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TiO_2: The Future of Water Treatment

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4: The future of water treatment with titanium dioxide – Will photocatalysis provide clean water for everybody?

Many people living in some of the world's poorest countries don't have access to properly treated drinking water. To make their water safe, such people would need to use point of use (POU) treatment methods. The best POU treatments are cheap, easy to use and effective at removing contaminants.

Photocatalysis with nano-structured titanium dioxide (TiO_2) promises to be a new solution to the drinking water problem because it only uses visible light from the sun and it doesn't rely on electricity or expensive equipment. Scientists are working on how to put the method into practice and how to scale up photocatalytic water treatment.

How could it work as a POU water treatment?

The catalytic activity takes place at the interface between the catalyst and water. Therefore, to maximise the effectiveness of the photocatalysis process, the catalyst (titanium dioxide), needs to have a large surface area. The simplest method would be to add nano-structured titanium dioxide powder to water in a transparent container.

The catalyst would not remain suspended in the water; as it settled, the available surface area would be much reduced. It would be very difficult to re-use the catalyst because it would have to be filtered out and then dried. This would require extra equipment and be time consuming. It would mean further handling of the water, the danger of clean water coming into contact with dirty hands and therefore defeating the point.

The choice of container for POU water treatment is very important. An appropriate container should be closable and have a narrow opening so that there is no danger of organic matter or dirty hands coming into contact with the water. For this reason, plastic bottles are a good choice. In remote areas, poly(ethylene terephthalate) (PET) bottles coated with TiO_2 could be used to disinfect drinking water and make it safe. The bottles are filled with water and placed on a flat surface which experiences un-restricted sunlight, typically the roof of a house, and left for several hours.

Applying the photocatalyst as a coating to a transparent surface is a way of fixing the catalyst in place. In the presence of an acid, it adheres well to glass and to common plastic bottles made from PET. Costs could be kept low by using recycled PET bottles instead of brand new ones.

Adding an acid converts oxygen atoms on the surface of titanium dioxide particles into OH-groups. PET is a poly-ester and can interact with the OH-groups on the surface of titanium dioxide to form hydrogen bonds. The OH-groups provide the positively polarised hydrogen and the ester groups provide the oxygen with available lone pairs, the two components needed to form hydrogen bonds.

It has been found that the acid, $HClO_4$, gives the best results for creating an even, bubble free coating on PET bottles. It is a strong acid and requires careful handling, making it difficult for householders to coat their own bottles without training.

What needs to be considered?

To make photocatalytic water treatment easy to use, reliable, safe, and effective, a number of practical and scientific factors have to be considered:

- How long does it take for the water to be disinfected?
- How do we know that harmful microorganisms are destroyed?
- How does the amount of microorganism affect the time it takes for disinfection?
- How does cloudy water affect the disinfection process?
- How does the light intensity at different times of the year or during different parts of the day affect the length of treatment time?
- Is the process temperature dependent?
- Is there a backup plan when there is no sun?
- Does the water in the coated PET bottles become re-infected when removed from sunlight?
- How long does the coating on the bottles last? How often can they be used?
- How can the coated bottles be distributed to remote areas?
- Can householders be trained easily to apply TiO_2 coatings to PET bottles?
- How can the water bottles be disposed of when they are no longer used?

Some solutions:

How do we know if the photocatalytic treatment has worked?

Water testing would not be an option in remote or underprivileged areas.

An organic dye could be added to help us see whether the photocatalytic process is working. When the dye is broken down and the colour disappears, we could assume that other organic substances and microorganisms have also been broken down and the water is now safe to drink.

Methylene blue is an organic dye which has been used for the staining of microorganisms and cell tissue for over one hundred years.

It has been found that methylene blue acts as a photosensitiser, a substance that is activated by light. Methylene blue absorbs red to far red wavelengths of light. It is non-toxic and the doses people can withstand have been well researched.

When you shine light onto methylene blue, it absorbs red light and electrons become excited and are raised to a higher energy level. The excited molecules transfer energy to oxygen molecules and create single oxygen or hydroxyl radicals. Radicals are very reactive chemical species that can damage and kill cells.

Potentially, a dye like methylene blue could be added to water being treated by photocatalysis with titanium dioxide. By the time that methylene blue is broken down, other organic substances and micro-organisms have also been broken down. Methylene blue would also support the destruction of microorganisms in its own right. It absorbs red light and generates free radicals which attack

microorganisms. A greater proportion of the visible spectrum could be used and more hydroxyl free radicals generated which attack microorganisms.

A combination of methods

Some of the potential problems identified above, could be overcome by using a combination of POU water treatments. If there is sufficient infra-structure and manpower available to distribute coated plastic bottles or to educate householders in how to coat the bottles, then chlorine based disinfectant tablets could be distributed as well. These tablets would be a back-up for when there is no sunshine or when more water is needed quickly.

How could a process be designed to scale up photocatalytic water purification?

If photocatalytic water purification could be used for large scale water treatment, it could benefit whole communities living in remote areas.

What would be needed to achieve this?

- A large transparent container.
- Shape of container that allows a large volume of water to be exposed to light.
- A method of maximising the catalyst surface, because the photocatalytic reaction takes place on the surface of the catalyst.
- A photocatalytic reaction vessel that allows ‘flow-in’ and flow-out’.
- A structure that maximises the through-put of water.
- A process that does not require several hours of treatment.

Even though it will be a while before some of the practical problems with photocatalytic water treatment have been overcome this method has the potential to provide a good alternative to water disinfection with chlorine. If a reasonably sized, cheap transparent container could be developed with long-lasting photocatalytic coating, real progress to water treatment in remote and underprivileged areas of the world could be achieved. It would give more people access to clean water and save lives.