Photocatalysis for Water Treatment

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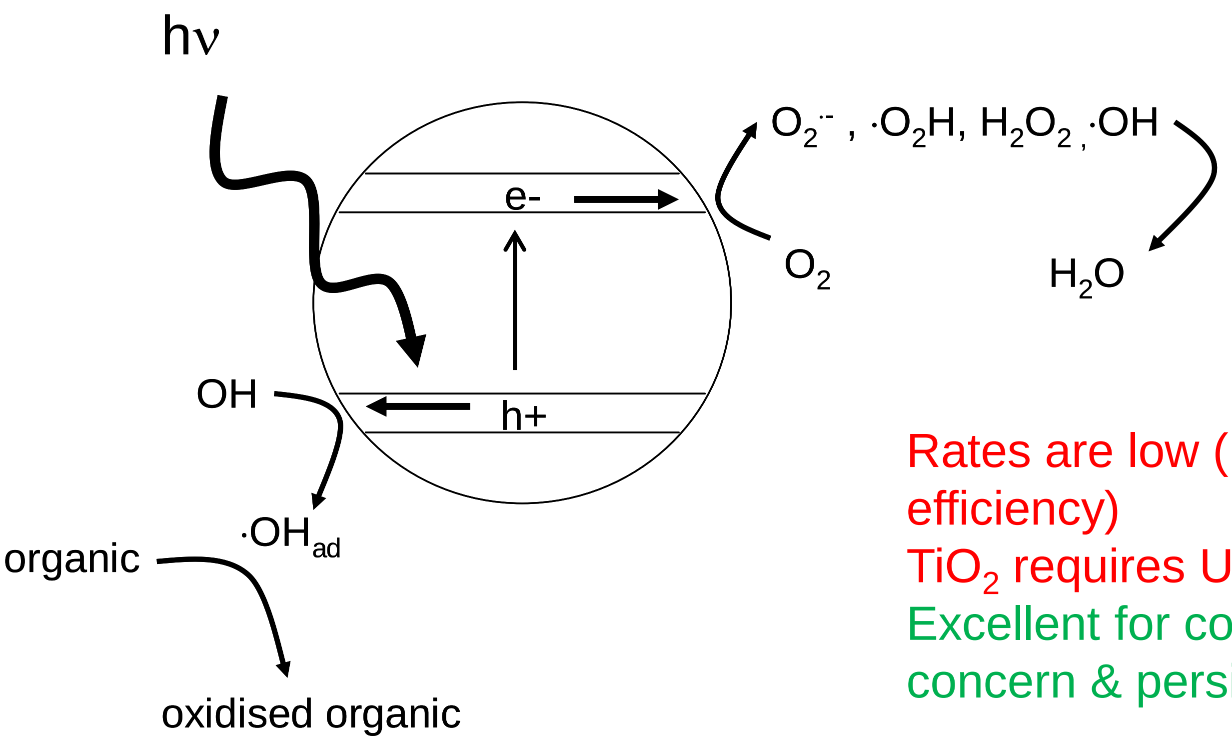
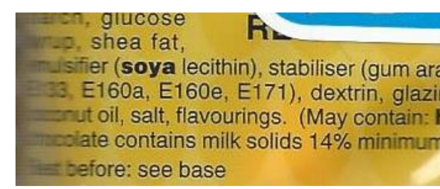
Basic mechanism of photocatalysis with TiO_2 in presence of O_2



Rates are low (typically 1% quantum efficiency)
TiO_2 requires UV (only 5% of sunlight)
Excellent for contaminants of emerging concern & persistent organic pollutants

- Nanomaterials give very high surface area for photocatalysis
- In some cases size quantisation effects may be observed
- Nano-engineering can give increased efficiencies
- TiO_2 most common photocatalyst due to stability and non-toxicity

Titanium dioxide (TiO_2)



Photocatalysis has been shown to be effective for the degradation of a wide range of problematic pollutants in water including EDCs, pharmaceuticals, pesticides, dyes, etc.

effective for the inactivation of disinfection resistant microorganisms including viruses, bacteria (including spores), fungi (including spores), protozoan parasites (including oocysts).

Puralytics solar bag

Solar Photocatalytic Disinfection of Water

The Millennium Project commissioned by the United Nations in 2002

Millennium Development Goal Target 10:

"by 2015, reduce by half, the 1.1 billion people lacking access to safe drinking water and basic sanitation".

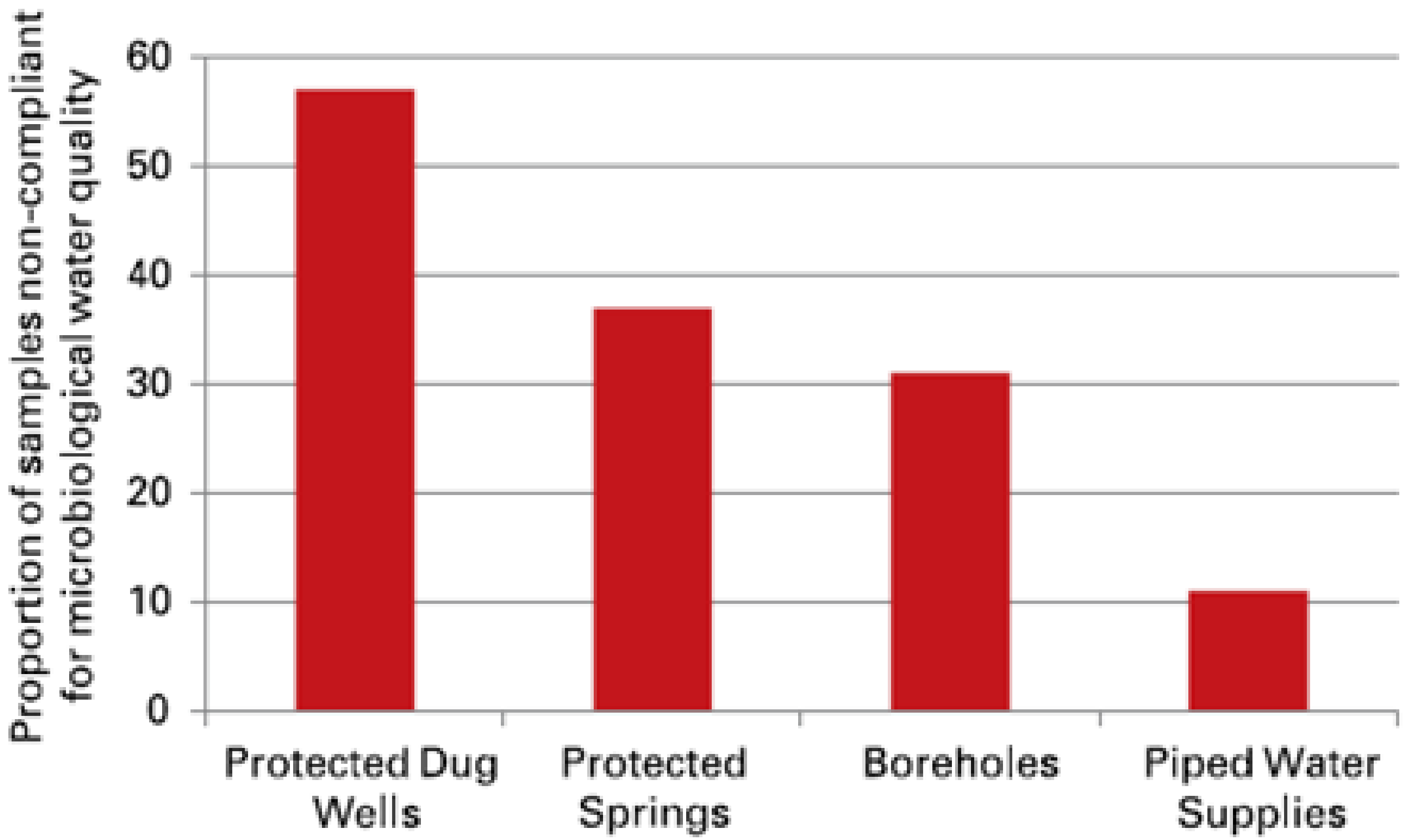
The MDG water target of 88% coverage was met in 2010

748 million people still do not have access to an improved water source for drinking

1.5 million children die each year due to unsafe water

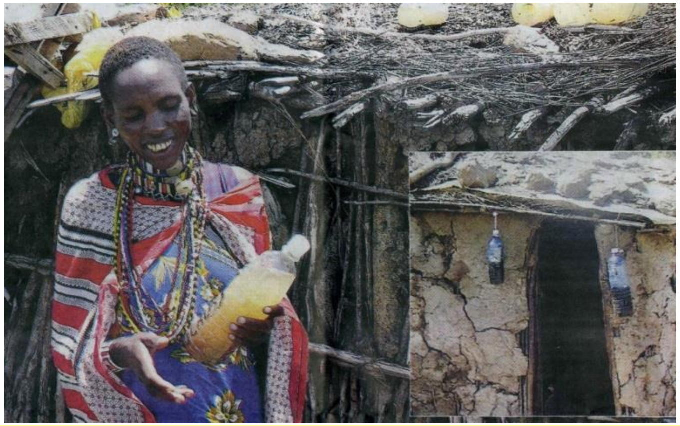
Progress on drinking water and sanitation, 2014 update,
World Health Organisation and UNICEF, 2014

Improved water source does not mean safe!



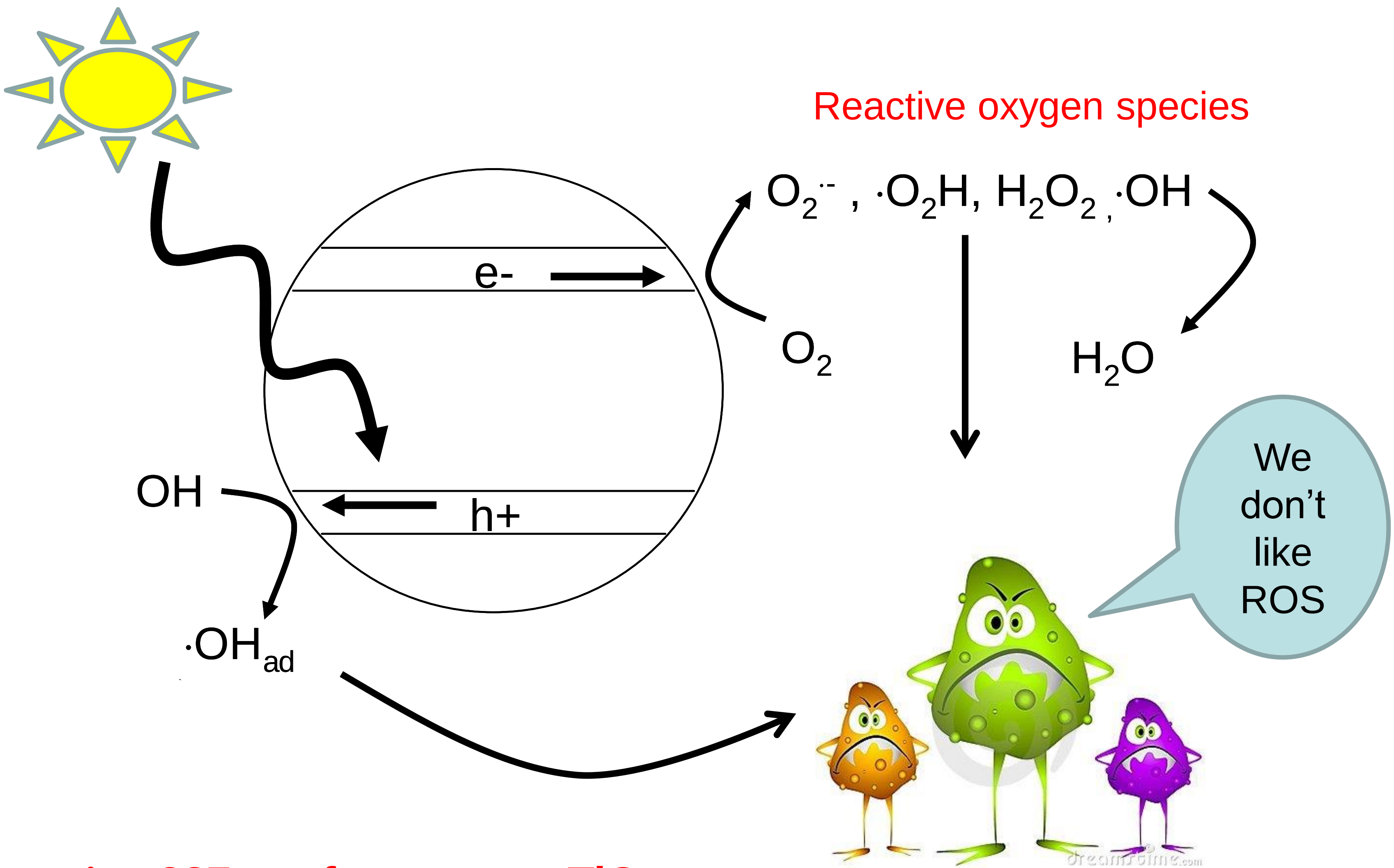
Non-compliance with microbiological water quality guideline values by improved drinking water source type. Proportion refers to percentage (from UNICEF and World Health Organization, Drinking Water Equity, safety and sustainability, JMP Thematic Report on Drinking Water 2011)

Solar disinfection of water (SODIS)



SODIS is used by more than 5 million people and in more than 30 countries around the globe

Solar Photocatalytic Disinfection

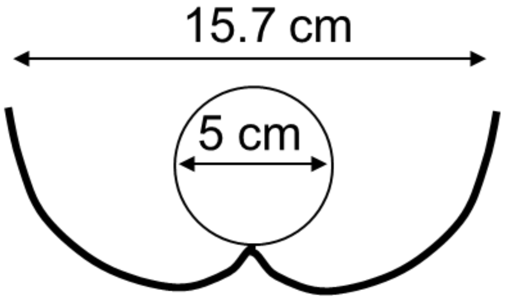


λ < 387 nm for anatase TiO_2

http://www.dreamstime.com/

Continuous flow photocatalytic SODIS reactor with add on CPC.

TiO_2 (Evonik Aeroxide) coated borosilicate glass tubes (0.4 mg/cm^2) were incorporated into the CPC-SODIS reactors used at PSA and used as a 7 L re-circulating batch system with *E. coli* K12 in saline ($1x10^6$ CFU/mL) as a model test organism.



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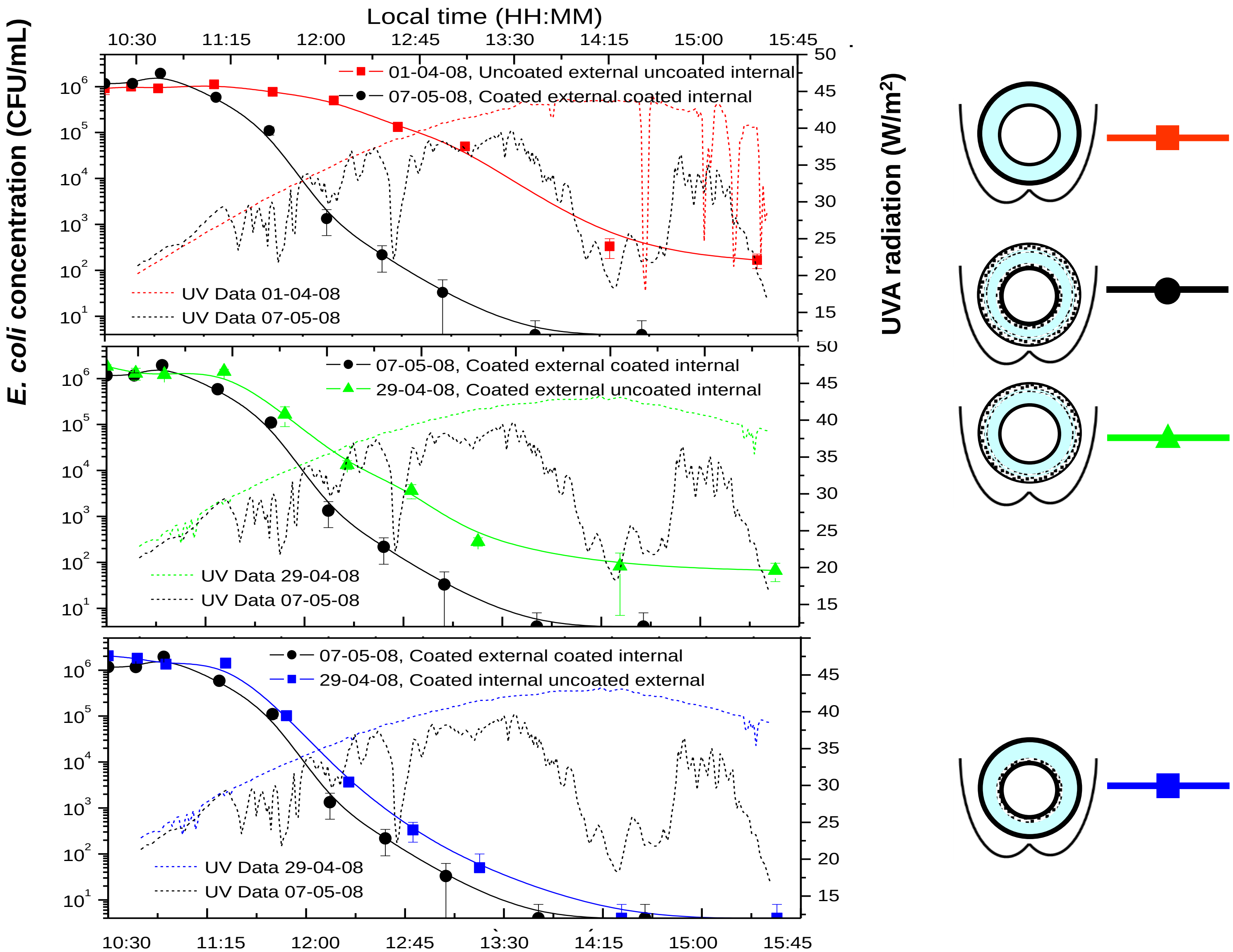
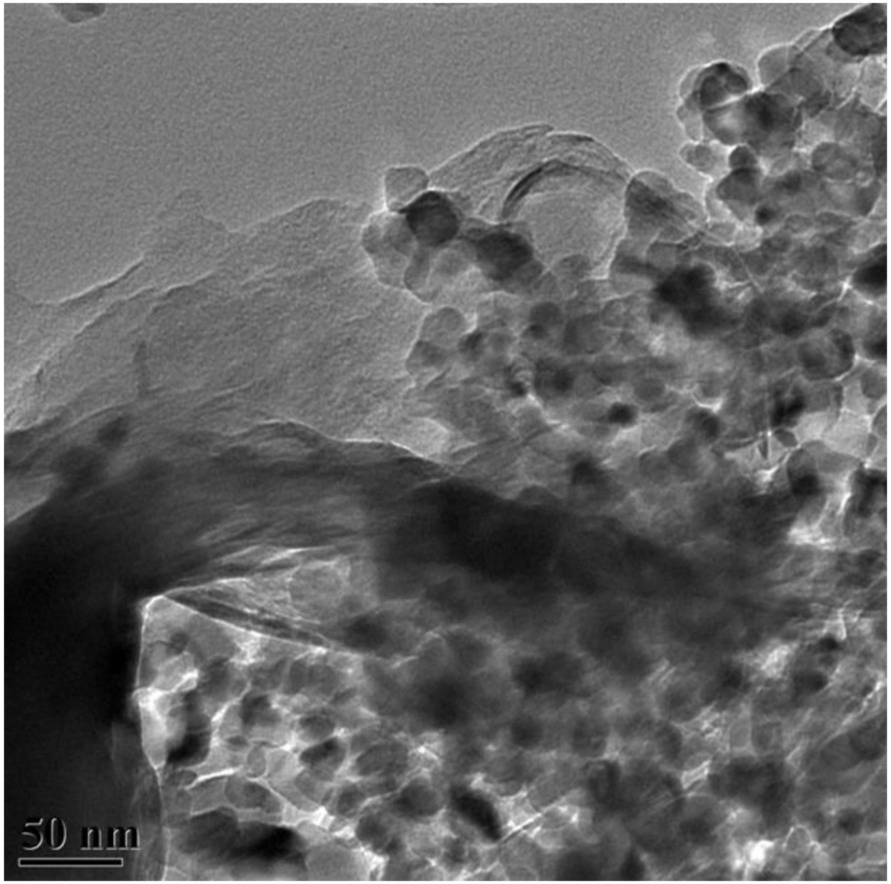
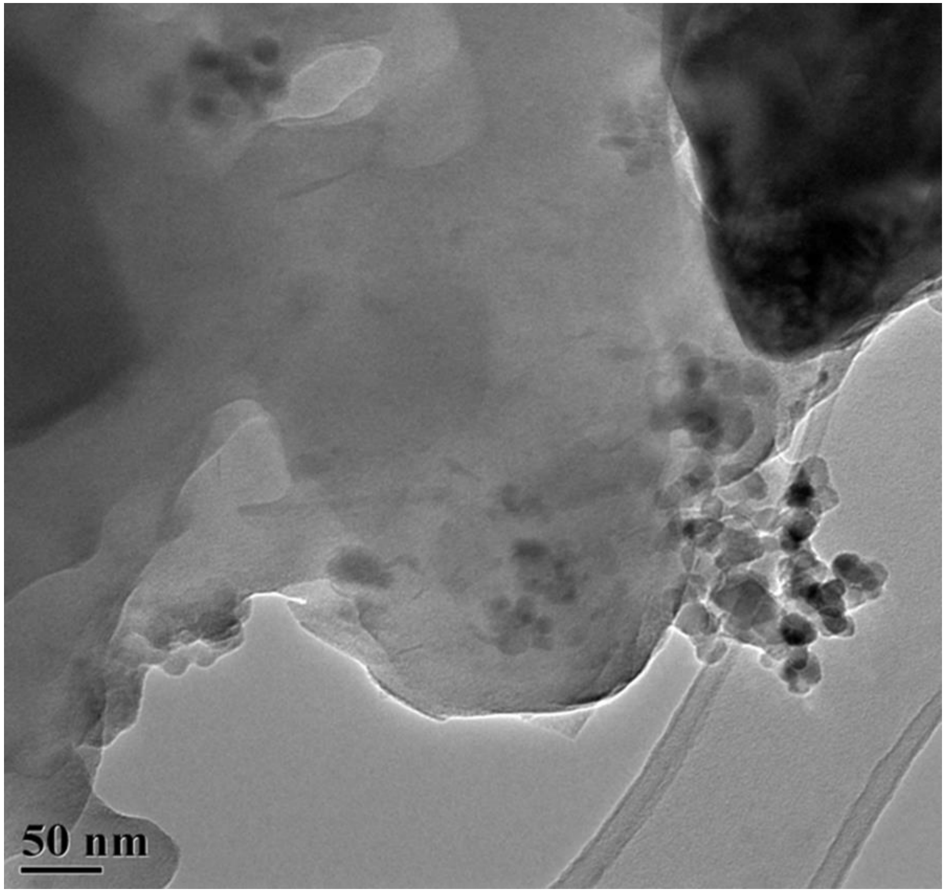


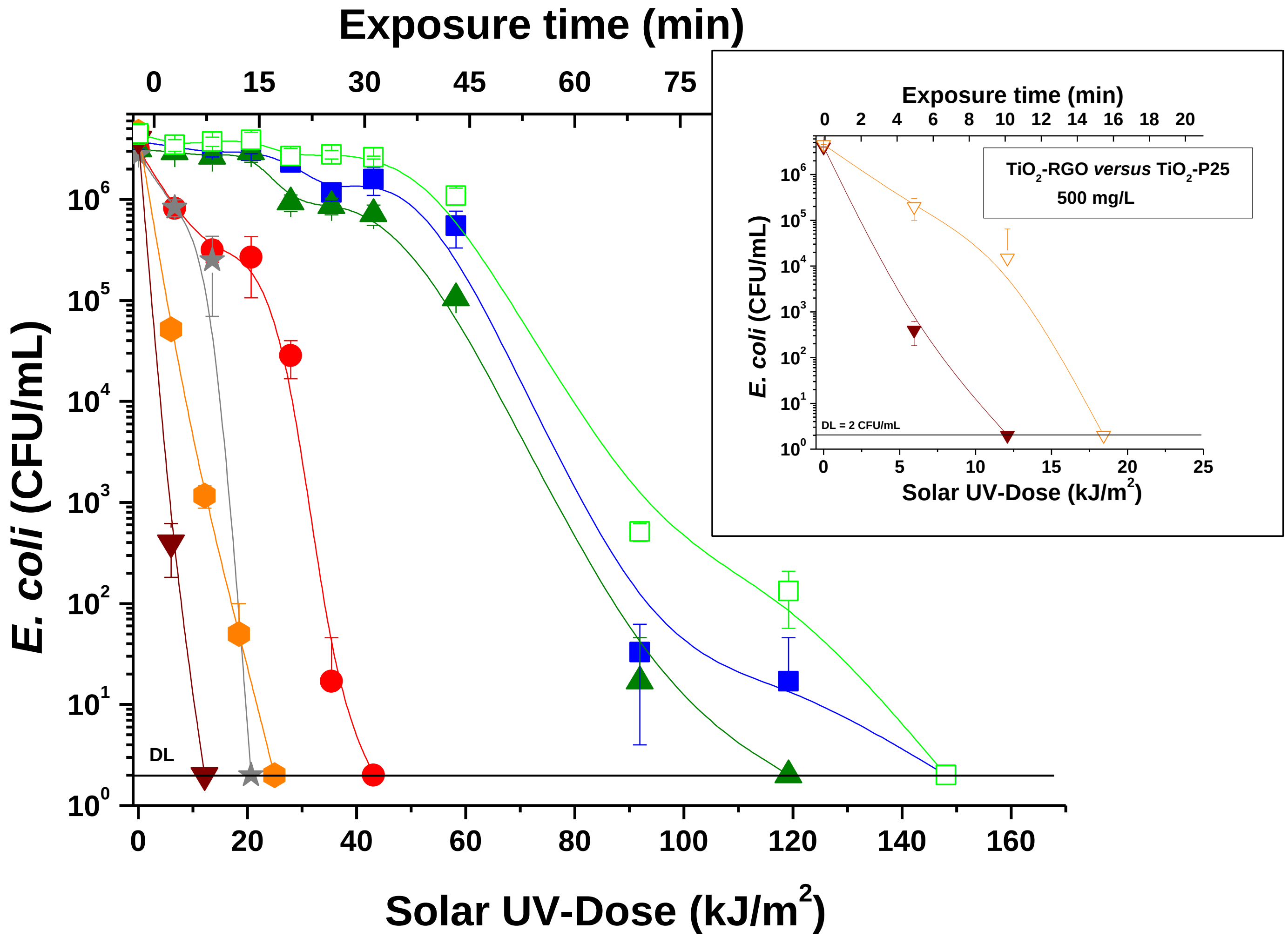
Titania-graphene composites



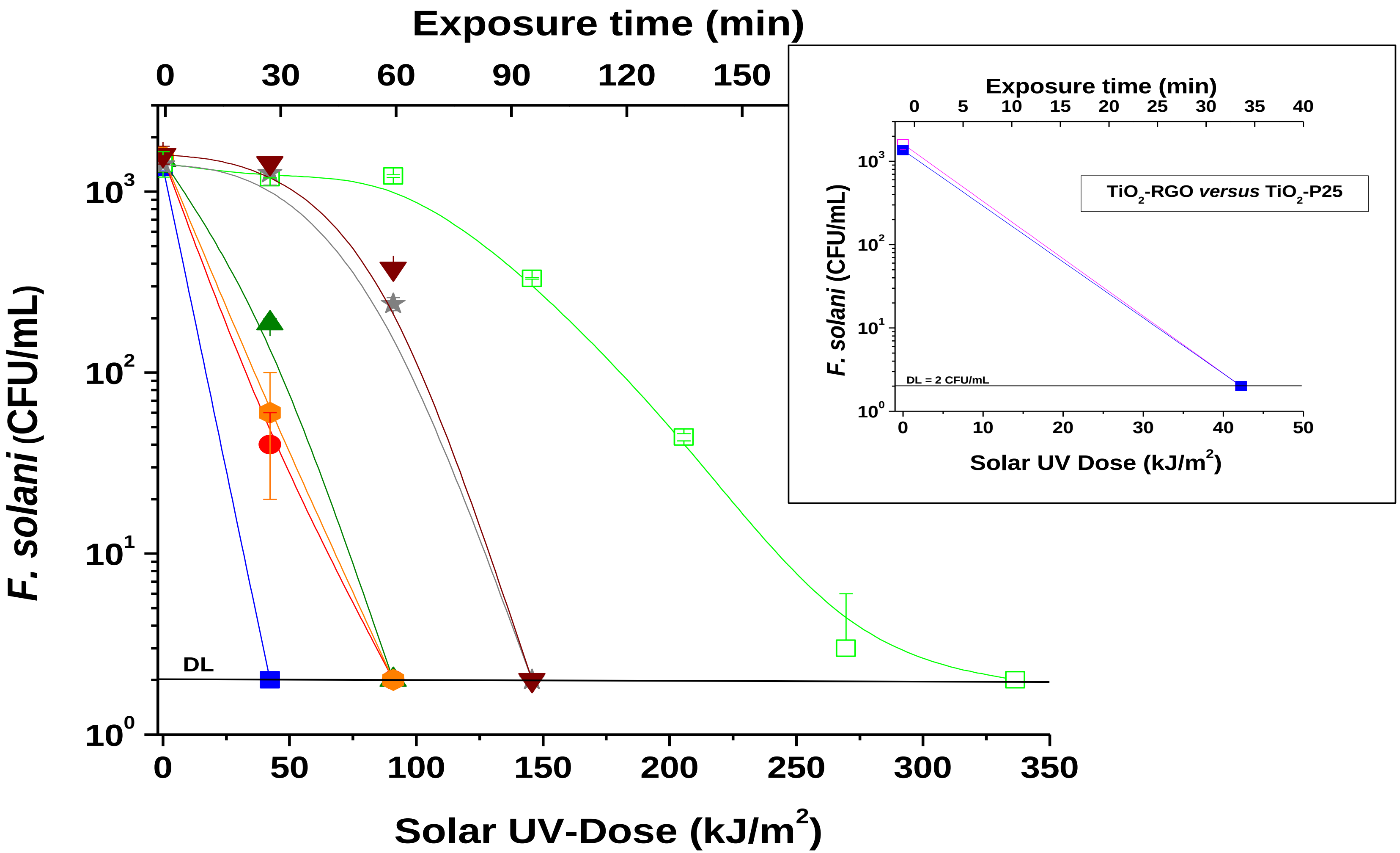


TEM of TiO_2-RGO following photocatalytic reduction

Fernández-Ibáñez et al (2014) Chem Eng J, DOI: 10.1016/j.cej.2014.06.089.



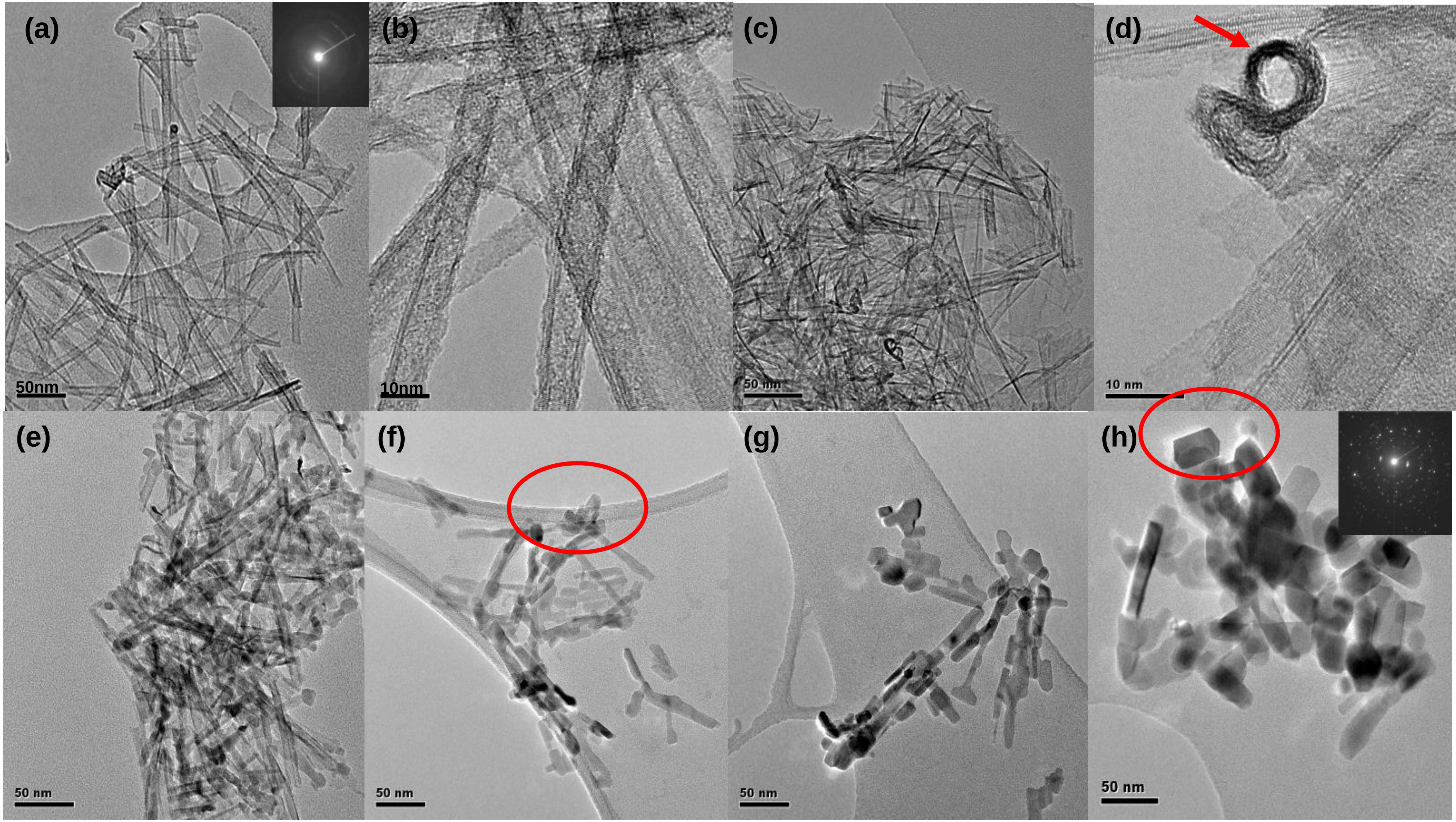
E. coli inactivation at several TiO_2-RGO concentrations: (□) 0 mg/L; (■) 10 mg/L; (▲) 20 mg/L; (●) 50 mg/L; (⬢) 100 mg/L; (★) 300 mg/L; (▼) 500 mg/L. DL (detection limit) = 2 CFU/mL. Inset shows the TiO_2-RGO (▼) *versus* P25 (▽) efficiency on the *E. coli* inactivation at 500 mg/L of catalyst concentration. DL (detection limit) = 2 CFU/mL.



F. solani spore inactivation at several TiO_2-RGO concentrations: (□) 0 mg/L; (■) 10 mg/L; (▲) 35 mg/L; (●) 50 mg/L; (⬢) 100 mg/L; (★) 300 mg/L; (▼) 500 mg/L. DL (detection limit) = 2 CFU/mL. Figure insert shows the efficiency of TiO_2-RGO (■) with 10 mg/L *versus* TiO_2-P25 (□) with 35 mg/L on the *F. solani* spores inactivation. DL (detection limit) = 2 CFU/mL.

Titania Nanotubes

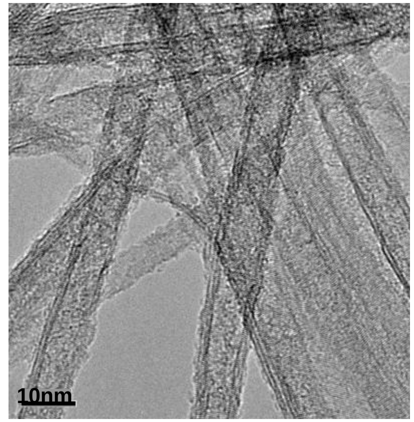
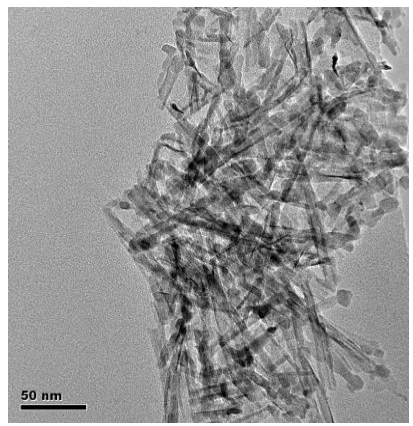
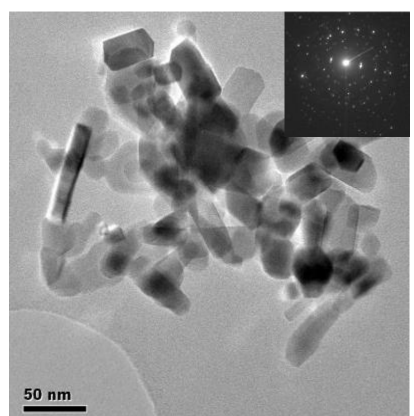
Comparison of titania nanostructures formed by hydrothermal treatment



HRTEM images of (a)-(b) as-prepared and samples annealed at (c)-(d) 300ºC (e) 400ºC (f) 500ºC (g) 600ºC (h) 700ºC

Wadhwa et al, *J. Adv. Oxid. Technol*. Vol. 14, No. 1, 2011

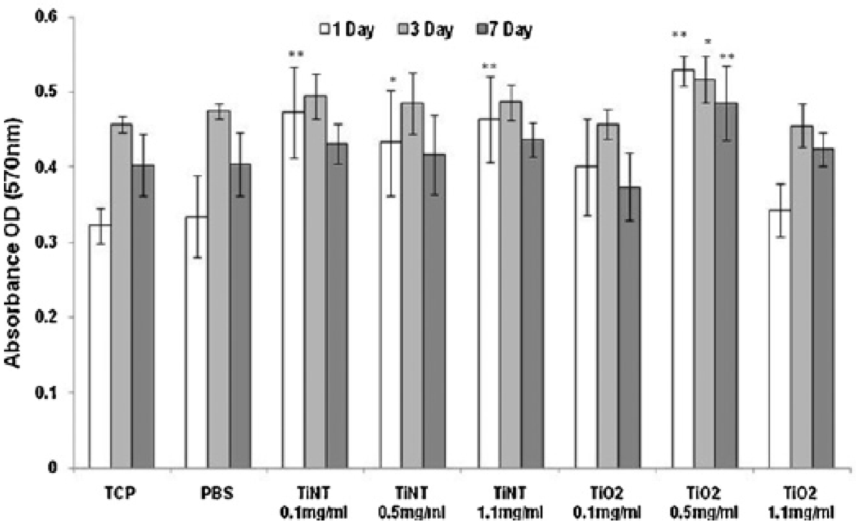
Observed best material depends on the model pollutant tested

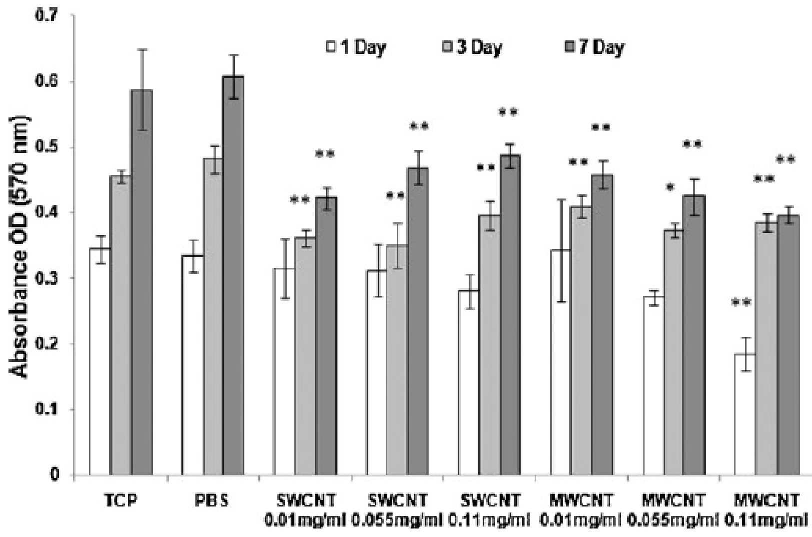
	HRTEM	Crystallinity, BET (m^2/g)	Optimum photoactivity for
As-prepared		Amorphous, ~401 100% tubes	
400°C		Anatase, ~265 30% tubes	formic acid
700°C		Anatase, ~48 100% hexagonal crystals	Phenol

Toxicity study of titania nanostructures as compared to MWCNTs

Cell viability was determined using A549 human lung adenocarcinoma cell line obtained from ATCC after 1, 3 and 7 days in culture
using the standard colorimetric MTT assay. A commercial MTT assay kit (Sigma–Aldrich, UK) was used, employing a modification of the Mosmann method

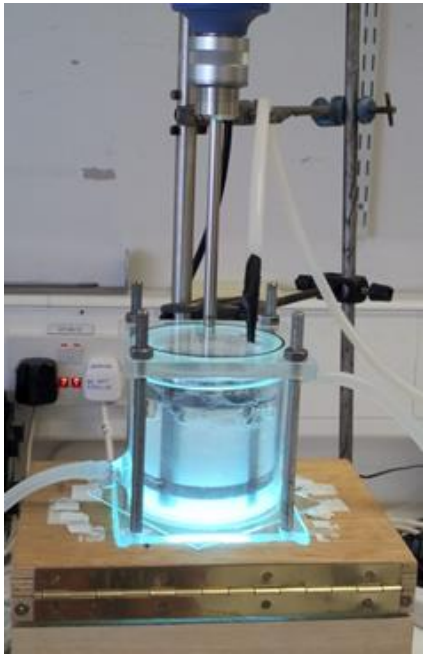
No significant cytotoxic effects were observed with titania but significant cytotoxic effects were observed with the MCNTs.





Wadhwa et al., *Journal of Hazardous Materials* 191 (2011) 56–61

Suspension vs Immobilised Photocatalyst



In laboratory scale experiments many researchers employ a basic photoreactor system utilising the photocatalyst as a powder suspension (slurry) in water.

The main issue with suspension reactors is catalyst recovery following treatment.

P25 is widely used. It has a small primary particle size (~ 25 nm) and is hydrophilic in nature forming well dispersed suspensions in water. The particles do tend to agglomerate to some extent giving a particle size between 0.2 - 0.45 µm.

Post treatment catalyst recovery would add to the overall capital and running costs of any system. Nevertheless, some workers have developed pilot scale and even full scale water treatment systems employing TiO_2 in suspensions.

Photocatalytic treatment plant at Plataforma Solar de Almeria, CIEMAT-PSA
http://www.psa.es/webesp/instalaciones/aguas.php

Challenges

There are few, if any, full scale photocatalytic water or wastewater treatment systems operating.

Effective reactor engineering is required to demonstrate photocatalysis can be applied at full scale and to demonstrate the cost-benefits

Novel visible light active materials are needed to improve the solar photocatalytic efficiency

Photocatalysis, like other AOPs is a degradative (not simply removal) therefore control engineering of the process is difficult

New photocatalytic materials must be assessed for toxicity and toxicology before deployment.

Acknowledgements

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