Clean water and waste-to-energy innovations

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Recent research on copper oxide-doped ultraviolet (UV) titanium dioxide semiconductor photocatalysis conducted in the Department of Chemical Engineering has revealed how the power of the UV energy from natural light sources can be unleashed in the degradation of organic impurities in water.

This technology makes it possible to improve the recycling of supernatant water from sludge ponds that receive backwash water and sludge from sedimentation basins at water treatment plants (Chirwa and Bamuza-Pemu, 2010). Lately, water wastage at treatment plants has escalated in the summer months due to excessive algal blooms (green soup). The revenue loss can be as high as R1 million per month for a sizeable plant that treats over 150 million litres of water from eutrophic water bodies per day.

It is customary to avoid recirculating water from sludge ponds to avoid the accumulation of the organic compounds that are produced by blue-green algae. These algae cause problems such as foul odour and taste due to the presence of the algal metabolites geosmin and 2-methyl-isoborneol. Disinfection by-products (DBPs), such as trihalomethanes and haloactetic acids, are also formed during disinfection with chlorine gas. DBPs are known to increase the rates of mutagenesis and cancer in populations that consume water with high organic content for prolonged periods.

The research group has also embarked on multidisciplinary research on the bioremediation of heavy metals, as well as nutrient removal and recovery from water and sludge. An example of this research is the project on bacterial reduction and the removal of the toxic forms of the metals chromium (VI) and uranium (VI) to the less toxic and less mobile trivalent (Cr(III)) and tetravalent (U(IV)) forms, respectively, that are easily removed by filtration and electrokinetic processes (Molokwane and Chirwa, 2009; Mtimunye and Chirwa, 2014).

In the most recent projects, the reduction and immobilisation of the metals were accomplished in microbial permeable reactive barriers (MPRBs) and in fixed-film bioreactor systems. Gram-positive species of bacteria from sludge samples completely reduced Cr(VI) to Cr(III) in a water sample with a Cr(VI) concentration of up to 400 mg/l. Gram-negative bacteria from uranium tailings dump soil achieved up to 92% removal of uranium (VI) in batches with a concentration of up to 200 mg/l. In both cases, the microorganisms

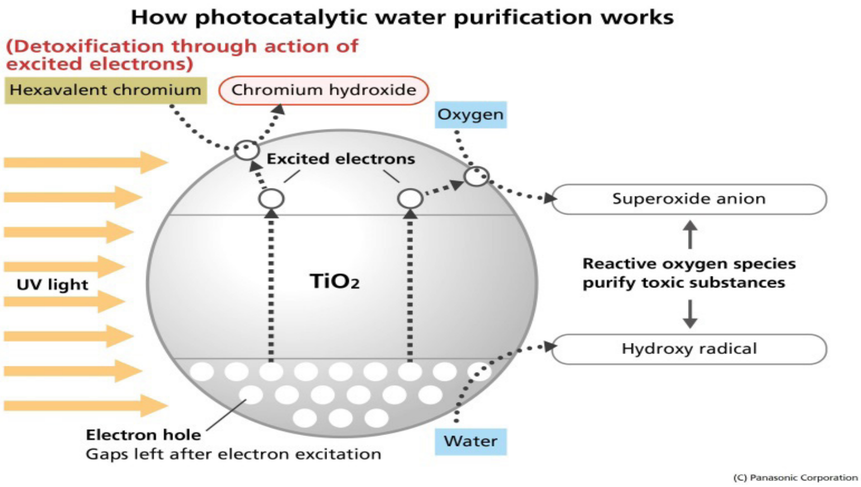
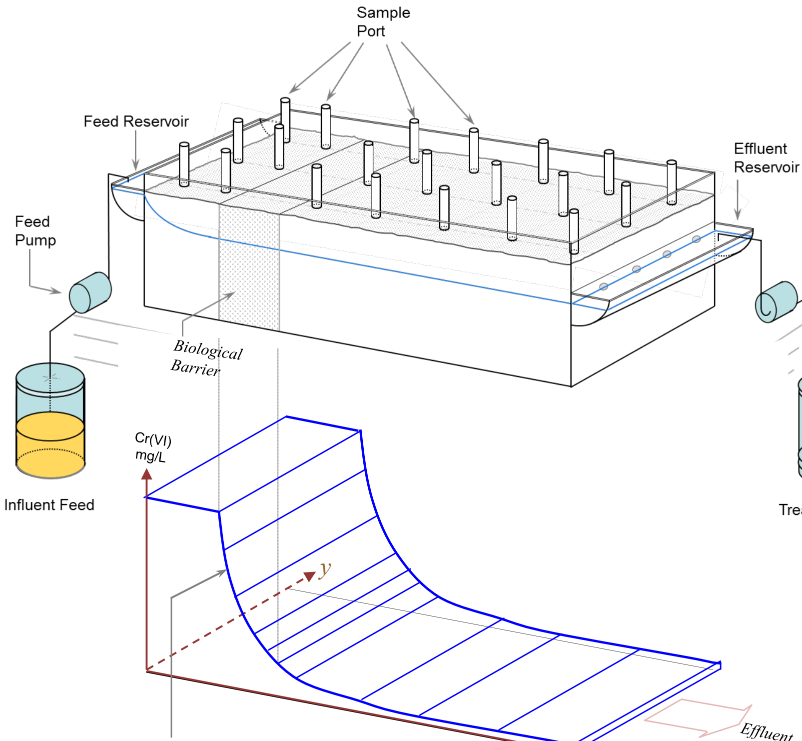


Figure 1: How photocatalysis works during the detoxification of water.

Algal growth studies for utilisation in wastewater treatment.



$$-\frac{dC}{dL}=\frac{\rho A_f}{Q_{in}}\cdot\frac{k_{mc}\cdot C}{K^{1-Cr/C_0}\cdot(K_c+C)}$$

Figure 2: A bench-scale reactor system for Cr(VI) reduction and immobilisation in a simulated groundwater flow biological barrier system.

that achieved the removal of the toxic metallic species were isolated from local wastewater and mine dump soil environments. Using this method, it has been demonstrated that the detoxification of wastewater streams containing high levels of metals can be achieved at a low cost by using environmentally compatible biological processes.

The Environmental Engineering Research Group in the Department of Chemical Engineering has developed concept proposals on the creation of energy from waste streams to address the need to increase the national inventory of renewable and mixed energy resources. Resourceful projects on the biogas output optimisation in waste-activated sludge digestion processes and the utilisation of energy sources within the activated sludge process have been under investigation since May 2010.

One such project looks at the utilisation of CO_2 and HCO_3^-, which are produced in the activated sludge and fermentation stages as electron donors during the production of methane. Another project looks at the introduction of microbial cathodes as a replacement of the expensive metallic cathodes in microbial fuel cells (MFCs). These two projects look at the aspect of converting wastewater treatment plants into energy-generating units with the aim of operating the plants from the national grid, and ultimately generating net energy for the grid.

The other waste-to-energy project involves the recovery of oil from waste petroleum sludge by using a mixed culture of biosurfactant-producing organisms. Conventionally, sludge containing oil is incinerated and the residue is dumped at landfill sites. Where recovery is attempted, chemical surfactants with toxic properties are utilised.

This results in a residue with a high chemical oxygen demand (COD), which is not suitable for land applications. The biological process promises to produce high-quality oil that can be utilised in value-adding processes and a cleaner residue with low COD and low toxicity. The quality of the final residue is such that it can be used safely for landfarming operations to improve soil quality for agriculture.

Using the knowledge accumulated during studies on algal blooms and metabolite accumulation rates from eutrophic waters, more work is planned on the recovery of oil from oily sludge and the utilisation of algal species in the recovery of carbon from oil refining and coal gasification processes.

References

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