Final Report

Grant Agreement no: 309846

PCATDES

Photocatalytic Materials for the Destruction of Recalcitrant Organic Industrial Waste

Collaborative Projects

FP7-NMP-2012-SMALL-6

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1. *Executive Summary*

Contamination of fresh water is widely recognized as a growing threat to sustainable global development and there is considerable pressure to develop effective means of purifying water. Photocatalysis has great appeal in this context because of the power of the oxidation process involved and the abundant energy available from the sun to drive it. The PCATDES project sought to address some of the issues that have hindered the practical utilization of photocatalysis and in particular the relatively low reactivity rates associated with the photocatalytic materials presently available. The multi-national team comprising 11 research groups from seven different nationalities (Thailand, Malaysia, Vietnam, Spain, Germany, Turkey & UK) set out to design and build a novel photocatalytic reactor based upon light emitting diodes with catalysts specifically tailored to operate under these new light sources.

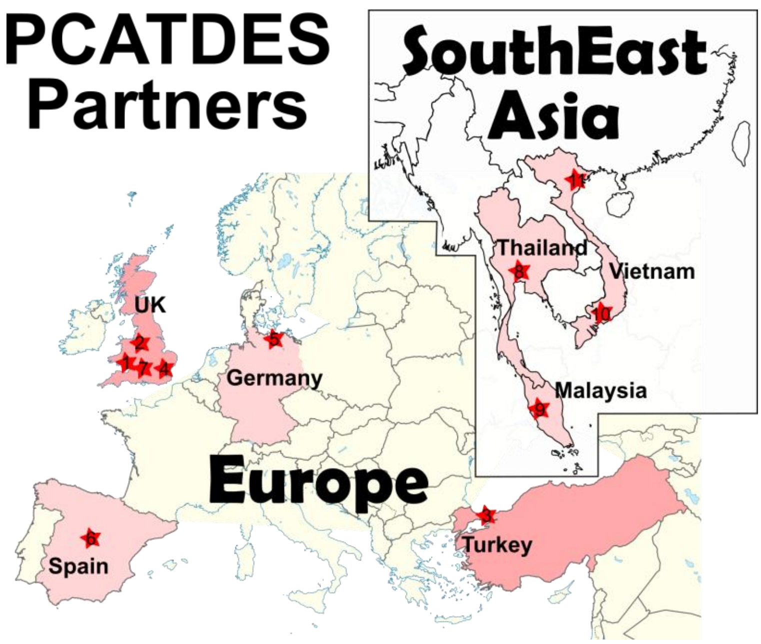
The four year research programme had separate strands linking the design and engineering of the reactor with the synthesis of both improved TiO_2 based photocatalysts and novel photocatalytic materials. The new materials were to be developed for the specific LED light sources incorporated into the final scalable reactor with the aim of testing the reactor against industrial wastewater. In addition, two teams studied photocatalytic mechanisms and the effect of poisons likely to be present in the waste water produced in the industries prevalent in the EU and ASEAN regions and finally two work packages considered the environmental impacts of the reactors and potential catalysts themselves and the possibility of their commercialization.

Figure 1The PCATDES scalable reactor in Vietnam before deployment

The PCATDES project successfully designed, built and deployed two types of LED based photocatalytic reactors. The first, the PCATDES "Standard" reactor was a small scale, batch reactor used by all the experimental teams in the project. As well as providing a first test bed for the LED light sources, these Standard reactors enabled teams to compare results with complete confidence that similar conditions were being used across the consortium. The Standard reactor design and light source is being shared with other researchers in the field. The second type of reactor was the PCATDES "Scalable" reactor which was deployed to sites in Vietnam, Thailand and Malaysia to work with palm oil mill effluent (POME) and seafood waste water. In addition, a great deal of fundamental science was achieved with new insights into the reaction mechanisms and the effects of poisons, new APCVD and sol-gel deposited catalysts with the highest photocatalytic reactivities recorded to date, novel carbon-nitride based catalysts with outstanding visible light activation and novel core-shell photocatalysts. The project engendered extensive collaboration between EU and ASEAN scientists with numerous opportunities for young researchers to visit collaborators' laboratories and engage in their work. Full team meetings were held every six months with conferences in Bangkok (2013 & 2014), Istanbul (2015), Kuala Lumpur (2016) and Hanoi (2017). The project supported 11 PhD level researchers and has so far resulted in 30 publications published or pending.

2. *PCATDES Consortium Partners*

Institution	Map Key	Research Leaders
Cardiff University	1	Prof Philip R. Davies Mr Nigel Pearson
Aston University	2	Prof Karen Wilson
Sampas Nanotechnology	3	Mr Eser Karakaya Mr Mehmet Mermutlu
University College, London	4	Prof Ivan Parkin Dr Raul Quesada
Universitat Rostock	5	Dr Hendrik Kosslick Prof Axel Schulz
Universidad Rey Juan Carlos	6	Dr Javier Mauragan Dr Ruud Timmers
University of Bath	7	Prof Chris Bowen Dr Duncan Alsopp Dr Chris T. Clarke
National Metal & Materials Technology Centre	8	Dr Angkhana Jaroenworatuck
SIRIM-Berhad	9	Isnazunita Ismail Mohamad Zahid Abdul Malek Dr Teng Wang Dung
Vietnam Academy of Science & Tech - ICT	10	Prof Dr Sc Cam loc Luu Dr Pham Thuy Phoung
Vietnam Academy of Science & Tech - IMS	11	Prof Nguyen Quang Liem Dr Ung Thi Dieu Thuy



3. *Project context and objectives*

There is a considerable pressure on the commercial sector to effectively decontaminate waste water streams before returning them to the natural environment, with increasingly stringent legislation in this area in most countries around the world. Large industrial concerns have the resources to invest decontamination of waste water but for smaller firms, with lower profit margins, the purity levels now demanded are becoming prohibitively expensive. Many such companies, particularly those in the agricultural industries, are situated in under developed, poorly monitored, rural areas. When costs of cleaning water are high there is a high probability of rules being ignored and contaminated water being released directly into the environment.

In Vietnam, the seafood sector is highlighted as an area of particular concern due to the sheer scale of production. On average 23 Mt of polluted water is generated per annum most of which is discharged as untreated waste into rivers[1]. Plant seed oil processing is another problem sector generating effluents containing phenolic compounds and long-chain fatty acids which are toxic to microorganisms and plants and constitute some of the strongest industrial pollutants. This sector includes palm oil production which, based on 2006/07 output,[2] produces ~250 Mt of effluent[3], and is identified as the largest cause of river pollution in the region. Similarly olive oil production in Mediterranean regions generates huge quantities of waste-water[4] with ~2.5 Mt of polluted waste-water generated per annum. Filtration and microbiological treatment using anaerobic and aerobic digesters provide cheap means to eliminate solids and some organic matter but are capable of removing only ~95% of the organic matter[5]. Complete mineralization of the residual "recalcitrant" material, (including humic acid and palmitic, oleic and linoleic triglycerides) currently requires energy intensive and relatively expensive treatments to meet legislative standards[6]. A survey undertaken by Malaysian Palm Oil Board (MPOB) demonstrates that the current tertiary treatment technologies employed are not able to consistently and continuously achieve the regulatory discharge target of biological oxygen demand (BOD) of 20 ppm (in East Malaysia), even though the industry has invested millions in installing the needed facilities.

Figure 2. POME purification ponds in Thailand, Particulate matter is allowed to settle before the water is pumped over farmland.

Photocatalysis is a promising option[7] for the remediation of low concentrations of organic pollutants in waste-water because of its high oxidation potential without utilizing any chemicals except for the catalyst and air. However, practical implementation of photocatalytic water remediation requires significant improvements in efficiency: the fraction of incident light used by current photocatalysts and the reaction efficiency of the catalysts are all far below where they need to be for the process to be commercially viable. The vision of the PCATDES team was to take advantage of the rapidly improving UV LED technology to create high intensity efficient light sources with wavelengths better suited to custom designed catalysts to create a technologically

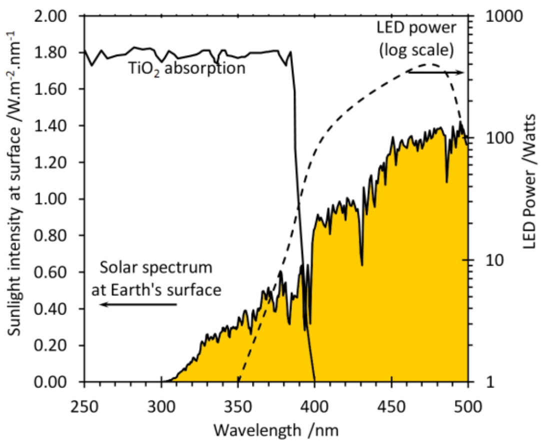


Figure 3. A comparison of LED power output (2012 data), incident sunlight on the Earth's surface and the absorption spectrum of TiO2.

advanced reactor, Figure 3, illustrates the way in which the LED light output matches the current best photocatalyst better than does incident sunlight.

The multidisciplinary PCATDES consortium drawn from across the ASEAN and EU regions brought together the necessary skills in environmental science, nanotechnology, materials design, modelling, electronic and chemical engineering to design & build the proposed reactors.

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2. C. Carter, W. Finley, J. Fry, D. Jackson, and L. Willis, *Eur. J. Lipid Sci. Technol.*, 2007, **109**, 307.
3. T. Y. Wu, A. W. Mohammad, J. M. Jahim, and N. Anuar, *Biotechnol. Adv.*, 2009, **27**, 40.

3.1 Strategy and main objectives of the project:

The overall targets of the PCATDES project were:

(i) Establish methods for artificially boosting natural UV radiation by using advanced UV light emitting diodes (LEDs) to greatly enhance the photo-catalytic process.

(ii) Nanoengineer the structural and electronic properties of semiconductor photo-catalysts to enhance the response to solar and UV irradiation and charge separation characteristics.

(iii) Bring together the "key enabling technologies (KET)" developed in steps (i) and (ii) to realize a prototype autonomous reactor powered by solar cells.

To reach these targets the project team were organized into 9 work packages which are illustrated in Figure 4.

3.2 The key scientific objectives of the research:

(i) To extend the wavelength range for which the catalysts are sensitive further into the visible region through a combination of materials discovery and catalyst optimisation.

(ii) To increase the catalytic efficiency of TiO_2 materials through the development of nanoengineered forms including nanofilm, nanotube and nanoshells and doped TiO_2 materials. This work will include novel preparation methods.

(iii) Establish the extent to which the efficiency of the new photo-catalysts can be enhanced by artificial light from arrays of **cheap** high-brightness LEDs (HB-LEDs) with catalyst band gaps matched to emission wavelengths.

(iv) Establish mechanisms and limiting reaction rates from studies of the catalytic kinetics and catalyst surface chemistry. Aspects of catalyst/particle growth will be elucidated and the effects and roles of likely poisons will also be investigated.

3.3 Overall technological objectives of the research:

(i) To evaluate the performance, lifetime and stability of catalysts in both the LED-based systems and using next generation visible active materials. The durability of both model and real substrates will be established.

(ii) To establish a prototype smart photo-catalytic reactor comprising catalyst support, catalyst, UV LEDs, light and flow sensors, a microprocessor for control, all powered by a solar cell array to create an autonomous system.

(iii) To evaluate practical reactor designs with different presentations of catalyst, kinetic modelling of the performance and scale up of the successful design.

(iv) To employ the reactor in field tests at suitable production sites, establish optimum designs for real-world operation and evaluate their processing efficiency.

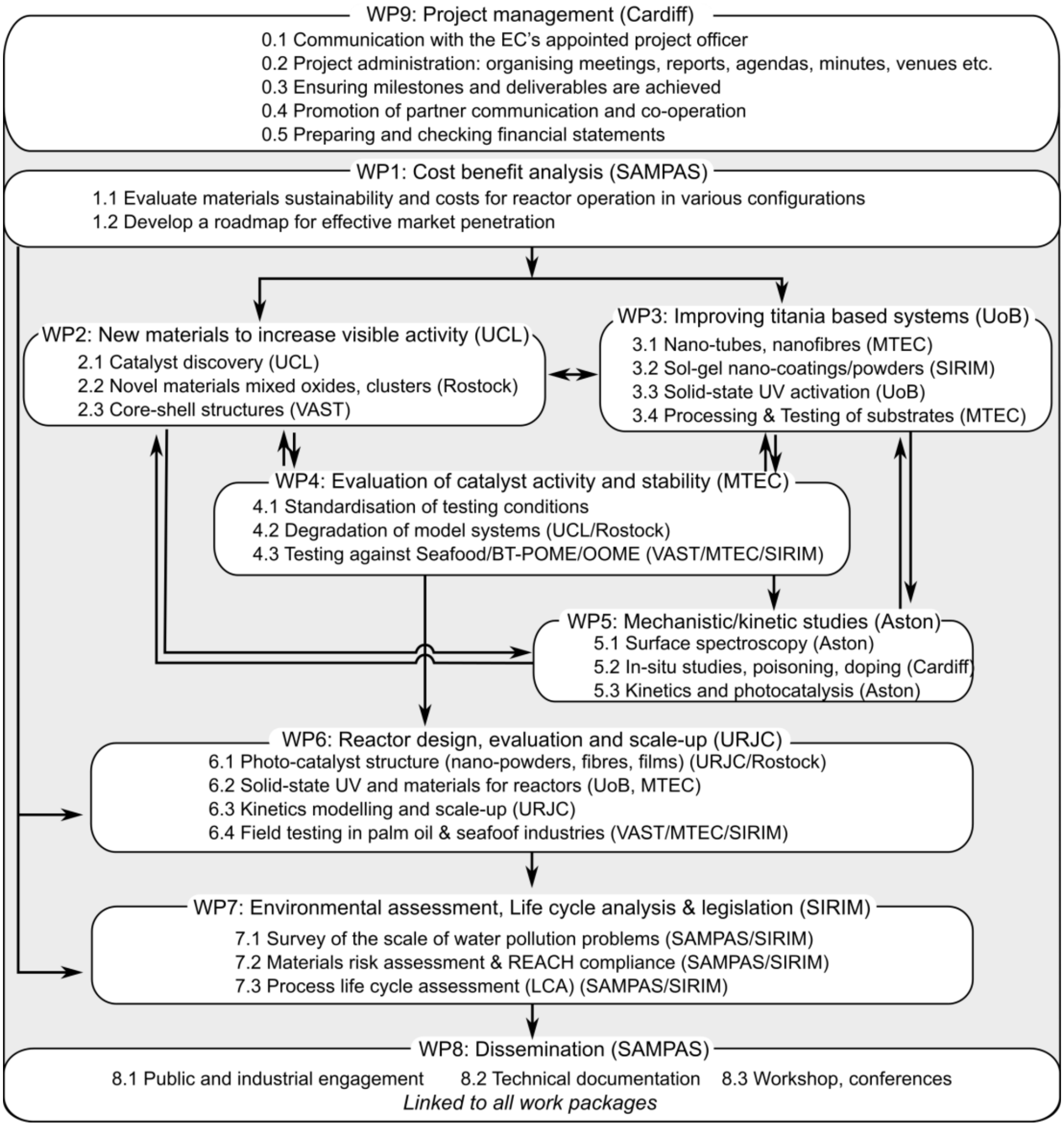


Figure 4. Organisation and details of the tasks for each workpackage in PCATDES

4. *Description of the main scientific and technological results*

The PCATDES activities were organized by Work Package as shown in Figure 4, and this structure served the project very well. However, there were considerable cross-workpackage interactions during the project and so the main results are organized here in terms of overall targets rather than by workpackage. There are four main components to the results: Synthesis of new catalysts, investigations of catalytic mechanisms, new catalyst support frameworks/coating and new reactors.

4.1 New photocatalyst materials

During project a large number of new and modified catalysts were synthesized and investigated, many of these are discussed in the project publications. We highlight here, three particular innovative catalysts:

One of the most significant advances, was the replication, as a coating, of the well-known anatase-rutile combination in the P25 catalyst. This was synthesized for first time using atmospheric-pressure CVD, Figure 5. The anatase-rutile (A-R) film showed outstanding extended photocatalytic activity in the UV range, exceeding that of any previous CVD coating. The work also established the optimum conditions for the scale-up deposition of these highly active coatings onto the porous substrates developed for the reactors and discussed in Section 4.3.

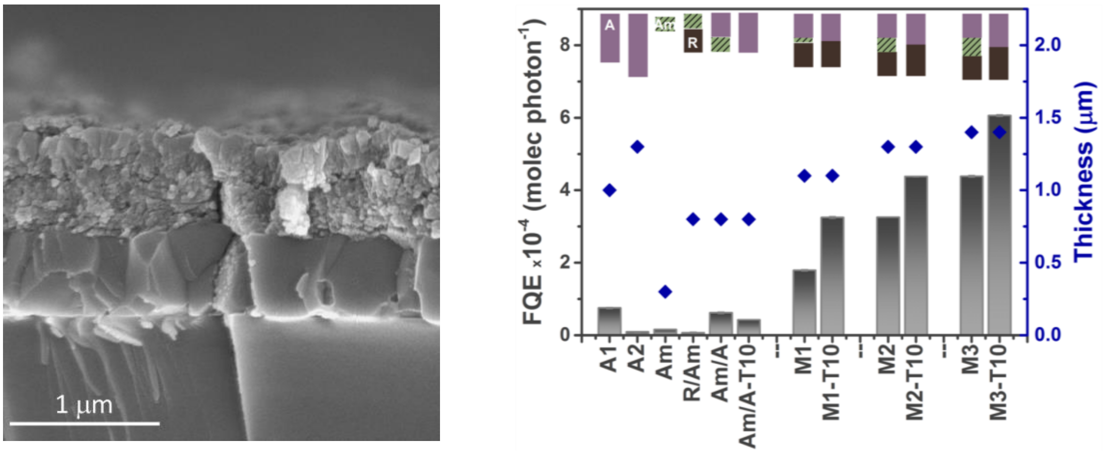


Figure 5. SEM of the anatase-rutile bilayer TiO_2 film and photocatalytic activities (given as formal quantum efficiency) of a range of TiO_2 multilayer coatings (A: anatase; Am: disordered layer; R: rutile). A clear enhancement in activity can be observed between standard anatase TiO_2 films (A1, A2) and the multilayer systems.

Another, important success for the project was the development of nanostructured WO_3/TiO_2 coatings, which had the best performance ever recorded for a catalytic coating, Figure 6. These films have been developed using combined aerosol-assisted and atmospheric-pressure CVD techniques. The bandgap energy of WO_3 (2.8 eV) is red-shifted with respect to that of anatase TiO_2 (3.2 eV) and thus it was hoped that a WO_3/TiO_2 heterojunction would extent the optical absorption to utilize ~9 % of the solar spectrum.

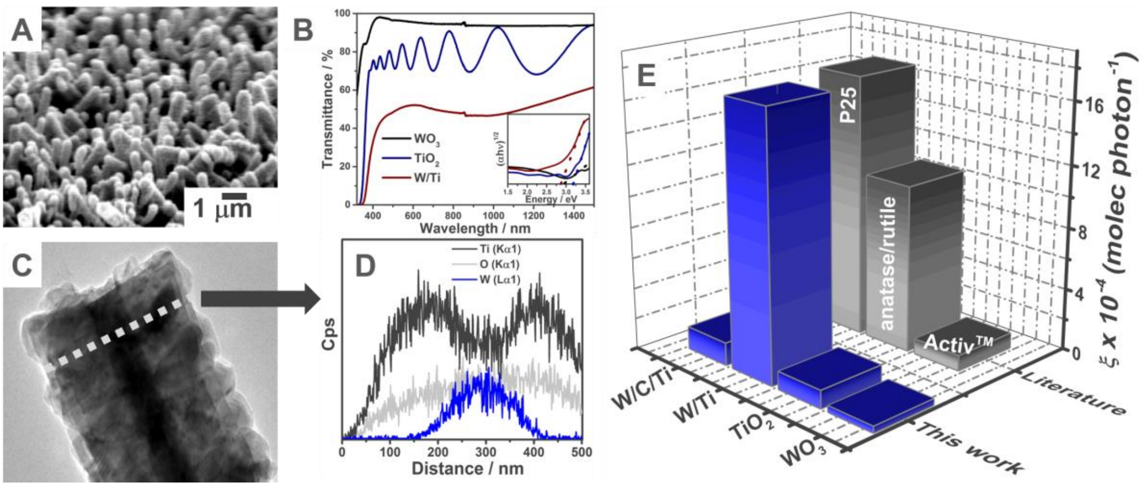


Figure 6. (A) SEM image of WO_3 nanorods coated with TiO_2, WO_3/TiO_2 heterojunction film (W/Ti). (B) UV-Vis spectra of pure metal oxides, WO_3 (black line) and TiO_2 (blue line), as well as the heterojunction WO_3/TiO_2 sample (burgundy line). The inset shows bandgap measurements derived from Tauc plot analysis. (C) HRTEM image of WO_3 nanorod enclosed with anatase TiO_2 coating. (D) EDS analysis across the WO_3/TiO_2 film, proving the complete encapsulation of the WO_3 by TiO_2. (E) Formal quantum efficiencies (ξ) of the different heterojunction films used in this work, WO_3/TiO_2 (W/Ti) and $WO_3/C/TiO_2$ (W/C/Ti), as well as the pure metal oxides WO_3 and TiO_2. The ξ values are given as molecules degraded per incident photon (molec×photon^{-1}) and were obtained from the rate of photodegradation of stearic acid under UVA illumination (3.15 mW·cm^{-2}). Typical ξ values of relevant photocatalytic materials are included as reference.

The WO_3/TiO_2 heterojunction thin films showed an extended photocatalytic response within the 400 – 420 region an important result for PCATDES, as one of the specific objectives was to extend the wavelength range of the as-synthesised photocatalytic materials further into the visble region. However, despite this extended wavlenght range of action, no visible activity (> 420 nm) was observed.

A third avenue of investigation for the project was to explore non-TiO_2 based catalysts. An example of that was a series of C_3N_4/silver vanadate composites supported on a range of different ordered mesoporous silicas (inc. MCM-41, MCM-48, SBA-12, 15, and-16 as well as KIT-6, and FDU-12). The photocatalyst was optimized to the highest catalytic efficiency against silver content. However, the structure and porosity of ordered mesoporous supports showed only a minor impact on the photocatalytic performance of the materials, which was unexpected. Investigations with SEM indicated that the prepared ordered mesoporous supports showed a similar morphology consisting of aggregates with sizes in the same order of magnitude, Figure 7. These particles represent mesocrystals composed of aligned nanoparticle of ca. 50 nm size and suggest that the overall morphology of the aggregates is important for photocatalytic conversion rather than the internal porosity.

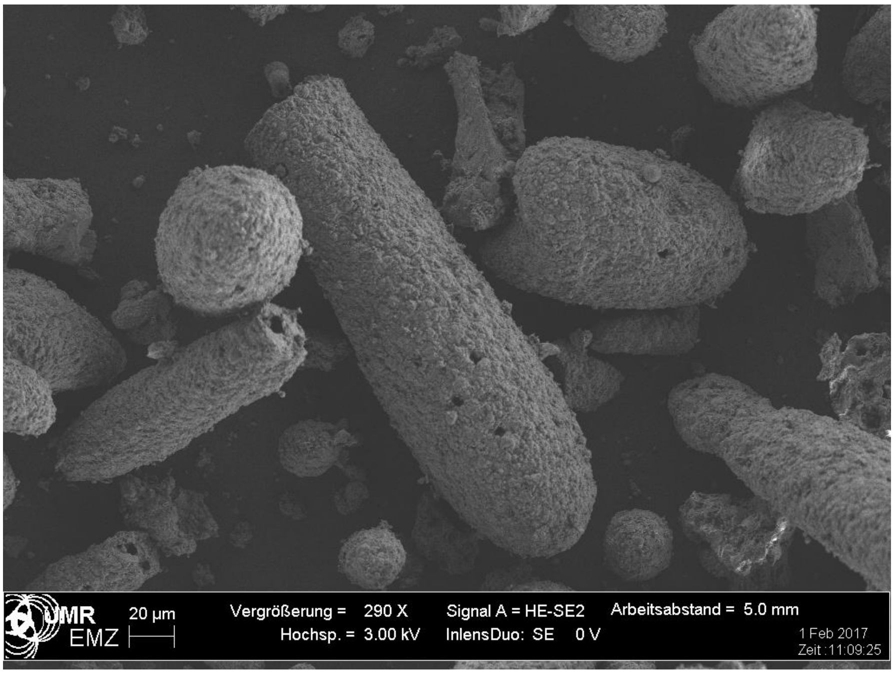
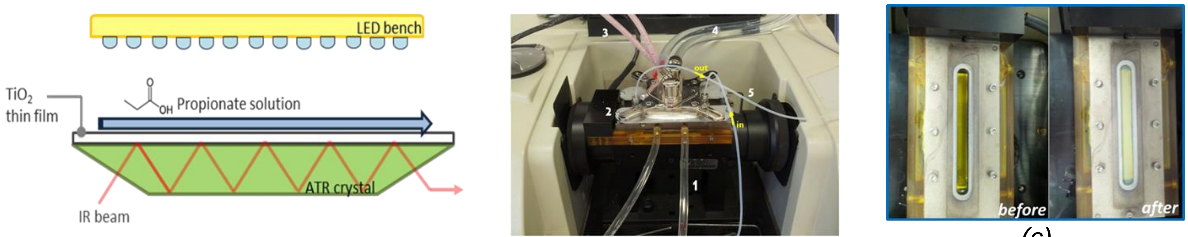


Figure 7.SEM image of KIT-6 aggregated in super structured dumbbell shape.

4.2 Mechanistic insights

The mechanism of the decomposition of the target molecules was investigated with a view to understanding the effects of likely poisons on the catalytic system. Two approaches were taken, firstly the adsorbed species were investigated using a thin film photocatalytic ATR reactor developed especially for the project, Figure 8.



(a) (b) (c)

Figure 8. a) Schematic view of the ATR flow cell reactor; b) Picture of the actual set-up c) ZnSe crystal before and after the titania coating.

Propionic acid was chosen as probe molecule, as despite the complexity of molecules present in the waste water; carboxylic acids are always detected as intermediates in the degradation reaction of organic compounds. The adsorption and the photodegradation of propanoic acid was studied on Degussa P-25, Anatase and Rutile TiO_2 nanoparticles. The interaction between propanoic acid and the P-25 and anatase surfaces was higher than that for rutile this may contribute to the slower degradation rate of propionic acid over the latter catalyst.

Decomposition through Photo-Kolbe decarboxylation is preferred when the bridging bidentate species is formed, which determines the rate of photodegradation.
The mechanism proposed from the FTIR data was supported by identification of the immediate products of cinnamic acid over photocatalysts using GC/MS. Cinnamic acid preferentially binds to titania in a bidentate fashion. This leaves the bound species open to attack by an oxygen species that results in C-C bond cleavage to give benzaldehyde, as seen in Figure 9. It is clear that the main mechanism for cinnamic acid degradation relies heavily on superoxide radicals. Effective purging of oxygen gas from the reaction reduces the advanced oxidation processes and switches the mechanism to those involving hydroxyl radicals.

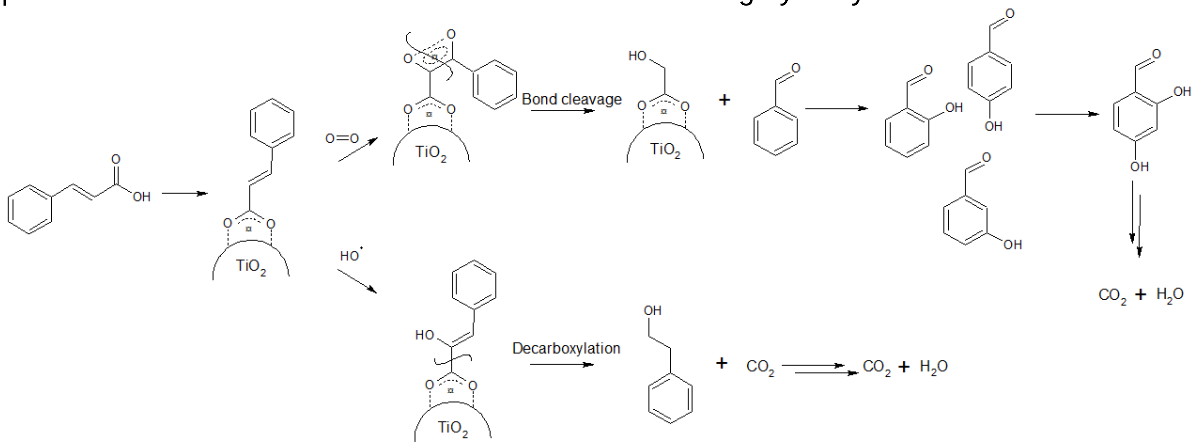


Figure 9.Proposed mechanisms for the degradation of cinnamic acid by titania photocatalysis.

Hydroxy-benzaldehydes form directly from the benzaldehyde intermediate via hydroxyl radicals and phenylacetaldehyde is also formed via hydroxyl radical addition to the α position followed by a decarboxylation.

The main poisons in the POME and seafood waste water were identified by the residue remaining on photocatalysts in test runs to be sulfates, chloride, potassium and sodium. Neither of the cations appear to have significant effects on the photocatalysis. The sulfate to inhibited the initial degradation steps of the cinnamic acid but only partially hinders the further mineralisation to CO_2. The chloride ion however has strong effect, not only on the rate of reaction but also on the nature of the products. The chloride radicals provide alternative mechanisms which supersede the degradation pathways involving just oxygen. The rate of cinnamic acid degradation increases when large amounts of chloride are present, however, the new chlorinated intermediates are more damaging to the environment and complete mineralisation is hindered. This work indicates that care needs to be taken using photocatalysis in some areas.

4.3 New catalyst frameworks and coatings

In addition to creating the new catalysts described in Section 4.1, a means had to be developed to present the materials in a form suitable for the LED reactors discussed in Section 4.4. The most successful format tested was a porous titania foam prepared via a ceramic processing method, Figure 10. TiO_2 (P25) powder was used as a main starting powder and prepared using selected polymer foams as pore templates. The strength of the 3D-TiO_2 scaffolds made by the micron TiO_2 powders was high enough

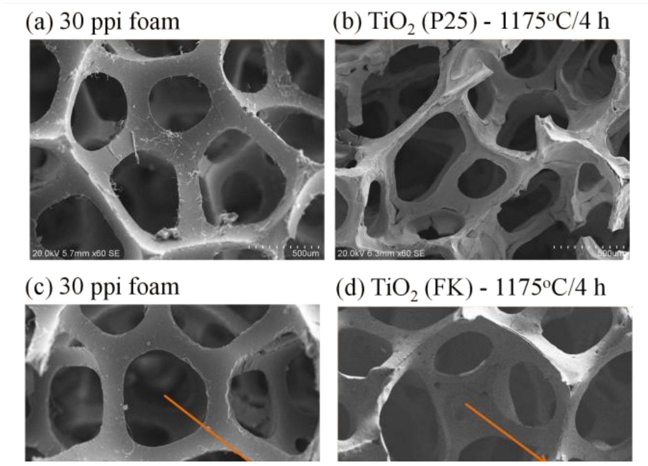


Figure 10. SEM images showing pore characteristics of two types of 3D-TiO_2 scaffolds made by nano- TiO_2 (P25) and micro-TiO_2 (FK) powder, prepared using 30 ppi foam and sintered at at 1175°C for 4 h

for coating, water immersion and surface polishing.

The optical properties of different pore size scaffolds were measured to determine the ideal porosity to allow light to travel through the disk to allow the best use of light in the reactor, Figure 11. The extinction coefficient (β*) was calculated for this foams in the linear absorption region and an equivalent absorption (K*) and scattering coefficient (σ*) was calculated for the developed photocatalytic foam material assuming the same scattering albedo as commercial P25. Hydraulic tests were also performed on these foams to establish the maximum flow rate possible with the scaffolds (1 L / min) and to estimate the pressure drop within the reactor. These data allowed the optimization of the final reactor design, Section 4.4.

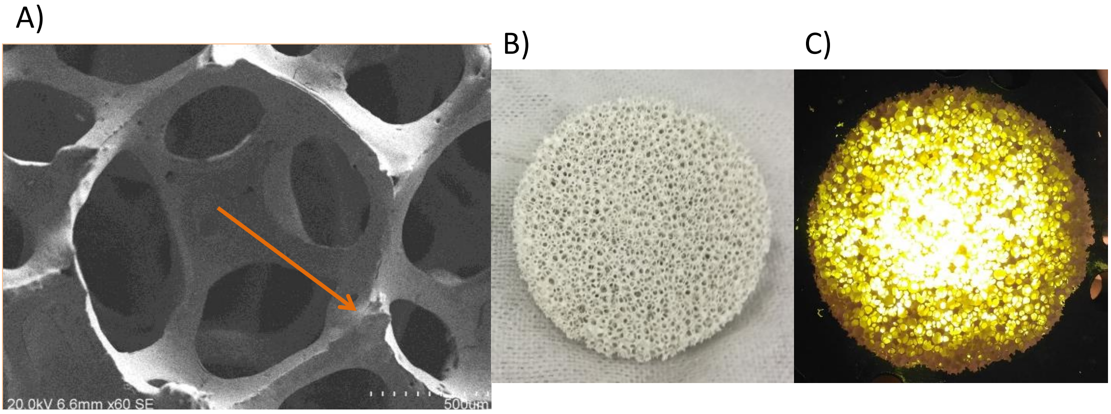


Figure 11:A) SEM image of a 3D-TiO_2 scaffold prepared using 30 ppi foam and micro-TiO_2 powder, and sintered at 1175°C for 4 h. B) 3D-TiO_2 scaffold and C) 3D-TiO_2 scaffold under UV illumination.

Coatings for the 3D-TiO_2 scaffolds were developed with a number of different approaches, the CVD coatings were discussed in Section 4.1. These extremely promising coatings could not be produced rapidly enough to be incorporated into the scalable reactor. Similarly, the C_3N_4/silver vanadate composites were also developed into coatings but were not ready for deployment by the end of the project. This work will continue in a collaboration between University of Rostock and VAST-ICT. The final design of the reactor therefore settled on Sol-Gel routes to coating the foams. A novel TiO_2/WO_3 sol-gel approach was developed which is illustrated in Figure 12. However, these tungsten containing films did not significantly enhance the photocatalytical activity and in the final reactor a TiO_2 only sol-gel based on titanium (IV) butoxide was used as the coating.

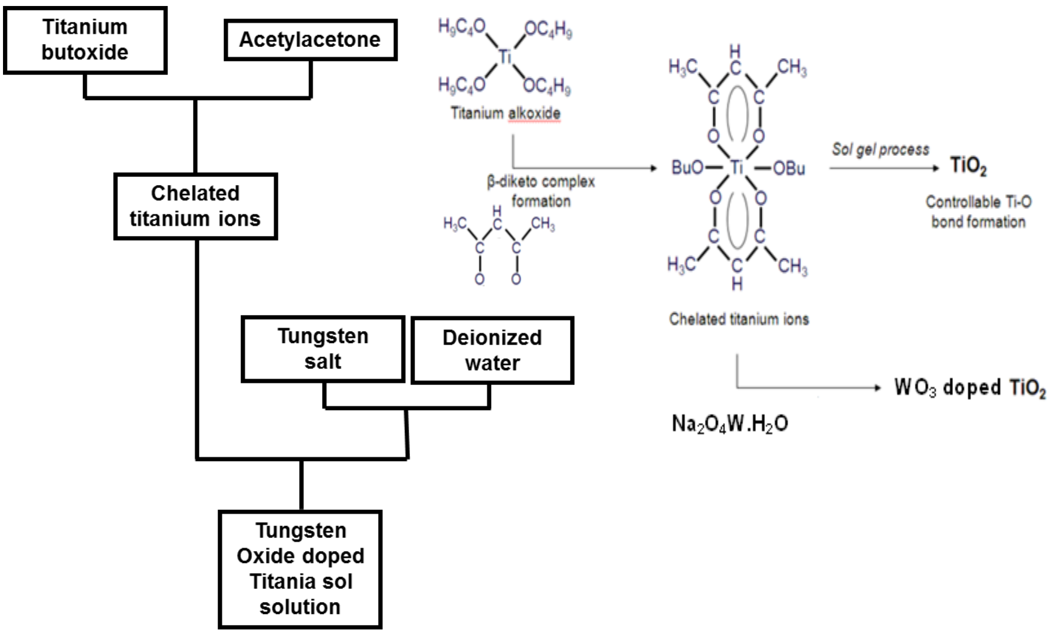


Figure 12. Schematic diagram of the synthesis of novel Sol-Gel TiO_2/WO_3 mixed oxide coatings

4.4 New photocatalytic reactor designs:

At the start of the PCATDES project the team realized that they needed to ensure results from different laboratories, on opposite sides of the world, could confidently compare data. To make this possible a standard reactor and standard reaction (cinnamic acid degradation, see Section 4.2) was designed. The PCATDES "standard" batch reactor is based on an LED light board with 36 LED's at a fixed wavelength of 365 nm. The board was later adapted to provide a variety of wavelengths, including 365 nm, 385 nm, 405 nm, 460 nm and 623 nm) for partners interested in probing other regions of the spectrum.

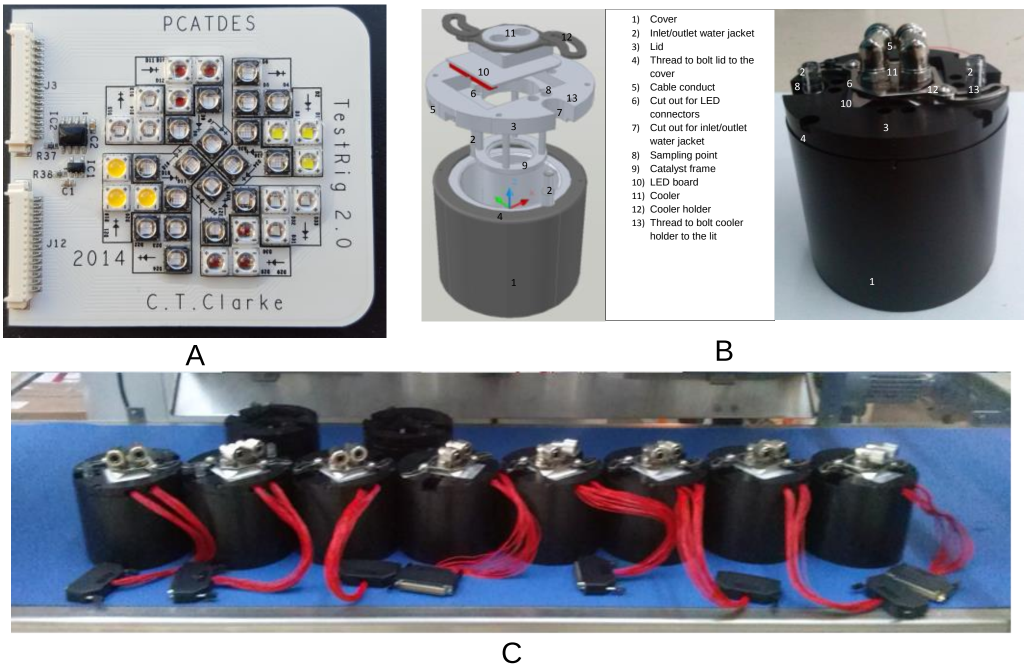


Figure 13. A. LED light board for standard reactor; B. Schematic representation of and photograph of the final reactor design; C. Reactors constructed for the partners.

The Standard batch reactor laid the groundwork for the final "Scalable" flow reactor that was built for testing in the field. The design contraints for the flow reactor were to reuse the same 36 LEDs power/control system with 6 LEDs in 6 columns along the flow tube. The engineering design was tested with a CFD model, and a prototype version built.

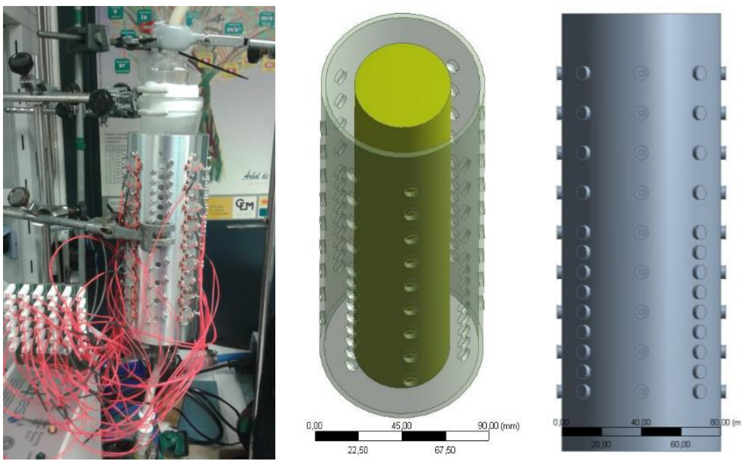


Figure 14. Prototype photoreactor and CFD model.

From the results with the prototype the final reactor dimensions were optimized to be a reactor length of 50 cm with an internal reactor diameter of 5 cm. The LED's source diameter was 10 cm allowing easy removal from the reactor tube. LEDs were mounted on a reflective, cooled, aluminum surface, with a distribution of 6 row x 6 LEDs, emitting 800 mW UV in staggered position. The reactor space time was determined in 48 s per pass.

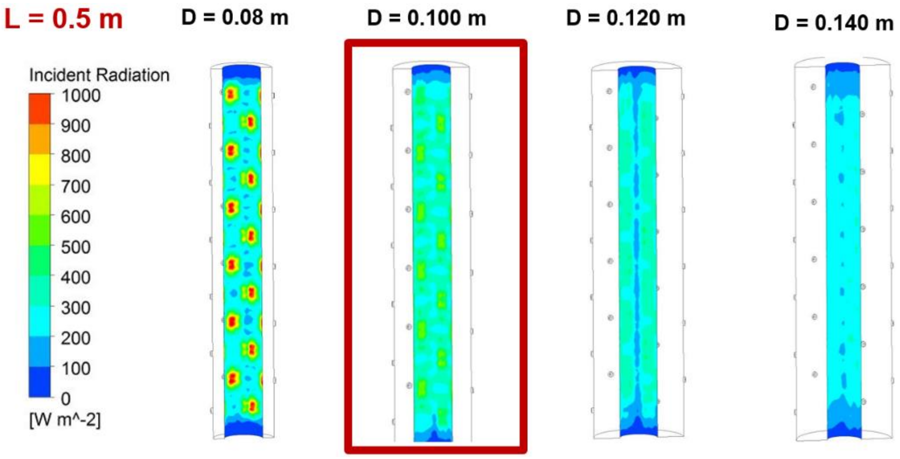
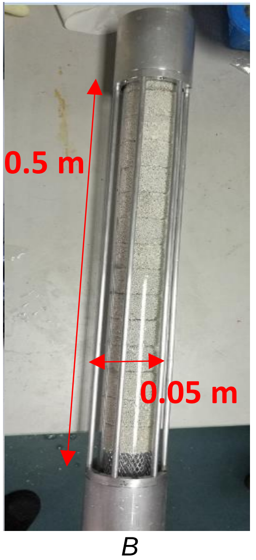


Figure 15. Computational results for the light reaching the reactor wall for different distance between the LEDs and the reactor surface.

Three scalable pilot reactors, Figure 16, were fabricated for MTEC (Thailand), VAST-ICT (Vietnam) and SIRIM (Malaysia) to study the removal of recalcitrant compounds from biologically treated palm oil mill effluent (BT-POME) and sea-food effluent.

A



B

Figure 16. A. Front view of the scalable pilot reactor. B. Photocatalyst coated scaffolds loaded into the column.

POME and seafood-effluent samples were first pre-treated (centrifugation, filtration and dilution) to reduce the particles present in the raw waste and avoid fouling and inefficiency in the photocatalytic reaction. The analysis of the samples was based on parameters such as pH chemical oxygen demand, (COD), total oxygen demand, (TOD) and total organic carbon (TOC). The COD and total suspended solids of the POME wastewater was successfully reduced by up to 80% in some of the samples but not all. Gas Chromatography analysis indicates that although photo-degradation of long chain fatty acids to shorter chains occurs this does not reduce the COD in samples from different companies, countries and compositions. Operation time was also studied, and showed that prolonged treatment duration does not give great impact on treatment efficiency.

Testing with the Scalable reactors will continue beyond the defined research period of PCATDES and we believe this to be an important step in the development of the advanced oxidation photocatalytic technique.

5. *The potential impact and the main dissemination activities and exploitation of results*

The PCATDES Project brought together international expertise from around the world with an ambitious target to treat high volumes of polluted wastewater created by agricultural and seafood industries. The collaboration has been positive and harmonious, all deliverables have been achieved and knowledge transfer is very evident with extensive cross fertilisation of ideas between the 11 centres of excellence situated throughout Europe and the South East Asia regions. The standard photocatalytic reactor developed in Year 2 was utilized by 10 of the 11 Partners for their ongoing research and has also been offered to other separate research groups. In Year 4, the Consortium built and deployed three, improved, Scalable reactors for deployment in South East Asia (Thailand, Malaysia and Vietnam) where they can be located close to relevant industries. Our preliminary analysis suggests that PCATDES has developed a photocatalytic reactor with the potential to assist affected industries. Pragmatism, and initial business analysis, made it apparent that it would be inappropriate, and poor value for money, at this stage, to construct a larger reactor capable of handling larger volumes of polluted waste water.

PCATDES was able to ‘field test’ the Scalable Reactors for two months at the very end of the project. The Project Coordinators considered whether it was viable to extend these trials by up to 6 months by re-profiling budget. However, after constructive dialogue with the EC the Consortium agreed that extra spend and additional field testing would not make a significant impact on eventual results.

5.1 Engagement with Industry

PCATDES Partners in South East Asia, in particular, developed strong cooperation with relevant local industries. In Thailand, NSTDA MTEC worked with both the. Suksomboon Palm Oil Company, Chonbury Province, Thailand and the A.S.T Palm Oil Co., LTD, Prajuabkirikhan Province, Thailand. Sirim Berhad, Malaysia also worked with a local Palm Oil Company. However, this long standing relationship was covered by a Non-Disclosure Agreement that prevented the naming of the Company. In Saigon, Vietnam, VAST-ICT cooperated with seafood supplier, Saigon Fishery Joint Stock Company (SG FISCO), located at Lot C 24-24B/II, St.2F, Vinh Loc Industrial Zone, Binh Chanh Dist., Ho Chi Minh City, Vietnam.

In Europe, the University of Bath developed strong links with ‘Foseco International Limited’ Tamworth, Staffordshire, UK. This Company has considerable experience in the production and deployment of commercial foams in industrial processes. At the PCATDES International Workshop, in Hanoi, 2017, David Bell of Foseco described the huge volumes produced and an indicative commercial price. This presentation gave delegates a valuable insight into commercial production and commercial pricing. It exemplified the problem of trying to model the costs of converting prototype reactors developed, under research conditions, by largely academic institutions into a viable commercial proposition.

Sampas Nanotechnology, Istanbul, Turkey, an SME, were included in the PCATDES Consortium to provide expertise on “Exploitation of Project Outcome” and “Dissemination and Public Awareness”. They also were involved with Sirim Berhad, Malaysia to advise on “Environmental” implications. The PCATDES Partners in Europe and Asia helped Sampas to survey relevant industrial producers dealing with seafood, palm oil and olive oil. However, responses were generally low. At the Second PCATDES Review, in Istanbul, in 2015, a local Palm Oil Producer suggested that small Companies, in particular, might not have the spending power to adopt new technology, new processes or comply with National environmental legislation.

5.2 Collaboration

The PCATDES Consortium has demonstrated that European and ASEAN Partners can collaborate very effectively. Despite very different time zones, languages and occasional cultural differences “Team PCATDES” has worked constructively, cohesively and cooperatively to deliver the project to plan. All Partners have fully engaged throughout the Project and the relationships developed during this time will inevitably lead to future collaborations. Several PhD students and young researchers have been involved in PCATDES, with a number of exchange visits between sites. Over the four years it has been running the project has provided these young researchers with excellent experience in international research.

The success of collaboration within PCATDES is illustrated by the following comments:

"PCATDES was a unique experience in the way researchers engaged with each other at an international level. It was inspiring and enlightening; a true success and cornerstone of many projects to come."
Dr. Raul Quesada-Cabrera, Senior Postdoctoral Researcher, UCL (University College London).

"I'm happy to say that "PCATDES gave me the opportunity to work and collaborate with many experienced researchers in a large team. It also allowed me to enhance my scientific skills and knowledge, as well as developing my confidence and presentation skills".
(Phạm Thị Thùy Phương – VAST-ICT, Vietnam)

PCATDES project allowed me to complete my PhD on "Application of Computational Fluid Dynamics tools to the modelling and simulation of photocatalytic reactors from intrinsic kinetic parameters" and allowed me to collaborate with other researchers in Europe and South East Asia. In addition to a very enriching scientific experience, this project has allowed me to approach other cultures and discover amazing people and countries.
Miss Cintia Casado, Researcher, Rey Juan Carlos University, Spain.

5.3 PCATDES people

77 people were involved 'directly' with the PCATDES Consortium, two of the three Coordinators were women and three of the seven Work Package Leaders were women as indicated by the following table:

Type of Position	Number of Women	Number of Men
Scientific Coordinator	1	4
Work Package Leader	3	4
Experienced Researchers	20	20
PhD Students	7	4
Other	3	11
Total Number	**34**	**43**

Table 1. Gender diversity of the PCATDES project

The numbers emphasize the equality and diversity of the project. 25 *additional* research team members were specifically employed to work on PCATDES, of which, 10 were women and 15 men.

Several Senior PCATDES staff were promoted whilst working on the Project. Including a Professor who became Dean of Faculty and Doctors who became Professors. There were also instances where staff were given wider responsibilities. It would be wrong to attribute these successes to PCATDES, however it does show that the Project did not impact on career development.

Sadly, Professor Ron Stevens, University of Bath, who had been instrumental in many aspects of the design of the project, passed away in year 1 of the Project. He was remembered by a named lecture in the Final PCATDES Review Meeting at Hanoi.

Environment

Sirim Berhad, Malaysia monitored the substances and materials in creating and using the Reactor to conduct a full Environmental impact and life cycle analysis. All of the substances were covered by risk management and none were being used in the quantities to fully utilise the REACH Life Cycle Analysis methodology.

5.4 Dissemination

Sampas Nanotechnology, Turkey, backed by the Coordinators, Work Package Leaders and Principal Investigators has led on dissemination of PCATDES. They created the PCATDES website (pcatdes.eu) in September 2013 and have kept the Project in the Public Eye with press releases and social media that includes: LinkedIn, Twitter and Facebook. In addition PCATDES colleagues have presented on 50 occasions, in Europe, Asia and America, to several thousand people, in total, see section 5.4.6.

5.4.1 PCATDES Launch and Annual Review Meetings:

- Bangkok, January 2013
- Bangkok, January 2014
- Istanbul, February 2015 and
- Kuala Lumpur, November 2016
- Hanoi, January 2017 (Final Review Meeting, incorporating the PCATDES International Workshop)

5.4.2 PCATDES International Workshop

The PCATDES International Workshop allowed PCATDES to turn the 'spotlight' on its young researchers – with each Partner showcasing its contribution by a presentation from a young researcher. In addition, a Poster Display (of 15 posters) was exhibited for 2 days again featuring young researchers.

Figure 17. The PCATDES participants at the Final Review meeting, Hanoi, January 2017

5.4.3 EU/ASEAN STI Days

PCATDES were major contributors to the EU/ASEAN STI Days run by *another FP7 Project allowing PCATDES to disseminate its activities to a wider audience:*

- January 2014,
  alongside other related FP7 Projects, LIMPID and 4GPHOTOCAT, presented on the photo catalysis theme,

- May 2016,
  Hanoi on 'water' themes. PCATDES contributed to a second successful EU/ASEAN STI Days Event with presentations, posters and a stand featuring a version of the Scalable prototype photocatalytic reactor.

5.4.4 Leaflets

Two versions of a PCATDES Leaflet were produced at the beginning and end of the Project. Hundreds of both versions were distributed at Review Meetings, STI Day Events or handed to Partners for further distribution.

The PCATDES Coordinators also participated in the ***European Cluster on Catalysis***, a coordination and advisory body for the European Commission in the field of catalysis within the Horizon 2020 framework. Dr Sylvia Gross delivered a presentation on the Cluster to the assembled PCATDES delegates in Istanbul, 2015.

5.4.5 PCATDES website: http://www.pcatdes.eu/

5.4.6 Events attended by PCATDES partners

1. 7th International Conference on Materials for Advanced Technologies, ICMAT 2013
   Date: 01.07.2013, Venue: Suntec, Singapore
   Topic: Manufacturing Processes For Nano-Tubes, Nano-Holes And Nano-Rods (Invited Lecture) ; Participant: BATH/Chris Bowen
2. World Intelligent Cities Summit And Exhibition
   Date: 27-28.11.2013 , Venue: Istanbul, Turkey
   Topic: Oral Discussions/ PCATDES Leaflet Distribution ; Participant: SNANO
3. Photocatalytic And Superhydrophilic Surfaces Workshop, PSS 2013
   Date: 12.12.2013 , Venue: Manchester, UK
   Topic: CFD Modelling Of Photocatalytic Systems ; Participant: URJC/Javier Marugán
4. ASEAN-EU Science Technology And Innovation Days. Workshop On Nanomaterials For Photocatalytic Depollution (1st Edition)
   Date: 21-23.1.2014 , Venue: Bangkok, Thailand
   Topic: Application Of Computational Fluid Dynamics To The Design Of Photocatalytic Reactors ; Participant: URJC/Javier Marugán, Cintia Casado
5. ASEAN-EU Science Technology And Innovation Days. Workshop On Nanomaterials For Photocatalytic Depollution (1st Edition)
   Date: 21-23.1.2014 , Venue: Bangkok, Thailand
   Topic: Preparation Of Nanostructured ZnO And Testing In The Photocatalytic Degradation Of Pharmaceutical Pollutants ; Participant: Universität Rostock
6. ASEAN-EU Science Technology And Innovation Days. Workshop On Nanomaterials For Photocatalytic Depollution (1st Edition)
   Date: 21-23.1.2014 , Venue: Bangkok, Thailand
   Topic: Nanocomposite TiO_2-SiO_2 Gel For UV Absorption ; Participant: MTEC/Angkhana Jaroenworaluck
7. META.XI Reunión De La Mesa Española De Tratamiento De Aguas
   Date: 16.6.2014 , Venue: Alicante, Spain
   Topic: Diseño De Reactores Fotocatalíticos Para El Tratamiento De Aguas Mediante Modelos De Fluidodinámica Computacional ; Participant: URJC/Javier Marugán
8. SPEA8. 8th European Meeting On Solar Chemistry And Photocatalysis: Environmental
   Date: 25.6.2014 , Venue: Thessaloniki, Greece
   Topic: The Design Of A Prototype Photo Reactor For Standardized Photocatalytic Activity Test Using A Computer-Controlled UV LED Light Engine ; Participant: URJC/Javier Marugán

9. SPEA8. 8th European Meeting On Solar Chemistry And Photocatalysis: Environmental
   Date: 25.6.2014 , Venue: Thessaloniki, Greece
   Topic: Modelling Of The Oxidation Of Methanol In A Tubular Slurry Photocatalytic Reactor By Computational Fluid Dynamics ; Participant: URJC/Javier Marugán
10. ICCE. II International Congress Of Chemical Engineering Of ANQUE
    Date: 1.7.2014 , Venue: Madrid, Spain
    Topic: Modelling Of The Photocatalytic Oxidation Of Methanol In A Tubular Reactor ; Participant: URJC/Javier Marugán, Cintia Casado
11. XXI International Conference On Chemical Reactors "CHEMREACTOR-21"
    Date: 23.9.2014 , Venue: Delft, Netherlands
    Topic: UV Led Prototype Photo Reactor For Standardized Photocatalytic Activity Tests ; Participant: URJC/Javier Marugán, Cintia Casado
12. 7th International Workshop On Advanced Materials Science And Nanotechnology IWAMSN2014
    Date: 2-6.11.2014 , Venue: Ha Long City, Vietnam
    Topic: - ; Participant: Universität Rostock
13. EMN Ceramics Meeting 2015 Orlando
    Date: 26.1.2015 , Venue: Orlando, USA
    Topic: Graded Ti Suboxide Fibres For Water Splitting ; Participant: BATH/Chris Bowen
14. 1st PCATDES Press Release Distribution
    Date: 16.3.2015 , Venue: /newsid=39405.php
    Topic: 1st PCATDES Press Release Distribution ; Participant: SNANO
15. 1st PCATDES Press Release Distribution
    Date: 19.3.2015 , Venue: /news.cgi?story_id=51129
    Topic: 1st PCATDES Press Release Distribution ; Participant: SNANO
16. 1st PCATDES Press Release Distribution
    Date: 25.3.2015 , Venue: news.html
    Topic: 1st PCATDES Press Release Distribution ; Participant: SNANO
17. Semiconductor Photochemistry And Solar Fuels Workshop
    Date: 1.4.2015 , Venue: Imperial College London, UK
    Topic: Photocatalytic Enhancement Of Rutile-Anatase Layered Tio2 Thin-Films ; Participant: UCL
18. 2015 MRS Spring Meeting & Exhibit
    Date: 6-10.4.2015 , Venue: San Francisco, California, USA
    Topic: Enhancement On The Photocatalytic Properties Of Rutile-Anatase Tio2 Thin-Films ; Participant: UCL
19. Gordon Research Conference On Environmental Nanotechnology
    Date: 21-26.6.2015 , Venue: West Dover, USA
    Topic: Synthesis And Photocatalytic Activity Of Tio2 Nanotubes Anodized On Titanium Microfiltration Membranes ; Participant: URJC/Javier Marugán
20. 3 rd. International Conference on Advanced Complex Inorganic Nanomaterials, ACIN-2015
    Date: 13-17.7.2015 , Venue: Namur, Belgium
    Topic: Impact Of Textural Properties Of Mesoporous Graphitic Carbon Nitrides On The Photocatalytic Activity Under UV/Visible Light ; Participant: Universität Rostock
21. 4th International Symposium On Energy Challenges And Mechanical - Working On Small Scales Aberdeen
    Date: 13.8.2015 , Venue: Aberdeen, UK
    Topic: Ti-Suboxides Structures For Water Splitting ; Participant: BATH
22. 250th American Chemical Society National Meeting & Exposition: New Advances In The Chemistry And Applications Of Advanced Oxidation Processes For Removal Of

Contaminants Of Emerging Concern.
Date: 16-20.8.2015 , Venue: Boston, USA
Topic: Photocatalytic Disinfection And Removal Of Emerging Pollutants From Real Effluents Of Biological Wastewater Treatment ; Participant: URJC/Javier Marugán

23. 4th European Conference On Environmental Applications Of Advanced Oxidation Processes
Date: 21-24.10.2015 , Venue: Athens, Greece
Topic: Communication On Comparative Study Between The Activity Of Tio2 Nanoparticles And Tio2 Nanotubes On Photocatalytic Membranes ; Participant: URJC/Javier Marugán
24. International Conference On Green And Sustainable InnovationICGSI 2015
Date: 9-10.11.2015 , Venue: Pattaya, Thailand
Topic: Photocatalytic Degradation Of Palm Oil Mill Wastewater Using An Led Reactor ; Participant: MTEC/Angkhana Jaroenworaluck
25. International Conference On Green And Sustainable InnovationICGSI 2015
Date: 9-10.11.2015 , Venue: Pattaya, Thailand
Topic: Utilization Of Rice Husk (RH): Fabrication And Properties Of Mullite Composite Membranes ; Participant: MTEC/Wadwan Singhapong
26. Photocatalytic And Superhydrophilic Surfaces Workshop, PSS2015
Date: 10-11.11.2015 , Venue: Guimaräes, Portugal
Topic: Enhancement Of Photocatalytic Activity Of Polymeric Graphitic Carbon Nitride With Post Thermal Treatment ; Participant: Universität Rostock
27. UKCC2016- UK Catalysis Conference
Date: 6-8.1.2016 , Venue: Loughborough, UK
Topic: Wide Spectrum Of Catalysis, Including Heterogeneous Catalysis And Photocatalysis For Water Treatment ; Participant: Aston
28. 2nd PCATDES Press Release Distribution
Date: 22.2.2016 , Venue: http://www.nanotech-now.com/news.cgi?story_id=53031
Topic: 2nd PCATDES Press Release Distribution ; Participant: SNANO
29. 2nd PCATDES Press Release Distribution
Date: 24.2.2016 , Venue: news.html
Topic: 2nd PCATDES Press Release Distribution ; Participant: SNANO
30. Nanoscale 2016
Date: 9-11.3.2016 , Venue: Wroclaw, Poland
Topic: An Image Analysis Technique: Quantitative Measurement Of Pore Size And Its Distribution Of Mullite Membranes ; Participant: MTEC/Angkhana Jaroenworaluck
31. Nanoscale 2016
Date: 9-11.3.2016 , Venue: Wroclaw, Poland
Topic: Pore Characterization Of Mesoporous Silica Particles Synthesized Using Rice Husk As A Silicon Source ; Participant: MTEC/Angkhana Jaroenworaluck
32. ASEAN-EU STI Days (3rd Edition)
Date: 10-12.5.2016 , Venue: Hanoi, Vietnam
Topic: Highly Efficient Room Light Active B-$Agvo_3$/Mpg-C_3N_4 “Core-Shell” Catalyst For The Photocatalytic Degradation Of Organics ; Participant: Universität Rostock
33. ASEAN-EU STI Days (3rd Edition)
Date: 10-12.5.2016 , Venue: Hanoi, Vietnam
Topic: Advanced Technology Treatment For Wastewater From POME And Seafood Processing Industries Using LED Reactors ; Participant: MTEC/VAST-ICT/Angkhana Jaroenworaluck
34. ASEAN-EU STI Days (3rd Edition)
Date: 10-12.5.2016 , Venue: Hanoi , Vietnam
Topic: New Tio_2 Based Photocatalysts For Water Treatment Applications ; Participant: MTEC/VAST-ICT/Angkhana Jaroenworaluck/Chris T. Clarke

35. SPEA9-9th European Meeting On Solar Chemistry And Photocatalysis: Environmental Applications
Date: 13-17.6.2016 , Venue: Strasbourg, France
Topic: Advanced Research Progresses In Environmental Photocatalysis And Photochemistry ; Participant: Aston University
36. SPEA9-9th European Meeting On Solar Chemistry And Photocatalysis: Environmental Applications
Date: 13-17.6.2016 , Venue: Strasbourg, France
Topic: Comparison Of UV-A LED And Fluorescent-Light-Driven Photocatalysis For Water Treatment: Chemical Oxidation And Bacterial Inactivation ; Participant: URJC
37. 5th International Conference On Structured Catalysts And Reactors
Date: 21-24.6.2016 , Venue: San Sebastian, Spain
Topic: CFD Modeling Of Photocatalytic Membrane Reactors ; Participant: URJC
38. IZC 18th International Zeolite Conference
Date: 19-24.6.2016 , Venue: Rio De Janirio, Brazil
Topic: Influence Of The Crystallinity Of Mesoporous Polymeric Graphitic Carbon Nitride On The Photocatalytic Performance ; Participant: Universität Rostock
39. International Conference on Electronic Materials, IUMRS-ICEM2016
Date: 4-8.7.2016 , Venue: Suntec, Singapore
Topic: PCATDES Related Discussions During The Event ; Participant: BATH/Chris Bowen
40. International Conference on Nanoenergy and Nanosystems, NENS2016
Date: 13-15.7.2016 , Venue: Beijing, China
Topic: PCATDES Related Discussions During The Event ; Participant: BATH/Chris Bowen
41. 21st International Conference On Photochemical Conversion And Storage Of Solar Energy (IPS-21)
Date: 25-29.07.2016 , Venue: San Petersburg, Russia
Topic: Multiphysics Modelling Of Photocatalytic Reactors ; Participant: URJC
42. 8th International Workshop On Advanced Materials Science And Nanotechnology IWAMSN2016
Date: 8-12.11.2016 , Venue: Ha Long City, Vietnam
Topic: - ; Participant: Universität Rostock
43. 8th International Workshop On Advanced Materials Science And Nanotechnology IWAMSN2016
Date: 8-12.11.2016 , Venue: Ha Long City, Vietnam
Topic: - ; Participant: Universität Rostock
44. 8th International Workshop On Advanced Materials Science And Nanotechnology IWAMSN2016
Date: 8-12.11.2016 , Venue: Ha Long City, Vietnam
Topic: Properties And Photocatalytic Activities Of CuO Thin Films Prepared By RF Magnetron Sputtering Method And The Following Oxidation ; Participant: VAST-IMS
45. 8th International Workshop On Advanced Materials Science And Nanotechnology IWAMSN2016
Date: 8-12.11.2016 , Venue: Ha Long City, Vietnam
Topic: Cu2O-Based Photocathodes For Solar Hydrogen Generation ; Participant: VAST-IMS
46. RSC Materials Chemistry Division Poster Symposium
Date: 25.11.2016 , Venue: London, UK
Topic: Design Of Hierarchical Photocatalyst ; Participant: Aston University
47. 3rd PCATDES Press Release Distribution
Date: 18.12.2016 , Venue: news.html
Topic: 3rd PCATDES Press Release Distribution ; Participant: SNANO

48. 4th PCATDES Press Release Distribution
    Date: 19.12.2016 , Venue: news.html
    Topic: 4th PCATDES Press Release Distribution ; Participant: SNANO
49. 3rd PCATDES Press Release Distribution
    Date: 28.12.2016 , Venue: http://www.nanotech-now.com/news.cgi?story_id=54214
    Topic: 3rd PCATDES Press Release Distribution ; Participant: SNANO
50. 5th PCATDES Press Release Distribution
    Date: 31.1.2017 , Venue: news.html
    Topic: 5th PCATDES Press Release Distribution ; Participant: SNANO
51. Collaboration workshop
    Date: 21/09/2015 , Venue: Xi'an China
    Topic: Collaboration discussions on topics particularly photocatalysis ; Participant: Cardiff University
52. Collaboration workshop
    Date: 24/09/2015 , Venue: Xiamen China
    Topic: Collaboration discussions on topics particularly photocatalysis ; Participant: Cardiff University
53. ECOSS 2016
    Date: 28/08/2016 , Venue: Grenoble, France
    Topic: Conference presentation on latest research ; Participant: Cardiff University
54. Collaboration workshop
    Date: 24/11/2016 , Venue: Hang Zhou China
    Topic: Collaboration discussions on topics particularly photocatalysis ; Participant: Cardiff University

5.4.7 Papers published

1. Photocatalytic decomposition of pharmaceutical ibuprofen pollutions in water over titania catalyst
   J. Choina, H. Kosslick, Ch. Fischer, G.-U. Flechsig, L. Frunza, A. Schulz
   Applied Catalysis B: Environmental, Volume 129, Pages 589–598, 2013
2. Photocatalytic Evidence of the Rutile-to-Anatase Electron Transfer in Titania
   Raul Quesada-Cabrera, Carlos Sotelo-Vazquez, Joseph C. Bear, Jawwad A. Darr and Ivan P. Parkin, Advanced Materials Interfaces, Volume 1, Issue 6, 2014
3. Photocatalytic properties of Zr-doped titania in the degradation of the pharmaceutical ibuprofen
   J. Choina, G.-U. Flechsig, H. Kosslick, V. A. Tuan, N. D. Tuyen, N. A. Tuyen, A. Schulz
   J. Photochemistry and Photobiology A: Chemistry, Volume 274, Pages: 108–116, 2014
4. Synthesis of CuS and CuS/ZnS core/shell nanocrystals for photocatalytic degradation of dyes under visible light
   Ung Thi Dieu Thuy, Nguyen Quang Liem, Christopher M.A. Parlett, Georgi M. Lalev, Karen Wilson
   Catalysis Communications, Volume 44, Pages: 62–67, 2014
5. Non-chapped, vertically well aligned titanium dioxide nanotubes fabricated by electrochemical etching
   Thu Loan Nguyen, Thi Dieu Thuy Ung and Quang Liem Nguyen
   Adv. Nat. Sci: Nanosci. Nanotechnol., Volume 5, Number 2, 2014
6. Critical influence of surface nitrogen species on the activity of N-doped TiO2 thin-films during photodegradation of stearic acid under UV light irradiation
   Raul Quesada-Cabrera, , Carlos Sotelo-Vazquez, Jawwad A. Darr, Ivan P. Parkin
   Applied Catalysis B: Environmental, Volumes 160–161, Pages: 582–588, 2014
7. Single-step synthesis of doped TiO2 stratified thin-films by atmospheric pressure chemical vapour deposition

Carlos Sotelo-Vazquez, Raul Quesada-Cabrera, Jawwad A. Darr and Ivan P. Parkin
J. Mater. Chem. A, Issue 19, Pages: 7082-7087, 2014

8. Multifunctional P-Doped TiO2 Films: A New Approach to Self-Cleaning, Transparent Conducting Oxide Materials
Carlos Sotelo-Vazquez, Nuruzzaman Noor, Andreas Kafizas, Raul Quesada-Cabrera, David O. Scanlon, Alaric Taylor, James R. Durrant, and Ivan P. Parkin
Chemistry of Materials, Volume 27, Number 9, Pages: 3234-3242, 2015
9. The influence of the textural properties of ZnO nanoparticles on adsorption and photocatalytic remediation of water from pharmaceutical
J. Choina, A. Bagabas, Ch. Fischer, G.-U. Flechsig, H. Kosslick, A. Alshammari, A. Schulz
Catalysis Today Volume 241, Pages: 47–54 , 2015
10. Synthesis and comparative study of the photocatalytic performance of hierarchically porous polymeric carbon nitrides
Yingyong Wang, Muhammad Farooq Ibad Hendrik Kosslick, Jörg Harloff, Torsten Beweriesc, Jörg Radnik, Axel Schulz, Stefanie Tschierleid, Stefan Lochbrunner, Xiangyun Guo
Microporous and Mesoporous Materials, Volume 211, Pages: 182–191, 2015
11. Sub-stoichiometric functionally graded titania fibres for water-splitting applications
Vaia Adamaki , A. Sergejevs, C. Clarke, F. Clemens, F. Marken, and C. R. Bowen
Journal of Semiconductors, Volume 36, No:6, Pages: 063001/1-6, 2015
12. Understanding the effect of morphology on the photocatalytic activity of TiO2 nanotube array electrodes
C. Adán, J. Marugán, E. Sánchez, C. Pablos, R. van Grieken
Electrochimica Acta, Volume 191, Pages: 521–529, 2016
13. Photocatalytic disinfection and removal of emerging pollutants from effluents of biological wastewater treatments using a newly developed large-scale solar simulator
K. Philippe, R. Timmers, R. van Grieken, J. Marugán
Industrial & Engineering Chemistry Research, Volume 55, Pages: 2952-2958, 2016
14. Photocatalytic Activity of Suspended and Immobilized Niobium Oxide for Methanol Oxidation and Escherichia coli Inactivation
L.A. Morais, C. Adán, A.S. Araujo, A.P.M.A. Guedes, J. Marugán
Journal of Advanced Oxidation Technologies, Volume 19 (2), Pages: 256-265, 2016
15. Photocatalytic Escherichia coli inactivation by means of trivalent Er3+, Y3+ doping of BiVO4 system
C. Adán, J. Marugán, S. Obregón, G. Colón
Applied Catalysis A: General , Volume 526, Pages: 126-131, 2016
16. Performance of tungsten oxide doped titania via sol-gel process for photo-degradation of trans-cinnamic acid
Tan Yong Nee, Abdul Hafiz Abd Malek, Mohamad Zahid Abdul Malek, Noor Zalikha, Mohamed Islam, Shamsul Azrolsani Abdul Aziz Nazri, Mat Tamizi Zainuddin
Journal of Industrial Technology Vol. 24, No. 1, 2016
17. Comprehensive multiphysics modeling of photocatalytic processes by computational fluid dynamics based on intrinsic kinetic parameters determined in a differential photoreactor
C. Casado, J. Marugán, R. Timmers, M. Muñoz, R. van Grieken
Chemical Engineering Journal, Volume 310, Pages: 368-380, 2017
18. On the apparent visible-light and enhanced UV-light photocatalytic activity of nitrogen-doped TiO2 thin films
Raul Quesada-Cabrera, Carlos Sotelo-Vázquez, Miguel Quesada-González, Elisenda Pulido Melián, Nicholas Chadwick, Ivan P. Parkin
Journal of Photochemistry and Photobiology A: Chemistry, Volume 333, Pages 49–55, 2017

19. Photocatalytic Performance of Highly Active Brookite in the Degradation of Hazardous Organic Compounds Compared to Anatase and Rutile
Huyen Thi Thuong Tran, Hendrik Kosslick, Muhammad Farooq Ibad, Christine Fischer, Ursula Bentrup, Thanh Huyen Vuong, Liem Quang Nguyen, Axel Schulz,
Applied Catalysis B: Environmental, Volume 200, Pages 647–658, 2017

5.4.8 Papers Pending

20. Impact of the crystallinity of mesoporous polymeric graphitic carbon nitride on the photocatalytic performance under UV and visible light
Muhammad Farooq Ibad; Hendrik Kosslick; Jens W. Tomm; Markus Frank; Axel Schulz
Journal of Mesoporous and microporous materials (Recently submitted), 2017
21. Highly efficient room light active β-$AgVO_3$/mpg-C_3N_4 “core-shell” catalyst for the photocatalytic degradation of organics
Muhammad Farooq Ibad, Matthias Lütgens, Marcus Frank, Yingyong Wang, Hendrik Kosslick, Xiang-Yun Guo, Stefan Lochbrunner, Axel Schulz
Applied Catalysis B (Recently submitted), 2017
22. Photocatalytic degradation of palm oil mill wastewater using an LED reactor
A. Jaroenworaluck, P. Wimuktiwan, P. Saiwanich, P. Henprasertta, J. Marugán, C. T. Clarke, A. Sergejevs, D. Alsopp, N. Gathercole, C. R. Bowen
Not certain yet, 2017
23. Photocatalytic performance of coated TiO_2 scaffolds
A. Jaroenworaluck, W. Singhapong, P. Manpetch
Not certain yet, 2017
24. Antibacterial activities of TiO_2 based photocatalyst coated on mullite support
W. Singhapong, R. Pansri, W. Chokevivat, P. Srinopakun, A. Jaroenworaluck
Not certain yet, 2017
25. Synthesis and characterization of mesoporous TiO_2 and its photocatalytic performance
C. Vanichvattana, W. Singhapong, P. Manpetch, A. Jaroenworaluck
Not certain yet, 2017
26. Brookite a superior photocatalyst for the photocatalytic degradation of dyes
Tran ThiThuong Huyen, Hendrik Kosslick, Nguyen Quang Liem, Axel Schulz
Not certain yet, 2017
27. Synthesis and Photocatalytic Performance of Highly Active Brookite Nanoparticles under Sunlight equivalent UV
Tran ThiThuong Huyen, Muhammad Farooq Ibad, Hendrik Kosslick, Nguyen Quang Liem and Axel Schulz,
Not certain yet, 2017
28. Model-based design and validation of a novel high intensity led photocatalytic reactor for standardized activity measurements
C. Casado, R. Timmers, A. Sergejevs, C.T. Clarke, D. Allsopp, C.R. Bowen, R. van Grieken, J. Marugán
Not certain yet, 2017
29. The photocatalytic decomposition of cinnamic acid and the mechanistic role of dissolved oxygen
E. Bouleghlimat, P. R. Davies
Submitting to: Applied Catalysis B: Environmental, 2017
30. Chloride ion poisoning of photocatalytic decomposition: reaction pathways and products
E. Bouleghlimat, P. R. Davies
Submitting to: Journal of Photochemistry and Photobiology A: Chemistry, 2017

5.5 Extending the PCATDES Collaboration

At present two grants have been awarded which arise from the PCATDES partnership

- "Cascade processes for integrated bio-refining of agricultural waste in India and Vietnam" CAPRI-BIO BB/P022685/1, funded under the GCRF Foundation Awards for Global Agriculture and Food Systems Research
  Partners: India (ICTM) and Vietnam (Vietnam National University, Ha Noi University of Science & Technology, Univerity of DaNang and the Vietnam Academy of Science & Technology)
  Value: £749,885.62.
- "Photocatalytic valorisation of lignin models"
  Partners: Cardiff, Bath & Madrid
  Value: £9,400