the effects of impurities, and the influence of operating temperature on yield and purity of the final products.

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The main aim of the current project is to develop tools that would allow EFC to be run in continuous mode. All the experiments for the two previous projects were run in batch mode, and even the Eskom pilot plant is designed to operate on a 20 day cycle. But batch processes often produce inconsistent quality, and they would in any case be unsuitable for industrial concerns that generate large volumes of waste on an ongoing basis.

As part of the project, a lab-scale continuous EFC plant was therefore designed, constructed and brought into operation at UCT. Although its capacity is only two litres, it is already proving its worth in a range of experiments. For example, it is being used to study ice scale formation and how this is affected by scraper speed, and also to investigate whether anti-scalants have an effect on the thermodynamics and crystallisation kinetics of both ice and salt.

In industrial processes, anti-scalants are often added to cooling waters and reverse osmosis feed-streams to prevent scaling of heat exchangers and membrane fouling, so the research aims to determine whether a pre-treatment step to remove them would be necessary. Initial work on phosphonate-based anti-scalants has shown that these have no effect on the solubility of sodium sulphate, nor on the freezing point depression of ice.

Of course, most of the experiments are conducted by students, working under Prof Lewis's supervision. To date, the three WRC projects, along with various industry-funded projects, have provided hands-on training for 6 PhD and 8 MSc students, as well as about 40 undergraduates. The WRC has been so impressed with the progress achieved that it bestowed the 2015 Knowledge Tree Award for 'new products and services for economic development' on Prof Lewis and her team.

"Eutectic freeze crystallisation is regarded as one of the WRC's flagship technologies," says Dr Jo Burgess, WRC Research Manager for mine water treatment and management. "We're proud to be associated with the progression of a technology from lab to full scale."

Prof Lewis points out that work on EFC started overseas in the

Prof Alison Lewis (far left) and some of her postgraduate students at the commissioning of the eutectic freeze crystallisation pilot plant at Eskom's Research and Innovation Centre in April.

Eskom's eutectic freeze crystallisation pilot plant, designed and built by PROXA at a cost of R8.3 million, is capable of treating 40 000 litres of water every 20-day cycle.

1950s, and over the years a number of researchers showed that it was technically feasible, but the concept was not pursued because freezing was considered too expensive. The vastly improved efficiency of modern-day compressors has now made it more commercially viable, but at the time she and her team began their own EFC research, the only other group working in the field was at the Technical University of Delft in the Netherlands.

"Our main contribution has been multi-component and complex hypersaline brines from mining operations, but there are lots of other potential applications, such as wastewater from the textile, paper and pulp, agriculture and food-processing industries, as well as fracking brines. We just happened to focus on mining because it was so relevant," she says.

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Asked whether EFC would be a suitable treatment technology for use on its own, she explains that for relatively dilute wastewaters, including most acid mine drainage brines, it is still more economical to use reverse osmosis to concentrate the stream before treating it with EFC.

"Otherwise, you'd make masses and masses of ice, and there are cheaper ways to separate water!"

Award winning scientist

Prof Alison Lewis was announced the winner of the Distinguished Woman Scientist: Research and Innovation Award at the Department of Science and Technology's 2016 Women in Science awards ceremony, held in Johannesburg in August. This is the second time she has been honoured in the awards, having been named Distinguished Woman Scientist in Physical and Engineering Science in 2012. In the same year she was given the National Research Foundation President's 'Champion of Transformation in Research' Award for her active involvement in training, fostering and mentoring black and female students.

Prof Lewis is the founder and Director of the Crystallisation and Precipitation Research Unit in the Department of Chemical Engineering at the University of Cape Town. She was appointed as a professor in 2007 and – following a two and a half year stint as Head of department – has since June 2015 served as the first female Dean of UCT's Faculty of Engineering and the Built Environment.

Prof Lewis recently co-authored a book, ***Industrial Crystallization: Fundamentals and Applications***, which has been published by Cambridge University Press.

To watch more on Prof Alison Lewis and her work, click here