Fluid Mechanics Meets Signal Processing

Conventional pipeline diagnostic systems possess certain limitations, with good reason – pipes are buried deep underground, out of sight and difficult to access. Current technology only covers a short range (200 meters or less), produces low-resolution data, targets specific faults, and is unable to forecast problems. These critical limitations call for a new diagnostic paradigm for water supply network monitoring and fault detection. However, establishing a proactive "wave" diagnostic platform is no simple feat. It will involve complex physics and mathematics, a highly dynamic environment encompassing a "web of pipes", numerous active devices and flow controls, noise from turbulence, traffic, construction activities, and random flow demands.

Overcoming these issues is now the focus of a groundbreaking inter-disciplinary Theme-based Research project, led by Prof Ghidaoui and supported by Hong Kong Research Grants Council. The Smart Urban Water Supply Systems initiative is a pioneering undertaking involving an international group of leading researchers from Hong Kong, Mainland China, North America, Europe, and New Zealand, together with the Hong Kong government's Water Supplies Department. The team brings together engineering experts in hydraulics and fluid mechanics, signal processing and wireless communications and structural mechanics as well as mathematicians.

The researchers are currently studying sensing of actively generated fluid waves traveling at high speed in pipelines and how to use the electronically captured wave echoes to "image" and diagnose the pipes. Theories are being evaluated in the lab at HKUST and in field studies in Hong Kong's urban area. A pilot-scale demonstration experimental test bed has also been developed in Beacon Hill, Kowloon, Hong Kong. Findings can crucially contribute to the sustainable development of Hong Kong through water conservation and locally developed innovation and technology. However, the focus is not solely on Hong Kong but on a system that will work anywhere in the world.

Prof Ghidaoui has published in leading journals such as the *Journal of Hydraulic Engineering*, *Journal of Fluid Mechanics*, and *Journal of Hydraulic Research*. In 2007, he received the Arthur Thomas Ippen Award, the highest honor presented by the International Association for Hydro-Environment Engineering and Research (IAHR). He now serves as Editor-in-Chief for the *Journal of Hydraulic Research*, IAHR.

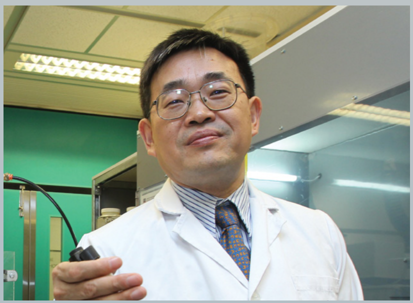
FROM SLUDGE TO SANI

Sewage sludge is a growing worldwide problem, as established cities deal with expanding populations and new urban areas spring up in developing economies requiring efficient treatment for sanitation. Conventional plants utilize biological processes that convert around 60% of the organic carbon in sewage to carbon dioxide and the remainder to sewage sludge. Such sludge is then disposed of in landfills or incinerated, contributing to greenhouse gas emissions and using up energy.

Seawater Change

Prof Guanghao Chen and his team have been working on the problem since 2004, studying the connections between seawater, sulfate and sludge, leading to the transformational SANI municipal wastewater treatment process that is generating opportunities for a cleaner environment through innovative ways to deal with "dirty water".

SANI launched a full-scale trial at Hong Kong's Shatin Sewage Treatment Works in the summer of 2014.



> "Urban sustainability to me means the three Rs: reduce, recover, and reuse"

PROF GUANGHAO CHEN
Chair Professor of Civil and Environmental Engineering

SANI stands for Sulfate reduction Autotrophic denitrification and Nitrification Integrated process, or "sludge killer" in Chinese. The original platform stems from a happy confluence: Hong Kong's use of seawater for flushing as an alternative to fresh water (it is one of the few places in the world to do so and is the result of a historical initiative to mitigate the city's lack of water resources); and Prof Chen's investigations into the potential of sulfate to reduce the sewage sludge produced from conventional wastewater treatments.

Three-wheel Cycle

The traditional two-wheel organic oxidation and nitrification biochemical reaction using the integrated carbon and nitrogen cycle employs microbes to convert organic pollutants into carbon dioxide and clean up sewage. However, such microbes grow rapidly through this process, creating large amounts of unwanted sludge as a by-product. The novel three-wheel integrated cycle proposed by Prof Chen employed slow-growing sulfate-reducing bacteria and sulfate in seawater together with nitrification to oxidize and eliminate pollutants. The method proved highly viable in lab and pilot testing, reducing oxygen needed for organic matter removal and minimizing sludge generation. From 2007 to 2010, a pilot test plant at Tung Chung Sewage Pumping Station in Hong Kong showed a 90% sludge reduction at a capacity of 10 cubic meters of sewage per day.

In 2013, with the assistance of Hong Kong government departments, Prof Chen set up a 1,000 cubic meter sewage demonstration plant that resulted in significant conclusions: 60%-70% reduction in biological sludge, 20% reduction in energy required for treatment and requiring 40%-50% of the space for treatment. Optimization is currently underway to make the process even more compact and effective at reducing sludge, and to ultimately achieve a more energy-saving system.

The revolutionary treatment process has brought 19 patents and resulted in over 70 publications and five international awards, including three from the eminent International Water Association. The technology drew interest from the UNESCO-IHE Institute for Water Education, leading to a three-year study involving Prof Chen, the European Union, and a SANI pilot demonstration plant in Cuba. The study, completed successfully in June 2017, highlighted ways to mitigate water scarcity on the island through leading-edge urban water management systems. SANI has also attracted attention from major national and international water and environmental companies.

Recovery Discovery

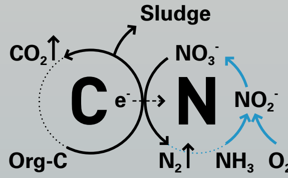
Exciting extensions to the fundamental SANI platform are now moving forward. Costly materials that normally cannot be synthesized on an industrial scale can be recovered from SANI sludge and two of Prof Chen's students will set up a company to take forward their innovative sludge-to-resource technology that can help realize production of sulfated polysaccharides, a high-valued raw material used in the food and pharmacy industries. The technology won the exhibition award at the 7th Annual HKUST One Million Dollar Entrepreneurship Competition in 2017.

Prof Chen and his research team are also exploring the recovery of phosphorus from human urine. Phosphorus, which is rapidly being exhausted, is an important element for food production through its use in fertilizers. In ongoing research, the team has shown the potential for seawater-catalyzed urine phosphate recovery in a process that adds seawater to hydrolyzed urine, leading to the formation of a valuable phosphorus-containing fertilizer (struvite precipitates). Related research has appeared in *Water Research*.

"Now we have SANI, our goal is to continuously lead the way for space-saving, energy-efficient wastewater treatment and resource recovery through the testing and application of new technologies," Prof Chen said.

Carbon Cycle – Nitrogen Cycle

Conventional Activated Sludge (CAS) process using the two-wheel organic oxidation and nitrification biochemical reactions.

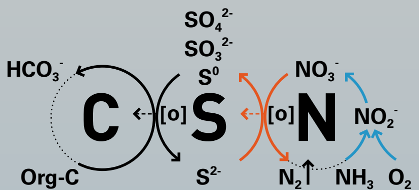


Sewage treatment area

Biological sludge *

Carbon Cycle – Sulfur Cycle – Nitrogen Cycle

The novel three-wheel integrated cycle proposed by Prof Chen - anaerobic sulfate reduction, sulfide oxidation and autotrophic denitrification, and nitrification process.



40%-50% reduction of space needed for sewage treatment

60%-70% reduction in biological sludge

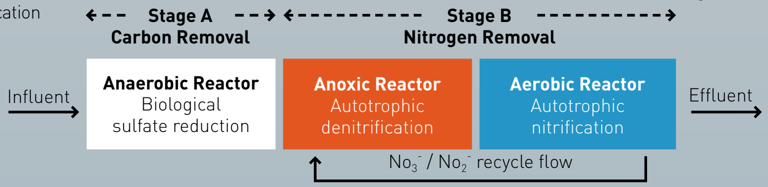


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*Photo: Sustainable Sanitation Alliance

In the first reactor (anaerobic), sulfate is reduced to sulfide by sulfate-reducing bacteria while organic carbon is oxidized to carbon dioxide (which dissolves as bicarbonate). In the second reactor (anoxic), sulfide is subsequently oxidized back to sulfate by sulfur-oxidizing bacteria while nitrate is autotrophically reduced to nitrogen gas. In the third reactor (aerobic), ammonia is oxidized to nitrate by the nitrifiers. All three functional bacteria are slow growers, i.e. they have very low yields and hence produce minimal sludge.

Fresh Links

In 2015, HKUST gained approval from the Ministry of Science and Technology of China to establish a Hong Kong Branch of Chinese National Engineering Research Center (CNERC) for Control and Treatment of Heavy Metal Pollution. The Center is led by Prof Guanghao Chen and encourages collaboration between Hong Kong, Mainland China, and overseas water experts.

The focus is on optimization of water systems and the development of new technologies for adoption by industry to enhance smart urban water and wastewater management, linking to Prof Mohamed Ghidaoui's and Prof Joseph Lee's work on waves in pipelines and turbulent mixing in rivers and oceans respectively. "Our main target is the use of different types of water – saline, brackish water – as alternative water resources to reduce the use of the increasingly precious resource of fresh water," Prof Chen said. "And to develop smarter urban systems in terms of quality assurance and monitoring."