A Fluid Situation

Chemical engineers are starting to think about wastewater treatment in an entirely new way

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AS ENGINEERS strive to provide clean water for all, it's safe to say that there is no current 'silver bullet' technology that will achieve this with positive impact on health, the environment, the economy and society. Chemical engineers need to begin thinking about water in an entirely new way: to look at developing socio-technological solutions tailored to specific challenges at specific locations within the water cycle, and put together bespoke collections of those solutions, to be deployed at point-of-need.

TWENTY65 – a newly-funded EPSRC Grand Challenge consortium aimed at bridging the innovation gap between cutting-edge academic research and the water industry – is taking up this challenge in the UK. Headed up by the University of Sheffield's Joby Boxall, the consortium – with its headline aim of "water for all" – will research eight socio-technical theme areas at the universities of Sheffield, Exeter, Reading, Manchester, and Newcastle, and Imperial College London.

Chemical engineering can address this challenge by pushing the boundaries of new science, as well as drawing on established technologies and techniques from industrial applications. Doing so will involve developing and demonstrating safe technologies at unusual scales, or within novel environmental or societal constraints. In many industrial applications, chemical engineers often see water as just one reagent among many. But if one is to intervene in the general water cycle, the challenge is to think of water not merely as an industrial medium containing materials you might wish to dispose of or recover, but as the focus and raison d'etre of the entire operation.

POTABLE WATER IS NOT JUST A BYPRODUCT OR REGULATORY REQUIREMENT, BUT A COMMITMENT WHICH MUST BE MADE ON AN ETHICAL LEVEL AS WELL AS A SCIENTIFIC AND TECHNICAL ONE

"Combining technologies at different scales and environments to produce a specific product is the bread and butter of chemical engineering" says Catherine Biggs, professor of environmental engineering at Sheffield. "But here clean, potable water is not just a byproduct or regulatory requirement, but a commitment which must be made on an ethical level as well as a scientific and technical one."

TWENTY65 starts from the assumption that the existing centralised paradigm in the provision of clean safe drinking water and sanitation is unsustainable in economic, sociological and ecological terms. Treatment plants are large, unpopular projects requiring considerable investment, for which neither the public nor private sectors show much appetite; many existing plants are reaching the end of their operating capacity or working lifespan, or both. Likewise, the major urban sewers, which – in the UK at least – were built to the standards and for the needs of a different age. Replacing them wholesale is an expensive prospect; when it comes to water infrastructure in particular, we must instead make better use of the large-scale assets we already have.

Within the theme Demand Based Technologies for Tailored Treatment (DBT), chemical engineering principles and technologies take centre stage. This is exciting news for the researchers involved. And, says Sheffield lecturer and course director Mark Ogden, it's a chance to show that chemical engineering "isn't just about characterising phenomena on the laboratory bench, but about putting those phenomena to work on real-world problems." While some of the phenomena are well understood in theory, applying them to water treatment outside of a purely industrial context involves a whole new set of operational considerations and challenges.

The DBT research focuses on three areas with potential to shake up existing technologies.

EXTRA STORAGE: BACKYARD WATER TANKS LIKE THIS ONE IN AUSTRALIA COULD BECOME MORE WIDELY USED

GRAVITY-FED MEMBRANE FILTRATION

The Sheffield team will be collaborating with Imperial College to investigate the potential of using gravity-fed membrane filtration to treat and re-use water from a variety of sources at household, neighbourhood or city scales.

For example, the water sector is currently showing renewed interest in urban rainwater capture, as it addresses a cluster of problems associated with climate change adaptation. Climate models predict that the future of British weather will be one of greater annual rainfall, but that rain is likely to arrive in shorter, more intense bursts. The recent floods in Somerset, Lancashire and Cumbria are early signs of this troubling 'new normal'. But flooding isn't the only problem: even in well-drained cities, heavy rainfall washes exotic toxins and pollutants off the impermeable surfaces of roads, pavements and carparks and into the drainage system; in many cases, this water may return directly to the watershed without further treatment.

BY USING BUILDINGS AS COLLECTION DEVICES, ROUTING THE RAINWATER THROUGH GUTTERING AND DOWNPIPES AND INTO STORAGE TANKS, IT SHOULD BE POSSIBLE TO BOTH REDUCE THE VOLUME OF RAINWATER REACHING URBAN DRAINS, AND TO SAVE THAT WATER FOR LOCAL (RE)USE.

Furthermore, short periods of intense rainfall make catchment management an even greater challenge: while you may be getting a greater volume of water each year, capturing it all so that it can be put to use – whether domestic, industrial or agricultural – requires either massive investment in new reservoirs, treatment plants and drainage systems, or some more subtle decentralised intervention.

By using buildings as collection devices, routing the rainwater through guttering and downpipes and into storage tanks, it should be possible to both reduce the volume of rainwater reaching urban drains, and to save that water for local (re)use. With the introduction of gravity-fed membranes, the range of uses to which that water could be put is increased, perhaps even to the extent of substituting for piped potable supply. Having a low-energy, highly reliable membrane treatment system available at a range of scales will open up a variety of water supply scenarios that are not possible today.

A DIRTY JOB: RESEARCH COULD SAVE STAFF FROM DESCENDING INTO SEWERS TO BREAK UP FATBERGS

Thames Water

FIGHTING FATBERGS WITH SYNTHETIC BIOLOGY

The second DBT research area brings together chemical engineering and synthetic biology in an attempt to intervene in the water cycle at a different location: under your kitchen sink. In recent years, you may have heard of something known as a "fatberg". Fatbergs are formed in sewers when FOGs (fats, oils and greases from food preparation) coagulate around bits of solid detritus – a process that can result in huge clumps of rancid fat blocking major sewerage routes. Removing fatbergs is currently an expensive, labour-intensive operation involving workers descending into the sewers and literally bashing them apart with sticks. It seems obvious that the easiest way to get rid of fatbergs would be to prevent all that grease getting into the sewers in the first place; addressing problematic fat disposal practices among rogue restaurateurs would help, but much of the fat that reaches the sewers is suspended in regular everyday dishwater, along with assorted cleaning products and all sorts of other organic waste.

The aim of this research is to develop a prototype under-sink fat-digestion unit which will make use of synthetic biological processes to remove some or all FOGs from dirty dishwater before they reach the sewers. This is somewhat more speculative a project than that of the gravity-fed membrane: while the latter involves a redeployment of an established solution in a new context, the fat-digester is a novel product concept in and of itself.

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However, the theoretical foundation work, namely the engineering of tailored microbes which successfully break down lipids into fatty acids, was actually demonstrated by a team of University of Sheffield students as their entry to the 2014 iGEM competition.

The challenge here is not only to ensure that the engineered microbes are both safe and effective, but also to house them in an affordable, reusable and easily-maintained consumer device – a unique collision of two very different design challenges.

DECENTRALISED, BESPOKE TREATMENT

The third DBT research area is a classical chemical engineering problem, only displaced into a new, more challenging context. In the majority of industrial recovery applications, the chemical engineer will have a predictable profile of contaminants which they must extract from the medium, which makes for fairly simple decisions regarding which reactants and ion-exchange strategies will get the job done.

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However, getting all the potentially useful goodies out of sewerage or greywater is a little more complex. For a start, while it is possible to account for the majority of different recoverable materials which might at any given time turn up in any given cubic meter of sewerage, accounting in advance for their relative amounts in any specific cubic meter of sewerage is next to impossible. As such, in order to develop treatment interventions aimed at not only purifying the water but also recovering useful materials from it (as opposed to simply getting rid of them), we need a system capable of coping with a wide range of different contaminants at variable concentrations. Furthermore, such a system needs to avoid using reagents or processes which successfully recovers one useful contaminant, but destroys or otherwise loses another.

DECENTRALISED TREATMENT SYSTEMS WILL LIKELY ALSO BE SMALLER AFFAIRS THAN THE EXISTING PLANTS – WHICH, WHILE IT MAY NOT MAKE DESIGNING THEM ANY EASIER, MAY MAKE THEM EASIER TO SITE WITHOUT OBJECTIONS FROM LOCAL RESIDENTS

The big question here is the matter of where in the water system such an intervention should be introduced. The current paradigm means that large treatment plants have to be able to cope with a very wide profile of potential contaminants, as they might be dealing with wastewater from domestic, agricultural or industrial sources, or even a blend of all three. However, if the site of intervention is more localised, it should be possible to limit the scope of the contaminant profile for that particular treatment system, thus reducing the complexity of the process design. Decentralised treatment systems will likely also be smaller affairs than the existing plants – which, while it may not make designing them any easier, may make them easier to site without objections from local residents. The crucial point is that there can be no "one size fits all" process design for such a system. But by looking at a sufficiently large number of use-cases (and hence contaminant profiles), it should be possible to develop a catalogue of tried, tested and mutually compatible process elements from which a bespoke, tailored process could be assembled.

PUTTING RESEARCH INTO PRACTICE

There are plenty of specific challenges for chemical engineers to chew on here, but the tailored solutions are only part of the story. TWENTY65 as a whole is aimed at not just developing new solutions, but getting them out of the academic literature and into real water systems – which implies that there is a backlog of potential solutions which might be matched up with problems in need of solving.

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TREATMENT: PLANTS HAVE TO BE ABLE TO COPE WITH A VERY WIDE PROFILE OF POTENTIAL CONTAMINANTS

"The DBT theme has identified three different specific challenges to address, but those are just the tip of the iceberg once we start thinking about water for all," says Biggs. "We will be looking far and wide across the industrial sector in order to identify new, emerging and existing technologies that might transform the way we deliver water and sanitation."

This strategic approach brings all the research themes together, but chemical engineering stands to benefit particularly from a comprehensive assessment of the current state of the art. There is always some degree of risk inherent in the introduction of new technologies into an existing system, and the need to quantify that risk led NASA to develop the Technological Readiness Level (TRL) framework, since adapted by many other agencies and institutions. The TRL scale stretches from 1 ("basic principles observed and reported") to 9 ("actual system proven in operational environment"). In other words, the readiness of a technology reflects some measure of the risks of using it in the larger system: higher readiness denotes lower risk; lower readiness, higher risk.

But as the scope of TWENTY65 makes clear, technological readiness alone cannot give a clear indication of risk in a large critical system, because it assumes the deployment for which the technology was originally developed. Seeking to reuse established technologies in new contexts hence requires an assessment of the *scientific* readiness of said technology. By way of example, the technology of ion exchange is well established, which earns it a high technological readiness rating; however, there is little knowledge as yet regarding how the process will behave within the novel deployments proposed by TWENTY65, which would be reflected by a lower rating on scientific readiness.

TWENTY65 is not simply concerned with demonstrating the application of existing technologies at different scales or in different circumstances, but in taking a systems approach to the water-for-all challenge. For each research theme, there is an imperative to survey not just the discipline in the frame, but also its connections and interdependencies with related disciplines. Through this, it should be possible to identify new paradigms, potentials and possibilities, to combine and adapt techniques and technologies both old and new to solve specific problems. This approach is speculative and future-focussed, but at its heart evaluative. As well as shaping the outputs of the research, it is hoped that the resulting technological roadmap might inform new research and new products for many years to come – within chemical engineering, and beyond it. ■