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Overview

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It is an indisputable observation, beyond climate change: that the urgent development of simple new technologies, to ensure the supply of quality fresh water for cities and towns, industry and agriculture, presents an existential challenge for humanity.

Several novel technologies that fill that need show that the job is not impossible. They are summarized in this volume. They are environmentally friendly and inexpensive.

They include techniques for seawater desalination, wastewater sterilization – including viruses –, selective removal of heavy metals from industrial wastewater, efficient concentration of wastewater slimes to recycle water, and the prevention of water cavitation for much cheaper transport. Other new techniques like high temperature reactions achieved in low temperature water, and low energy desalination are in the wings. Borrowing from biology, new and edible class of surfactants is environmentally friendly, and can replace standard surfactants in present usage. The new technologies are cheap and scalable.

They became possible once we realised that the theories of physical, colloid, surface and electrochemistry are deeply flawed due to sins of omission and commission. Those of commission have to do with erroneous treatment of molecular forces in solution and their specificity (Hofmeister effects). Those of omission are due to neglect of effects of dissolved gas. Both are ignored in classical and textbook theories. The Greeks taught us there were 4 elements, earth (salt), water, fire (heat) and air. We forgot the air, even Descartes, who might instead of his saying: "I think, therefore I am", might have better said: "I breathe, therefore I am," The inclusion of gas changes the world of physical chemistry and opens up new vistas.

DESALINATION

Seawater desalination offers an unlimited source of fresh water, the demand for which we are increasingly unable to meet. Different desalination techniques are already commercially available. It is unlikely that they can be improved further in terms of energy efficiency as well as operational simplicity to meet the needs of an ever expanding industrial scale. Some of these techniques have not been changed for half a century, reverse osmosis membranes being the most familiar. Their limitations are well known.

Two novel desalination processes are described here. The first is the bubble column evaporator (BCE), which is simple, scalable and requires low maintenance. The BCE operates primarily by direct contact of the seawater with heated gas. In a further development, helium carrier gas consumes less energy than other processes and can be recycled in a closed system. High overall heat- and mass-transfer is achieved. The BCE process can be used extensively in many applications such as desalination, water/wastewater treatment and even for the thermolysis of solute decomposition (e.g. ammonium bicarbonate).

A new way of decomposing and recycling ammonium bicarbonate in aqueous solution has been developed using a membrane-transport process with both dense and porous hollow-fiber membranes. The decomposition of ammonium bicarbonate solutions occurs via contact through a permeable membrane, of the solutions pre-heated to 80°C with a continuous counter-flow of dehumidified air at room temperature. In this process, ammonia (NH_3) and carbon dioxide (CO_2) gases permeate through the membrane and are thereby separated from the feed solution; they can then be collected into aqueous solution for recycling.

The BCE method also offers a fast and robust way to decompose ammonium bicarbonate solutions and readily meets industrial-scale requirements. Combined with this, we have produced a novel, sustainable ion exchange desalination process based on low cost resin regeneration. It uses ammonium bicarbonate solution in place of the usual, and expensive, acid and base washing.

Regeneration using this salt further allows the use of novel ion exchange resins which contain the cation and anion exchanging groups in close proximity, that is, nanometers apart rather than millimeters apart. These resins are more efficient and can be regenerated *in situ* without exposure to either acid or base solutions. This offers a second energy-efficient desalination method. It is a serious competitor for, and indeed superior to reverse osmosis desalination on all fronts and is close to large scale implementation.

WATER TREATMENT

The treatment of water contaminated with hazardous heavy metal ions, is also needed to supply clean water. These metal ions are produced naturally or through industrial processes, and can infiltrate water supplies for general or agricultural uses. Naturally occurring arsenic is a massive problem for millions of people world-wide. New techniques are required to remove hazardous ions from drinking water, especially at low-level concentrations.

One potential technique is ion flotation, and with environmentally friendly, meaning biodegradable, surfactants. In principle these should be highly efficient and specific absorbers of hazardous ions from aqueous solutions. In biology, enzymes have an exquisite capacity to select and bind specific ions.

So taking that lesson from biology, we have taken cysteine, which is a natural amino acid, and has a high affinity to bind with a range of contaminant ions, to explore what can be done. As an example, the Na^+ salt of the N-octanoyl-cysteine surfactant showed highest efficiency in the ion flotation process. It has a high water solubility and exhibits extensive foaming in a typical flotation chamber over a wide pH range. In a batch ion-flotation process, this surfactant was able to remove 97–99% of lanthanum, arsenic and various divalent heavy metals present at 5ppm levels in contaminated water, in a simple, single-stage physiochemical process. This surfactant showed significantly lower efficiency for the removal of iron, selenium and gold ions and hence these studies also show how the ion-flotation process could be used to remove specific ions selectively from mixed ion solutions. The most promising aspect of the selectivity achieved is probably for future developments involving rare earth separation and the treatment of nuclear wastes.

The design of environmentally friendly surfactants that have specific ion binding properties is a long standing aim of the chemical industry, and something devoutly to be wished for.

Our "exhibit one" surfactant is such an environmentally acceptable compound. It can be readily decomposed into cysteine (an amino acid) and octanoic acid (or caprylic acid), both of which can be taken as a dietary supplement). The surfactant, as an efficient and specific collector, has the potential for wide usage in both ion and froth flotation. The surfactant has also been shown to have a high affinity to bind with ions like copper, lead, arsenic. It is promising in the treatment of mining wastewater sites contaminated by such ions worldwide. Naturally occurring arsenic contamination in drinking water is a huge problem in various countries and this surfactant is a winner not yet harnessed for the task.

A novel, efficient synthesis method has been developed to produce the N-octanoyl-cysteine surfactant.

This gives cheap high product yields with a simple and straight forward method. The high synthesis yield of this product is important, as it offers an environmentally acceptable agent for the removal of a range of heavy-metal ions from contaminated water and soil.

More importantly, it could also be used in general household-detergent/personnel-cleaner formulations and even in toothpastes! Replacement of standard surfactants like sodium dodecyl sulfate and a myriad quaternary ammonium or related cationic surfactants is urgent. Their manufacture from petroleum products is a large part of industrial CO_2 production in Europe.

In addition, the surfactant could be used to facilitate the removal of PFAS compounds from soils. The PFAS surfactants are negatively charged, but often bind to negatively charged particles of sand, clay and humic acid-coated materials, and microorganisms via bridging multivalent cations. Hence, it could be more environmentally acceptable to use this biodegradable surfactant, which would combine cation chelation properties with foam fractionation separation of surface-active (e.g. PFAS) components in soils.

STERILIZATION, CARBON DIOXIDE AND VIRUSES

Inactivation of viruses has been an insuperable inhibition to the use of recycled water. Hence the ubiquity of plastic bottled water in cities. Current processes such as UV irradiation, chlorination, ozonolysis and even treatment with bacteriocides, such as quaternary ammonium surfactants, all produce varying levels of potentially toxic by-products and subsequent environmental issues. We have said goodbye to all that. In a surprising development, we found an environmentally friendly technology for sterilizing water by doing just that. The technology bubbles heated, un-pressurized carbon dioxide (or even exhaust gases) through contaminated wastewater in a bubble column. The process kills both waterborne bacteria and viruses close to 100%! The technique is extremely cost effective, with no by-products to bother about, and has already been successfully scaled-up industrially. Substantial success so far achieved in solving the problem of pathogens is here extended. A novel technique based on the use of a continuous, high density flow of carbon dioxide bubbles, over a range of temperatures – depending on application, can effectively sterilize wastewater – without the risk of harmful byproducts. Efficient use of hot, waste combustion gases can be used for wastewater sterilization and at the same time produce pure, condensed product water using a bubble column evaporator. In the near future, testing of COVID-19 susceptibility may also prove interesting and might lead to further sterilization applications for this simple technique (See Postscript for rapid progress here).

DE-WATERING SLIMES

Industrial wastewater slimes are currently treated in several ways, e.g. flocculation, filtration, hydrocyclone treatment, centrifugation, all of which raise issues and problems associated with each particular process. We have developed a novel method based on the use of hot gas bubbles which both fluidize slimes whilst at the same time efficiently removing water vapour which can then be condensed as a pure water product. The bubble column evaporator enables slime de-watering up to levels where the dispersions are only maintained in a fluid state by the continuous flow of hot gases. This facilitates the industrial use of this process via the continuous deposition into flat open drying trays where the material is deposited in solid form for ultimate evaporative drying and disposal. Our surprising observations with heated helium gas might further dramatically improve the efficiency of the process, with the incorporation of helium recycling.

At the end we found a good method to inhibit scaling in pipelines. And this has opened up new insights into the core of physical chemistry –the energy sources of reactivity in ordinary and biochemistry (See Postscript).

CAVITATION PREVENTION

Another novel process has been developed which completely prevents the cavitation caused by the rapid rotation of a propeller in water. Cavitation has a deleterious effect on the efficiency of fluid transmission, and generally leads to material degradation in hydraulic systems. A major part of transport costs by shipping is due to cavitation. Currently, the main approaches by industry to reduce the effects of cavitation are to select operating conditions, use geometric designs that reduce the occurrence of cavitation, or use hard materials to resist wear caused by cavitation. For example, the maximum shaft speed of propellers is typically limited to ensure that cavitation does not occur at the blades.

In the recent advance described here, a novel method of releasing de-gassed water towards the low-pressure side of a propeller was developed. This forms a boundary layer completely preventing cavitation. This is extraordinary, simple and has game changing implications.

The prevention of cavitation and associated noise has widespread practical implications for commercial shipping and the navy; it improves energy efficiency and reduces propeller damage, and also can have a dramatic effect on the effective operating speed of ships and submarines. Following proven laboratory scale tests, a multidisciplinary research approach involving fluid engineers, propeller designers, ship-makers with expertise in cavitation is now required to develop this innovation for large scale applications. We wish them well in the enterprise.

The novel technologies presented in this volume offer promising new environmentally friendly processes for desalination, water treatment, water sterilization, and the total prevention of cavitation. Some of these technologies have already been patented. Each of these innovations has been brought to the stage where further development might lead to full commercialization with global implications.