Enmix A.I.S.B.L.

European Nanoporous Materials Institute of Excellence

Newsletter - No. 4, August 2013

In this issue:

Dear Partners and Friends of ENMIX,

Welcome to the fourth newsletter of the European Nanoporous Materials Institute of Excellence (ENMIX)!

Since the last ENMIX newsletter dated October 2012 a number of relevant changes and occurrences took place. As a significant and far-reaching event, Etienne Vansant, Jens Weitkamp and Francisco Rodríguez-Reinoso relinquished at the BoD and GA meetings in Alicante not only from their posts as BoD members, but also as ENMIX members. For ENMIX this is a truly historic event because these three outstanding personalities have decisively shaped ENMIX. Etienne Vansant was the first CEO of ENMIX, and it was him who proposed many activities which we implement or pursue nowadays. During Jens Weitkamp's term as CEO, ENMIX was re-shaped based on the ideas set forth previously by Etienne Vansant. As a long-standing BoD member, Francisco Rodríguez-Reinoso ("Paco" as we all called him) was an intellectual pillar of ENMIX, an excellent advisor and a sensitive and clever strategist. ENMIX not only lost three great personalities, but also internationally highly renowned, outstanding scientists. Etienne, Jens, and Paco, we wish you an ongoing good health and full enjoyment of the new liberties retirement offers!

At our meeting in Alicante on November 13, 2012, the ENMIX GA elected a new ENMIX BoD. Elias Klemm and Slavko Kaučič were, respectively, elected as CEO and Vice-CEO of ENMIX. Pegie Cool was elected as treasurer, and Jürgen Caro as a new BoD member. Antonio Escribano-Sepúlveda, Vassilis Zaspalis (ENMIX secretary) and Nikolaos Kanellopoulos will continue to serve as members of the BoD. The new ENMIX BoD will do its best to move ENMIX forward towards a leading role in the field of nanoporous solids in Europe.

It is another major objective of ENMIX to strengthen the European industry and to contribute to its global competitiveness. To meet this objective it is indispensable to be in close contact with European companies, both large and small enterprises, which are key players in the field of nanoporous materials. At the ENMIX workshop in Hanover, March 25-27, 2013, a large number of participants from industry could be welcomed, and the first meeting of industrial partners for implementation of an ENMIX Industrial Advisory Board took place. Thanks to the enormous efforts of Jürgen Caro and his team, the workshop in Hanover turned out to be a huge success (read more in this newsletter).

It gives us particular pleasure to refer to the 17th International Zeolite Conference held in July 2013 in Moscow. At this conference, Jürgen Caro was honored with the Donald W. Breck Award 2013 granted by the International Zeolite Association for the most significant contribution to molecular sieve science and technology achieved within the past four years. Jürgen Caro received this prestigious award for his innovative work on inorganic membranes. We would like to congratulate Jürgen on this outstanding achievement!

Last but not least, it is worth mentioning that ENMIX is now a member of SPIRE, a public-private partnership dedicated to innovation in resource and energy efficiency in the process industries. ENMIX is also represented in SusChem, the European Technology Platform for Sustainable Chemistry.

We wish you much pleasure while reading the new edition of the ENMIX newsletter!

Elias Klemm

Slavko Kaučič

Jürgen Caro received Breck Award

Jürgen Caro, Professor of physical chemistry at the Leibniz University Hanover, was honored, together with Professor Michael Tsapatsis, University of Minnesota, Minneapolis, MN, USA, with the Donald W. Breck Award of the International Zeolite Association (IZA). The award is named after Donald W. Breck, a former leading zeolite scientist working with Union Carbide Corporation. The Breck Award is granted every three years for the most significant contribution to Molecular Sieve Science and Technology made within the past four years. J. Caro and M. Tsapatsis received the highly prestigious prize at the 17th International Zeolite Conference held in Moscow in July 2013, in the presence of almost one thousand participants, for their pioneering work on novel molecular sieve membranes. The photo shows from left to right: A. Corma, Universidad Politécnica de Valencia, Spain, Chairman of the IZA Breck Award Committee; J. Caro, Leibniz University Hanover, Germany; M. Tsapatsis, University of Minnesota, USA;and G. Bellussi, Eni Research, San Donato Milanese, Italy, President of the IZA.

3rd ENMIX Workshop Report

The 3rd European Nanoporous Materials Institute of Excellence Workshop was held in Hanover (Germany) from March 25 to March 27, 2013. ENMIX plays a leading role in the field of nanoporous solids in Europe and contributes, by using novel nanoporous materials, to the solution of the great challenges our modern society is faced with. The 3rd Workshop was organized by Jürgen Caro (local organizer) and Elias Klemm (CEO of ENMIX). Besides keynote lectures and oral presentations by leading European experts and renowned researchers from within the network, it was mainly directed towards intense discussions between representatives from industry and the ENMIX partners.

As the title suggests, the Workshop has presented the latest developments in the field of the preparation of zeolites, MOFs and porous carbon, as well as their advanced and innovative applications. Four excellent speakers presented an overview of the latest developments: Gabriele Centi (Zeolites in Catalysis - Recent Developments and Perspectives), Stefan Kaskel (MOFs: Synthesis, Adsorption, and Shaping), Francisco Rodríguez Reinoso: Novel Nanoporous Carbons for Energy and Environmental Applications), and Freek Kapteijn (Catalysis with MOFs - Opportunities and Limitations). Nine renowned researchers from academia and four researchers from industry and the European Commission delivered the lectures in which they presented the latest developments in the fields of preparation of nanoporous materials and their applications. 14 researchers had the opportunity to present their research interests and results in the form of posters at the poster session.

The Workshop offered an excellent opportunity to meet researchers from academia and industrial partners. 12 representatives from companies that are active in the production or application of porous materials were attending the 3rd ENMIX workshop. Integration between basic chemical research and industry is still limited. Thorough chemical knowledge about the structural properties in order to understand the functionality of new and old materials and on the other hand the technological knowledge for industrial up-scaling and application should be brought together. A strategic meeting of the ENMIX board of directors and representatives from the industrial partners (implementation meeting of the Industrial Advisory Board) was held during the workshop.

Tomaž Fakin, NIC, Ljubljana

ENMIX 2013 Paper Award

It was the second time that the ENMIX Paper Award was presented. This award is granted for the best scientific publication of the respective year dealing with nanoporous materials. Particularly preferred are high-level scientific and innovative papers authored by at least two ENMIX partner laboratories. The recipient must be a PhD student or a postdoc from one of the ENMIX partner laboratories.

The ENMIX Award 2013 goes to Tomas Binder, who is a PhD student in the group of Prof. Jörg Kärger at the University of Leipzig, for his paper entitled "Micro-imaging of transient guest profiles in nanoporous host systems of cylindrical symmetry" by Tomas Binder, Florian Hibbe, Christian Chmelik, Jörg Kärger (University of Leipzig), Alberto Martinez-Joaristi, Jorge Gascon, Freek Kapteijn (Delft University of Technology), and Douglas Ruthven (University of Maine in The Journal of Chemical Physics 137 (2012) 165704.

This paper deals with the diffusion of guest molecules in nanoporous materials which is relevant for many applications like heterogeneous catalysis or separation processes with membranes and adsorbents. With the help of interference microscopy two-dimensional, time-dependent concentration profiles can be measured and analysed with appropriate diffusion models. A necessary prerequisite is the synthesis of large nanoporous crystals possessing high crystallinity and phase purity. This has been reached with a zeolite of structure type DDR.

The ENMIX 2013 Paper Prize was awarded by the CEO of ENMIX, Prof. E. Klemm, during the 3rd ENMIX Workshop in Hanover, Germany.

University of Alicante, E
Department of Chemistry, Advanced Materials Laboratory

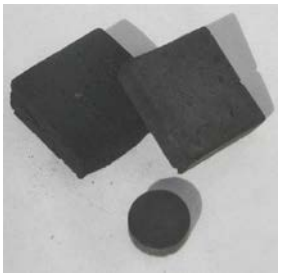
The research group Laboratorio de Materiales Avanzados (LMA) was founded in 1981 by Prof. Francisco Rodríguez-Reinoso (now Emeritus Professor, reinoso@ua.es), when he occupied the chair of the Inorganic Chemistry Department at the University of Alicante. Since 2009 the group is directed by Prof. Antonio Sepúlveda-Escribano. The research activities of the LMA group have been devoted mainly to the design, synthesis, characterization and application of porous materials, especially activated carbons with a wide range of physical and chemical properties, obtained from a wide variety of raw materials. Synthesized nanoporous solids with the desired physical form and porous structure have been applied in adsorption processes, energy storage and catalytic applications. This research has been reflected in more than 400 publications in international peer review journals, over 50 PhD thesis and several international patents. Interaction with industry has been very intensive in the last twenty years, with over 60 research contracts carried out for mainly European companies.

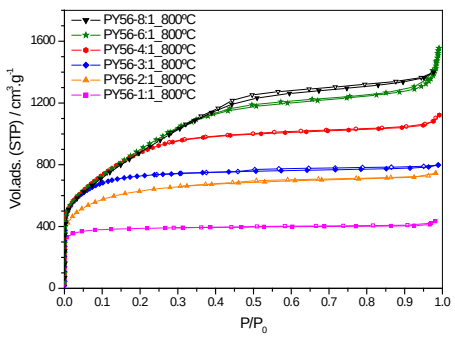
The LMA group has an international reputation as a centre of excellence in the fields of porous materials, adsorption and catalysis, with special emphasis in specific applications such as control of environmental pollution (e.g., CO2 capture, VOCs removal, air and industrial gas purification/separation, and so on), energy storage (e.g., natural gas storage, supercapacitors, batteries, and so on) and heterogeneous catalysis, among others.

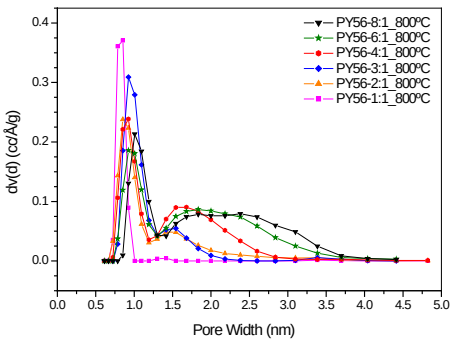
Research activities

- **Synthesis of porous adsorbents**

  The design, development and description-characterization of porous materials, especially activated carbons, are essential not only for the control of environmental pollution but also for satisfying the increasing demand for purity in natural and synthetic products. The research carried out in the last thirty years has permitted an in-depth knowledge of all processes implied in the preparation of activated carbons, and this has been used to propose new manufacturing routes, either to solve a specific problem (purification and separation of gases, removal of odours, gas storage, and so on), or to be able to prepare materials with well-defined porosity, ranging from purely microporous materials to materials combining micro- and mesoporosity in any required range (see enclosed figures). These carbon materials can be prepared in any desired physical form (powder, monolith, cloth, etc.). Furthermore, the LMA group has experience in the synthesis, characterization and application of other porous materials such as zeolites, mesoporous silicas (SBA-15, MCM-41), MOFs, etc.

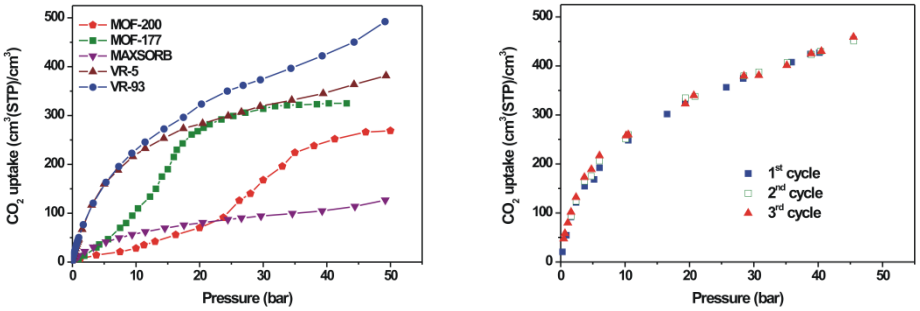






- **Carbon materials for CO_2 capture**

  CO_2 capture at atmospheric and high pressure requires the design of porous materials with a well-defined microporosity. By appropriate selection of the carbon precursor (lignocellulosic residues, petroleum residues, etc.) and the synthesis conditions (chemical and/or physical activation), carbon molecular sieves with a high storage capacity (up to 380 mg/g at 273 K and 1 bar), a high selectivity for CO_2/N_2 (~14) and for CO_2/CH_4 (∞), and last but not least an easy regeneration under ambient conditions can be obtained. Furthermore, these materials outperform the best MOFs materials, in a gravimetric basis, at low and high pressure with an extremely large working capacity (see enclosed figures).



- **Carbon materials for energy storage (natural gas storage)**

  A hotspot nowadays in energy storage concerns the development of storage systems able to fulfill the market requirements in terms of storage capacity and delivery under milder conditions of temperature and pressure. An appropriate design of the synthesis conditions (chemical activation with KOH) allows the preparation of carbon materials with an extremely high storage capacity at 35 bar and 298 K (>160 v/v). Taking into account that actual technology considers the use of higher pressures, an appropriate modification of the porous structure (slight widening of the micropores) by changing the preparation conditions provides materials with more than 322 v/v at 100 bar and 298 K that corresponds to a delivery of 300 v/v. Furthermore, the synergetic hybridization of two materials such as graphene and MOF is being used for the synthesis of new adsorbents with optimized physical properties needed for the on-board application in the natural gas storage.

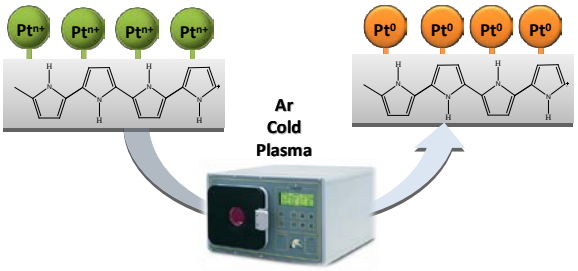
  Another interesting approach for natural gas storage concerns the formation of chlatrate structures in the confined environment of the porosity. Chlatrate structures are able to store large quantities of methane at relatively low temperatures (275 K) and relatively high pressures (40-80 bar). Taking into account the size of the chlatrate structure, large cavities or voids (pores above 2-3 nm) are required. The synthesis of carbon materials with a certain degree of mesoporosity provides the confined space to grow chlatrate nanocrystals, as observed for the first time by the LMA group using neutron scattering, with a high storage capacity (~258 v/v) and, more importantly, a high delivery between 100 bar and 30 bar (239 v/v).

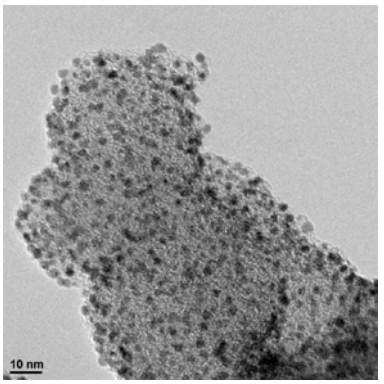
- **Carbon materials for energy storage (supercapacitors/batteries)**
  Supercapacitors are an important alternative or complement to another energy storage or generation devices such as secondary batteries and fuel cells. Our work involves the use of binderless monoliths prepared from petroleum residues, with very high surface area and relatively good electrical conductivity able to provide very efficient energy storage with excellent stability over long-term cycling experiments. Our work also involves the search for batteries for the electric vehicles as an alternative to the present production of batteries principally based on Li-ion technology.

- **Miscellaneous adsorption applications**
  Since the LMA group is able to produce at laboratory and pilot plant scales activated carbon with the surface area, pore size distribution and physical form required for any specific application, the number of carbons prepared along the last thirty years is very large (as a typical example, the number of carbons prepared in a project for Petrobras was 131). This is the background knowledge that LMA uses for the new developments. Some examples of applications studied include: natural gas storage, biogas purification, industrial water purification, drinking water treatment, odour removal, activated carbon cloth for NBC use, first response gas masks, desulphurization of gasoline and diesel, humidity controllers, cigarette filters, etc.

- **Carbon materials as catalyst supports**
  The LMA group has a great expertise in the use of carbon materials as catalyst supports. The understanding of the effects of the porosity and surface chemistry of carbonaceous materials on the catalyst preparation and even on their catalytic behavior in different reactions has made it possible to design the preparation routes and to choose the optimum carbon support for a given applications. Platinum-based catalysts, bimetallic catalysts, promoted catalysts, etc. have been prepared and applied for reactions such as Fischer-Tropsch, selective hydrogenations, and transformations of biomass-derived compounds.

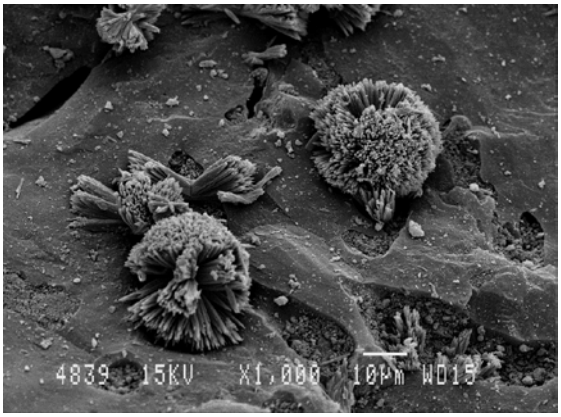
  A recent research line involves the use of conducting polymers, such as polypyrrole and polyaniline, as catalysts supports. In our group, these materials are synthesized by chemical oxidative polymerization using different dopant agents ($FeCl_3$, $K_2S_2O_8$, I_2, etc.). Furthermore, new reduction and activation treatments are being studied, both energetically and environmentally sustainable. In this way, cold RF argon plasma is being used to decompose and reduce the metal precursors, this allowing to carry out this treatment at low temperatures (< 100 ºC) and avoiding the use of chemicals such as hydrogen, sodium borohydride, hydrazine, etc. These catalysts are being used in reactions that are carried out at low temperature (given the relatively low thermal stability of the supports), such as the reduction of nitrates in water.





PPy-2%Pt-Plasma

- **Catalytic materials for energy and environmental applications**
  Within this research activity, heterogeneous catalysts are prepared, fully characterized and studied in reactions such as VOC's combustion, low temperature water gas shift, PROX, steam and aqueous reforming and valorization of biomass-derived products (glycerol, ethanol…). The different catalytic systems include carbon-supported catalysts (Au, Pt, Pt-Sn, Ni) promoted by partially reduced oxides (ceria, titania, etc.). Different types of carbonaceous materials are used: activated carbons, graphitized carbon blacks, carbon nanotubes and nanohorns, reduced graphite oxide (graphene), etc. For these systems, the preparation routes are tailored to obtain a high dispersion of both the active metal and the oxide promoter, in order to enhance their mutual interaction. New preparation procedures such as microwave-assisted hydrothermal routes are being investigated.



CeO_2 crystals grown on activated carbon

Infrastructure

A broad spectrum of instrumentation for the characterization and testing of adsorbents and catalysts is available at LMA, as well as at the Research Technical Services of the University of Alicante: XRD, XRF, ICP, XPS, temperature-programmed techniques (TGA, DTA, TPR, TPO, TMA), FTIR-DRIFT and UV-Vis techniques, etc. On the other hand, it should be noted that the laboratory is equipped with different adsorption systems which allows for the complete characterization of the porous texture of solids: manual and automatic adsorption systems, high precision adsorption, high pressure adsorption, vapors adsorption at different temperatures, adsorption microcalorimetry and immersion calorimetry. Catalytic materials are tested in different reactions using both home-made and commercial reaction systems, and the analysis of products is carried out by means of gas chromatography and mass spectrometry. The complete available infrastructure can be found in the group's web page (web.ua.es/lma).

ENMIX key personnel

Prof. Dr. Antonio Sepúlveda-Escribano received his Diploma in Chemistry in 1985 and his PhD degree in Science in 1989, both from the University of Alicante (Spain). He kept positions as a postdoctoral researcher in the Institute of Catalysis and Petrochemistry (Spanish Council for Scientific Research, CSIC) in Madrid (Spain), and in the Institute of Research on Catalysis (National Centre for Scientific Research, CNRS) in Lyon (France), performing research on environmental catalysis. In 1993 he joined the Laboratorio de Materials Avanzados at the Department of Inorganic Chemistry at University of Alicante, where he became Associate Professor in 1996 and Full Professor in 2003. Since 2009 he is the Director of the research group. He has supervised 10 PhD theses and has participated in 40 research projects. He has published 115 articles in first level international journals, and 5 chapters in scientific books. His research interests are centered in the fields of adsorption and catalysis: synthesis, characterization and applications of adsorbent materials (activated carbons, zeolites, mesoporous materials) and supported heterogeneous catalysts for different applications. It is also of interest the development of partially reducible oxides to be used as catalyst supports and/or promoters in different applications.

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University of Stuttgart, Germany
Faculty of Chemistry, Institute of Chemical Technology

The University of Stuttgart is a member of the TU9 German Institutes of Technology e.V. About 20,000 students are enrolled at 10 faculties. The Institute of Chemical Technology belongs to the Faculty of Chemistry but has strong links to the Institute of Chemical Process Engineering (Professor Ulrich Nieken) and to the Institute for Interfacial Engineering (Professor Thomas Hirth), both of the Faculty of Energy Technology, Process Engineering and Biological Engineering. The Institute of Chemical Technology further cooperates with Fraunhofer Institutes and the German Aerospace Center on the campus in Stuttgart Vaihingen. In addition, there are many external partners distributed all over the world. The Institute has about 20 Ph.D. students and four groups which are described in greater detail in the following sections. The director of the Institute is Professor Dr.-Ing. Elias Klemm.

Heterogeneous Catalysis, (Micro) Reaction Engineering (Prof. Dr.-Ing. Elias Klemm)

The research of the group is devoted to heterogeneous catalysis and chemical reaction engineering, especially micro reaction engineering.

Due to their high surface-to-volume ratio and the sub-millimeter lateral dimension of the reaction channels, *microstructured reactors* allow an intensification of heat and mass transfer and of surface phenomena. Thus, with microstructured reactors *new process windows* are possible like operation at higher temperatures and pressures, under solvent-free conditions, or in the runaway/explosion regime. These potentials are exploited in current projects for methane, cyclohexane and o-xylene oxidation, alcohol alkoxylation and anionic polymerization of butadiene. In the latter two cases, the transfer of the results from lab- to pilot-plant scale is the overall goal.

The *raw material change* will be a crucial challenge for the chemical industry. In four current research projects, the group contributes with possible solutions by investigating the conversion of carbon dioxide and lactic acid to value-added products. Carbon dioxide is activated catalytically and electrocatalytically. For the utilization of lactic acid efficient separation and conversion processes are necessary considering the interface of biotechnology and chemical technology.

In the field of *heterogeneous catalysis,* the group focuses on *metal organic frameworks (MOFs)*. In four ongoing projects, MOFs are applied as hydrogenation and oxidation catalysts and as adsorbents for the separation and purification of products. The research is devoted to activity, selectivity and enantioselectivity of the MOF materials, with elucidating the molecular interactions and steps leading to the macroscopic performance in a technical reactor or separator.

Heterogeneous Catalysis, Energy-Related Catalysis (Prof. Dr.-Ing. Jens Weitkamp)

The research of the group focuses around heterogeneous catalysis in the fields of petroleum refining and basic petrochemistry. Another important research field is materials science of nanoporous solids, especially of zeolites, *viz.* their hydrothermal synthesis, post-synthesis modification and characterization, *inter alia* by suitably selected catalytic reactions exploiting shape selectivity effects. An example is the characterization of the effective pore width of zeolites *via* determination of the Spaciousness Index (SI) which has been introduced by the group.

Petroleum refining reactions which have been extensively studied by the group include hydrocracking of model hydrocarbons that are relevant for petroleum fractions, such as long-chain alkanes, skeletal isomerization of gasoline and diesel constituents, and isobutane/butene alkylation on solid acid catalysts. In many instances, zeolite catalysts are used in such studies. The objectives can be very different, ranging from finding answers to fundamental questions related to carbocation chemistry till the development of novel catalytic processes for solving current or future problems in refining or petrochemistry. An example is the discovery of the catalytic chemistry for converting surplus aromatics, *e.g.* in pyrolysis gasoline, into a synthetic steamcracker feed *via* shape-selective catalytic hydrocracking. Currently, the group has placed a strong focus on finding catalytic solutions for selectively converting polynuclear aromatics in diesel fuel into environmentally benign, hydrogen-rich hydrocarbons with excellent cetane numbers.

Heterogeneous Catalysis, Solid-State NMR (Prof. Dr. Michael Hunger)

The work of the group focuses on the application of solid-state NMR spectroscopy for research in the field of adsorption processes and heterogeneous catalysis. These activities can be summarized by the following topics:

- Preparation of new microporous and mesoporous materials,
- Solid-state NMR characterization of surface sites and of the local structure of framework and extra-framework atoms in microporous and mesoporous materials,
- In situ solid-state NMR spectroscopy of adsorbents and working catalysts in combination
- with other analytical methods.

In the group, a number of novel in situ solid-state NMR techniques have been developed, which are suitable for investigating adsorbents and catalysts under continuous-flow and stopped-flow conditions. By application of these in situ techniques, catalytically active sites, adsorbate complexes, intermediates, and deposits formed on adsorbates and catalysts are studied. Examples are the conversion of methanol to olefins on acidic zeolite catalysts and the alkylation of toluene, aniline, and phenol on basic and acidic zeolites.

In situ ^{13}C MAS NMR spectroscopy of the conversion of methanol on zeolite H-ZSM-5 and silicoaluminophosphates under continuous-flow conditions supported the formation of hydrocarbon pool compounds consisting of a mixture of branched aliphatic and aromatic compounds. The pulsed field-gradient NMR technique is utilized for studying molecular diffusion, e.g., in zeolite catalysts, which are partially coked by conversion of methanol.

Bruker Avance III Spectrometer 400 MHz

In situ MAS NMR probe for flow experiments

Heterogeneous Catalysis, Alkane Activation (PD Dr. Yvonne Traa)

The main focus of the group is the non-oxidative activation of inert reactants, mainly light alkanes. Test reactions studied are the alkylation of toluene or benzene with ethane, propane or mixtures of ethane and propane as well as the dehydrogenation of propane. Thermodynamic limitations are overcome by process intensification using a packed-bed membrane reactor with a hydrogen-selective membrane. The catalysts are tailored with regard to the concentration of acid sites, with regard to the metal sites by using appropriate promoters as well as with regard to the shape-selective properties, e.g., optimization of zeolitic pore systems and zeolite crystallite size, pore size engineering, coke selectivation and core/shell systems. In this context, also nanocrystalline zeolites are synthesized, characterized and utilized.

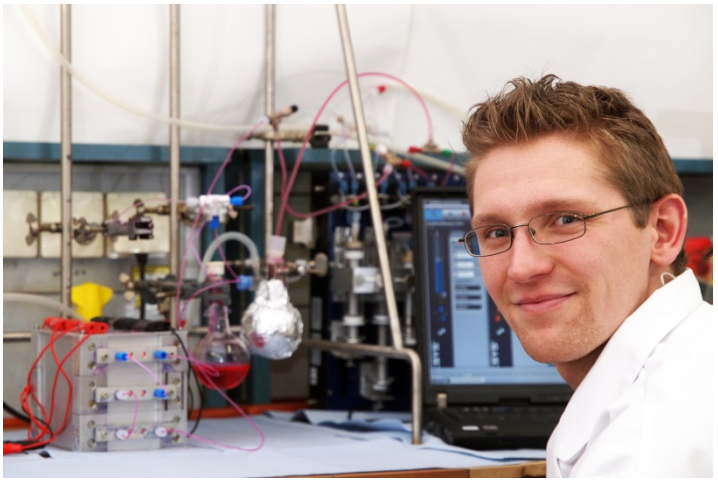
Another focus is the direct liquefaction of coal, also an “inert” reactant. Here, new catalysts are developed. In addition to subbituminous coal and highly volatile bituminous coal, biomass-derived coal with its comparable carbon and oxygen content is also converted. This could open up new ways for biomass conversion by local small-scale production of biomass-derived coal, which can be transported with low cost due to its high density and low water content to large facilities, where it can then be converted into liquid fuels under optimized reaction conditions.

Photochemical Reaction Engineering (Dr. Dirk Ziegenbalg)

The work of the group focuses on the reaction engineering aspects of photochemical processes. To enhance the reaction control of light induced reactions mainly microstructured photoreactors are used. The intrinsic feature of low fluid thickness enables an improved illumination and as a result undesired (dark) side reactions are suppressed. As a consequence the overall process performance is improved.

Light generation is a critical issue for photochemical processes since the efficiency of the energy to light conversion of the light sources mainly determines variable costs and currently does not exceed 40 %. To challenge this, the group investigates the efficiency of photon coupling into the photoreactors and the use of alternative light sources. These aspects are currently examined for photooxygenations utilizing OLEDs as light sources.

The group further deals with the oxygen evolution reaction for photocatalytic water splitting. The emphasis is on advanced reactor concepts which are able to directly incorporate the generated oxygen into organic compounds. Such reactors can improve the overall efficiency of photocatalytic water splitting processes by coupling the hydrogen generation with the syntheses of value-added products.



Equipment

Solid state NMR (Bruker AvanceIII 400MHz); X-Ray diffraction (Bruker D8); X-Ray diffraction with reaction chamber (Siemens D 5000); ICP-OES (Varian Vista-MPX); CHN analyzer; tapered element oscillating microbalance (Rupprecht & Patashnick); Thermogravimetry (Setaram); Physisorption/Chemisorption (Quantachrome Autosorb-1); IR spectrometer with ATR cell (Bruker Vector 20); Flow microcalorimeter; Dynamic light scattering (Horiba LB-500); High performance liquid chromatography: Configuration (HPLC HP 1100 Series / Agilent 1200 Series): Vacuum degasser, binary pump, autosampler, thermostat-controlled column compartment, digital array detector (UV/Vis), refractive index detector; Discontinuously operated stirred autoclaves (Parr); Microstructured reactors; Berty-type gradientless reactor; Packed-bed membrane reactors; Gas chromatography; Mass spectrometry.

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MAST Carbon International Ltd

MAST Carbon was established in 1995 from the Carbon and Catalysis group of the BP Research centre with the initial goals of :

a) continuing to support the ammonia synthesis technology developed by BP and licenced to KBR and
b) continuing to develop the polymer derived carbons and their applications discovered as part of the ammonia project.

This has been achieved through a combination of collaborative EU and UK sponsored projects and confidential projects on behalf of industrial organisations and the Ministry of Defence. Since 1995 MAST has been involved in 20UK government projects and 27 EU projects several of which were managed by MAST. These R and D projects are backed up by extensive test and measurement capabilities combined with furnace and polymer processing equipment that allow the production of these specialist carbon materials from the gm scale up to the 100's kg scale. These materials are also sold for R and D projects on a world wide basis. MAST relocated in 2011 to a 25,000sq.ft facility in Basingstoke in the South East of England conveniently located close to Heathrow, Gatwick and Southampton Airports.

The main areas where MAST is active include:

a) Adsorption and Separation covering both gas and liquid phase. This includes extensive work in the area of nanoporous carbon membranes

b) Catalysis – One of the foundations of MAST was the work on the new Ruthenium on Carbon catalysts that is now in use in 7 of the worlds largest ammonia plants. More recently this has concentrated on liquid phase and mixed gas liquid phase catalysts for oxidation and hydrogenation using a range of structured reactor systems

c) Biological applications – this relates mainly to the use of our carbons as therapeutic agents in haemofiltration and as oral adsorbents. A key attribute of the MAST carbons in these applications is their excellent biocompatibility and absence of cytotoxicity.

d) Electrochemical – MAST is involved in the development of controlled structure carbons for a range of electrochemical processes. The most significant is capacitors including supercapacitors for automotive applications but also in a range of bioelectrical applications

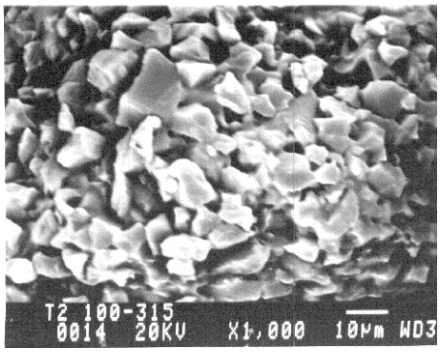
e) Environmental Applications – This encompasses air purification (VOC control and military civilian protection devices), carbon dioxide capture and potable water purification (removal or trace levels of pharmaceutical and agrochemical residues)

The majority of MAST's work in concerned with high added value polymer derived carbons which provide a greater level of control of purity and other critical structural parameters. The materials and their key applications areas are shown in the table. Beyond these materials and applications we are always open to discuss new applications where existing carbon materials do not have the required combination of physical form and structural characteristics.

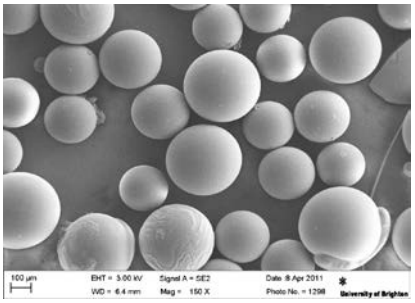
	Phenolic Resin Based				Cellulose based		PAN	Natural Precursors	
	Composite	Sintered Monolithic	Solvent templated	Fibre	Fibre	Granular	Fibre	Cellulose	Lignin
Electrochem	X	X	X	X	X	X			
Catalytic Systems		X	X			X	X		
Biomedical		X	X		X			X	X
Gas Environment		X	X		X				X
Water Environment		X	X		X				
Structural Materials	X			X			X		

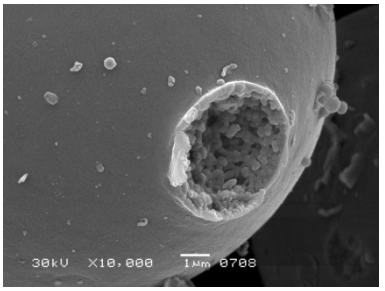
More recently we have extended these to ligno cellulose derivatives although still focussing on high added value products. From this matrix the majority of our work currently focuses on the phenolic resin derived carbons as these provide the widest range of properties with the two main product areas being the sintered monolithic and solvent templated products. In all cases the phenolic derived carbons have a unique micropore structure with a mean pore size of approximately1nm. The larger meso and macro pores are then superimposed on this by a range of processing routes that can provide bimodal, trimodal and quadramodal pore size distributions.

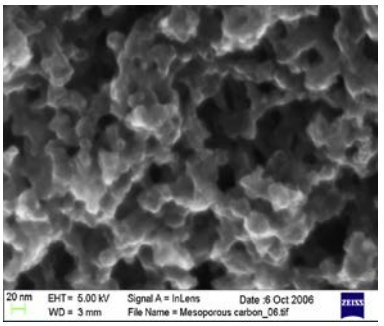
The sintered route relies on the production of a phenolic resin with a controlled level of cure. After milling to a fine powder, where the eventual macropore structure is fixed by the particle size, the resin powder can be sintered by cold pressing, pelleting or extrusion to provide the porous phenolic in a wide range of physical forms. This is then converted to the activated carbon on a net shape basis by pyrolysis and activation. Key attributes of these materials are very low pressure drop and good electrical and thermal conductivity.



The solvent templated route is based on curing a solution of the phenolic resin and the curing agent. This results in the solvent being trapped in fully cured resin. When this is removed it creates a porous resin with pores in the meso-small macro pore range (5- 500nm) where the pore size is controlled by for concentration. This porous resin can be produced either as beads by dispersion of the solution into hot oil or as a granular material depending on the end use. The meso-macro pore structure of these carbons provides excellent kinetic performance which is critical in the catalytic and biomedical applications areas.







If you would like to discuss the use of our materials in your applications, the development of special materials on your behalf or the involvement of MAST in collaborative projects we can be reached on :

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