Recovery of Valuable Elements from Municipal Solid Waste Incineration Ash: Finding Treasures in Waste

In our daily lives, we generate garbage. This garbage is called municipal solid waste (MSW), and most of it is transported to incineration facilities, where it is incinerated and turned into **municipal solid waste incineration (MSWI)** ash. Most of the MSWI ash is currently transported to final disposal sites and landfilled. In Yamaguchi Prefecture, MSWI ash is also recycled as a raw material for cement production. The incineration process leaves many of the elements contained in the MSW in the MSWI ash, including various valuable elements. For example, MSWI ash contains Fe, which is used to make structural steel, steel frames, and steel pipes used in construction, and Al, which is used to make beverage cans and spray containers. On the other hand, iron ore and aluminum ingots are dependent on imports. Therefore, our research focuses on the **recycling of MSWI ash** to explore **effective recovery technologies** for the effective utilization of valuable elements such as Fe, Al, Au, Ag, and Ti, which are treasures lying dormant in the waste, and to implement such technologies in society.

Municipal solid waste incineration ash used in this research.

About Researcher

CHENG Yingchao, Dr.Eng.

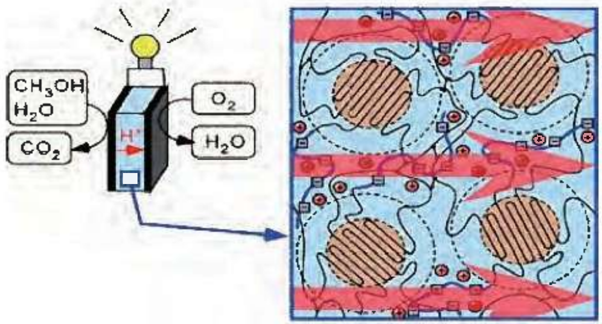
Dr.Eng., 2020, Kyoto University

Preparation and Evaluation of Low-Cost Direct Methanol Fuel Cells

Direct methanol fuel cells (DMFCs) using **polymer electrolyte membranes** (PEMs) represent one of the most attractive power sources for various applications, from vehicles to portable devices. DMFCs, which are characterized by a higher level of electrical efficiency than conventional heat engines, stable operation at relatively low temperatures, simple structure, and high energy density compared to lithium ion batteries, use high-concentration methanol solutions as fuel. Use of PEMs, however, suffers from the crossover of methanol through the membrane and from a requirement for large amounts of a precious platinum catalyst to achieve high power density.

Our research topics are (1) **ion exchange polymers** prepared from commodity polymers and (2) preparation and analysis of fuel cell units (membrane electrode assemblies, or MEAs) in order to create a new fuel cell that is characterized by cost-effectiveness, ease of preparation, and high performance.

We expect our findings to drive advances in the area of electrochemical processes, for example electrolysis and electrodialysis.



Schematic image of a direct methanol fuel cell and polymer electrolyte membrane having ion paths by nano-phase separation

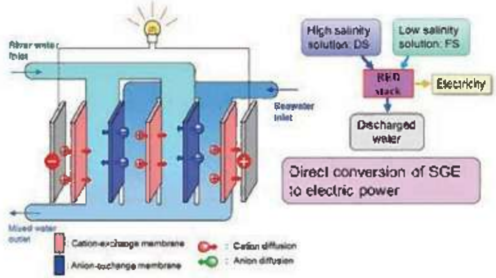
About Researcher

ENDO Nobutaka, Ph.D.

Ph.D., 1999, Yamaguchi University

High-Performance Membranes in Water Treatment and Energy Production

We have prepared many types of high-performance membranes from block copolymers and graft copolymers and proposed novel chemical engineering systems using the membranes in water treatment and energy production. The subjects of our research are as follows: (1) polymer electrolyte membranes for **direct methanol fuel cells**, (2) ion-exchange membranes for electrodialysis (desalination and water treatment) and **reverse electrodialysis** (energy production from salinity gradients), (3) ion-barrier membranes for forward osmosis and **pressure retarded osmosis** processes (water treatment and energy production), (4) charge mosaic membrane with high salt permselectivity (water treatment), and (5) external stimuli-responsive charged membranes for smart sensors and intelligent drug delivery systems.



Reverse electrodialysis system (RED) for energy production

About Researcher

HIGA Mitsuru, Dr.Eng.

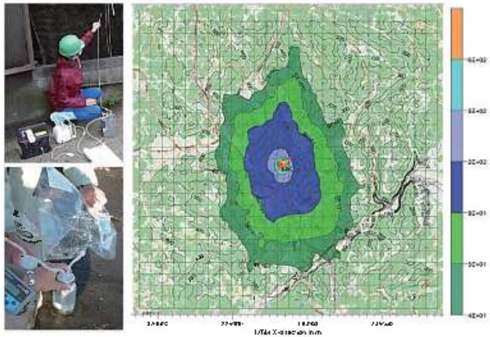
Dr.Eng., 1991, Tokyo Institute of Technology

WEB ≫ http://piano.chem.yamaguchi-u.ac.jp/English.html

Evaluation and Control of Environmental Odors

Given the current worldwide realities of increasing human population and industrial activities, odor pollution is becoming a critical issue for most local governments. Odor emissions are considered to be the main cause of disturbances noticed by the citizens living near some facilities. Such emissions affect quality of life, leading to psychological stress and symptoms such as insomnia and loss of appetite.

For appropriate evaluation of **environmental odors**, it is necessary to develop a reliable odor measurement method. Since environmental odors consist of many different odorous compounds, both comprehensive evaluation of odors using the human sense of smell and instrumental analysis of individual chemicals are indispensable. Odor intensity, odor concentration, and odor index are the principal parameters by which odors are characterized, and they serve as remarkably common and important sensory indicators of environmental odors. **Sensory evaluation** of odors reflects people's perception of odors and contributes to effective odor management, including impact assessment and implementation of control measures. Research activities in my laboratory are focused on evaluation and control of environmental odors. Other interests include toxicity assessment of gaseous pollutants and **solid waste management**.



Odor sampling (left) and odor impact assessment (right)

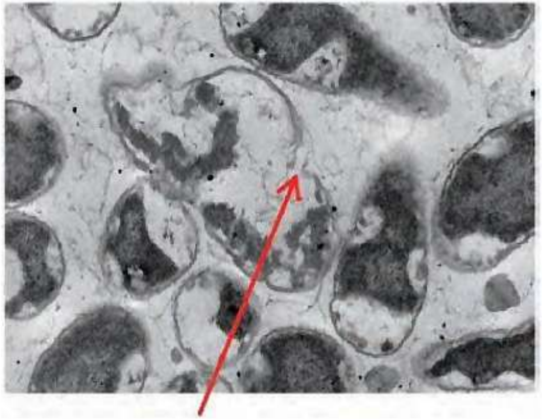
About Researcher

HIGUCHI Takaya, Dr.Eng.

Dr.Eng., 1996, Kyoto University

Water and Wastewater Treatment Technology and Biomass Energy Development

Our research interest is in **environmental technology**, particularly water and **wastewater treatment** for the purpose of conserving the water environment and **energy production from biomass** to help achieve a sustainable society. We believe that environmental technology should be simple and cheap because such technologies are amenable to broad application and adoption in not only developed countries, but also developing countries. Therefore, we focus on the development of these simple and cheap environmental technologies. Research now underway in our laboratory is focused on the following five fields: (1) a novel oxygen supply process based on contact of water film with air, (2) effects of high-dissolved gas (CO_2, N_2, etc.) water on the disinfection of microorganisms, (3) bio-hydrogen production from biomass under extreme thermophilic anaerobic conditions, (4) a novel oil-water separation process based on a combination of microbubbles and normal bubbles, and (5) a novel process for removing CO_2 from various gases (biogas, industrial exhaust gas, etc.) using a high-concentration gas dissolver.



Disinfection of *E-coli* bt bursting

Novel disinfection method using only low-pressure CO_2 (0.2 to 0.3 MPa) as a disinfectant

About Researcher

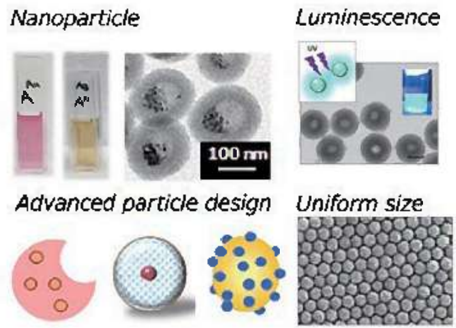
IMAI Tsuyoshi, Ph.D.

Ph.D., 1995, Kyushu University

WEB ≫ http://ds.cc.yamaguchi-u.ac.jp/~imai/index.html

Particle Design Based on Chemical Engineering for Environmentally-Friendly Processes and Applications

My research interest is the design of functional particles and their applications. Particles composed of inorganic and organic materials are essential for our lives because they have a variety of applications. Although numerous particles have been prepared using various methods, there is a need for advanced functional particles to solve global problems and novel methods for considering the global environment. I firstly focus on the **development of environmentally-friendly, cost-effective approaches to particle processing**. For instance, I have refined emulsion polymerization (the main industrial method for preparing polymer particles) by reducing the amount of surfactant used. Secondly, I focus on how to **design functional particles according to requirements**. I have developed original methods for preparing functional particles with nanoparticle assemblies, meso-pores, and hollow chambers. My ultimate goal is to find appropriate applications for the functional particles prepared based on the above two research foci.



Examples of particle design with unique structures and properties.

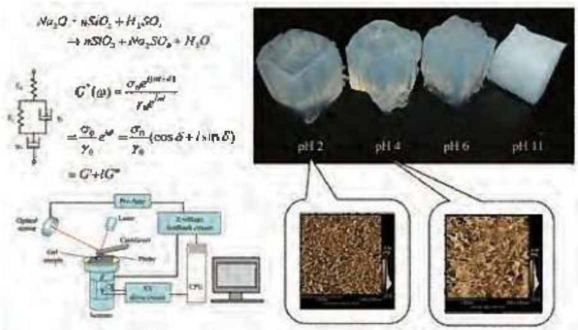
About Researcher

ISHII Haruyuki, Dr.Eng.

Dr.Eng., 2009, Osaka University

Complex fluids and gelation
— Cooperative research with industry through rheology

Have you ever been interested in why a pudding or a jelly gelated? You may have seen a bouncy drink or a paste-like food recently. These are called complex fluids, which are what we consider in our research. For example, we always consider the feel of a sample as smooth or viscous in order to make it more convenient. Besides such human senses, we also evaluate quantitative data with proper devices: rheometers. Engineering to control such flow characteristics is called '**rheology**.'
In addition, in the case of a pudding or jelly, which I introduced in the beginning, the water of the periphery is contained in an additive which has a minute network structure. It is necessary to observe directly to understand why they gelated. Such techniques belong to morphology. We work on various problems using rheology, morphology, surface chemistry, and simple chemical engineering. In order to develop measurement techniques for **approaching human senses** and **improving the convenience of products**, we research flows scientifically.



The silica gels with different appearances show individual internal structures, which can be captured by a scanning probe microscope.

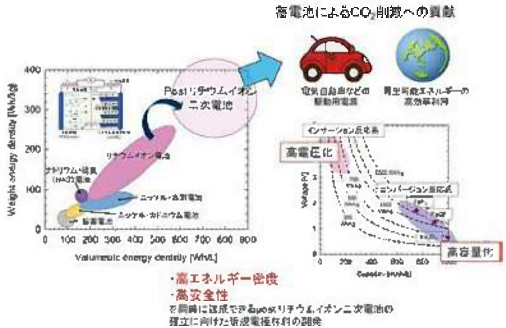
About Researcher

KAIDE Aya, Ph.D.

Ph.D., 2014, Yamaguchi University

Development of post-lithium-ion batteries with high cost performance

A new energy supply system using renewable energy is required to realize a low-carbon society and worldwide environmental conservation. The energy supply system will need to feature large-scale grid energy storage as a load leveling system. The demand for large-scale rechargeable batteries has thus been growing, and their safety level and cost performance has become an important issue. To realize post-lithium-ion batteries with low cost and a high safety level, we are investigating **sodium-ion batteries** and **all-solid-state batteries**, and so on. In addition, the conversion-type cathode materials, which utilize all of the valence changes between the oxidation state and metallic state of the cations in an electrode-active material with the breakdown of the initial crystal structure, are also being investigated because of their high energy density. However, conversion-type cathodes have some disadvantages that must be resolved: large irreversible capacity, large overpotential, low cyclability, and low rate capability. To adapt conversion-type cathodes to go beyond lithium-ion batteries, the detailed conversion reaction is also being investigated using synchrotron-based XRD and XANES measurements.



Weathering steel rust and exposure tests

About Researcher

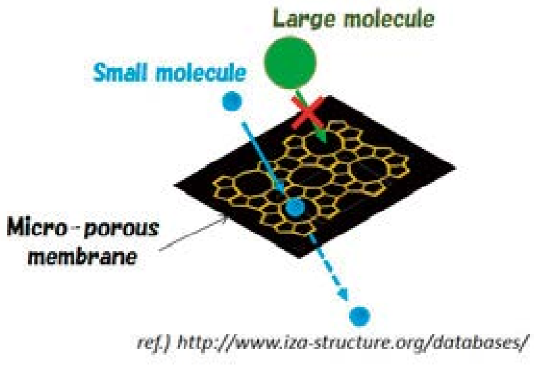
KITAJOU Ayuko, Dr. Eng.

Dr. Eng., 2006, Kitakyushu University

Membranes and Functionalized Nano-Materials for Environmental and Energy Applications

We are working on **membrane science**, including synthesis, characterization, simulation, and applications in energy and environmental processes. We have been involved in various national and international projects, ranging from fundamental research to more application-oriented research. For example, zeolite membranes, a type of micro-porous inorganic membrane, have been industrialized based on technology that was developed in our department. Since then, the **membrane dehydration process** has gained acceptance as an energy-efficient alternative to azeotropic distillation. There are many other fields where membranes can offer innovative processes. Our laboratory is currently working on the following topics:

- Development of acid-stable inorganic micro-porous membranes for dehydration applications and **catalytic membrane reactor** applications
- Development of inorganic micro-porous membranes and mixed matrix membranes for gas separation, for example carbon dioxide separation and hydrogen purification
- Membrane separation combined with fermentation for efficient bio-fuel production
- Catalytic membrane reactors for water treatment



Molecule sieving by means of a micro-porous membrane

About Researcher

KUMAKIRI Izumi, Ph.D.

Ph.D., 2000, The University of Tokyo

WEB ≫ http://web.cc.yamaguchi-u.ac.jp/~bunshi/

Environmental Cleanup and Resource Recycling Based on Separation Technology

Our group works in the area of environmental system engineering, resource recycling engineering, and separation technology. Progress in science and technology has led to the proliferation of various substances such as artificial chemical substances and heavy metals as contaminants in the environment. Many of these substances are harmful to ecosystems and human beings, making it necessary to develop **environmental cleanup techniques**. We are investigating the development of **innovative and environmentally friendly technologies** for controlling and removing these contaminants from soil and groundwater. Another issue is rapid depletion of natural resources caused by mass production and mass consumption. To maintain the sustainable development of human society and to save natural resources, **resource recycling** and effective utilization of unused resources are important. We are investigating the development of a recycling system for valuable metals, for example rare metals, from secondary resources (obtained from a so-called **urban mine**) such as spent catalysts, spent batteries, and wastewater based on separation and purification operations.

Spent hydrodesulphurization (HDS) catalysts as a treasure trove of rare metals

About Researcher

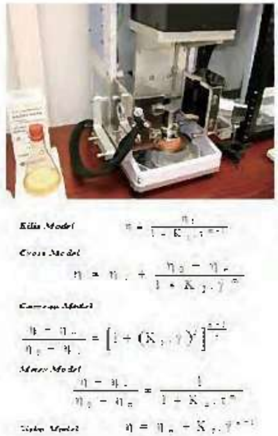
NIINAE Masakazu, Dr.Eng.

Dr.Eng., 1992, Kyoto University

Study of Deformation and Flow of Matter under Applied Stress

Our research interests lie in the area of complex fluids, for example suspensions, polymer solutions, and gels, which show impressive properties intermediate between those of fluids and solids (so-called "soft materials"). Our group has characterized such matter with a combination of rheological and morphological measurements to understand the mechanisms of sol-gel transition, viscoelastity, thixotropy, and so forth. Our research interests have included the suitable design and operation of chemical processes for treating complex fluids. Research now underway in our laboratory is focused on the following four fields: (1) **drag reduction** caused by surfactant solutions, (2) **sol-gel transition** of silica, (3) development of new **organogelators**, and (4) **rheology of foods**.

To date we have investigated rheology primarily at the academic level, but wider dissemination of the technology through cooperation with industry could bring enormous energy-saving benefits and contribute to the goals of green sustainable chemistry.



What is Rheology? Mathematics, physics, and engineering!

About Researcher

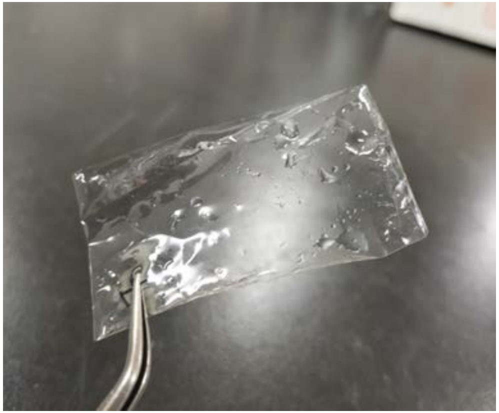
SAEKI Takashi, Ph.D.

Ph.D., 1995, Yamaguchi University

WEB ≫ http://www.saeki.chem.yamaguchi-u.ac.jp

Development of Ammonium Ion Recovery System for Normalization of Nitrogen Cycle Balance

Nitrogen on earth passes from the atmosphere to the ocean, land, and living organisms, and is then released back into the atmosphere. However, through human social activities, large amounts of nitrogen compounds are being discharged into the environment, seriously disrupting the balance of the global **nitrogen cycle**. As a result, eutrophication of soil and oceans, acid rain, and climate change are occurring. In order to restore the nitrogen cycle balance to normal, it is necessary to develop ways to recover nitrogen compounds discharged into the environment. Therefore, we are working on the **recovery of ammonium ions**, one of the forms of nitrogen compounds contained in factory effluents. Since there are many ions contained in the effluents, the most recent challenge is to create a special membrane (ammonium-selective **ion exchange membrane**) that can recover only ammonium ions from them. The recovered ammonium ions are converted to ammonia, which is used for CO_2-emission-free ammonia power generation. This research is expected not only to normalize the nitrogen cycle balance, but also to provide a solution to energy problems.



Ammonium-selective ion exchange membrane under development

About Researcher

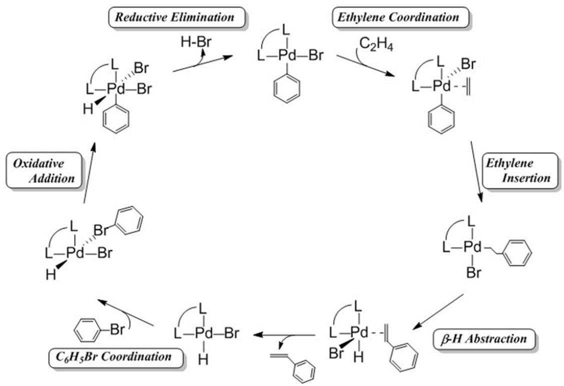
SUGIMOTO Yu, Dr. Agr.

Dr. Agr., 2017, Kyoto University

WEB ≫ http://piano.chem.yamaguchi-u.ac.jp/

Theoretical Study on Investigation of the Reaction Mechanism and the Molecular Property

Our research interest is to investigate the reaction mechanism and the molecular property using **theoretical calculation**. Current research is focused on three fields: (1) theoretical investigation of **metal-catalyzed reaction mechanism**, (2) theoretical estimation of **molecular properties** with a large π-conjugated aromatic system, and (3) development of a new functional molecule and a route for synthesizing it.
Theoretical investigation of metal-catalyzed reaction mechanism is a key project. A transition metal complex has been used as a catalyst in various organic synthesis reactions. Those catalyst reactions exhibit various structures as well as bonding and reactivity to which the metal atoms' d orbitals contribute, making them very interesting. Moreover, multiple electronic system catalysts exhibit large molecular sizes, facilitating a flexible electronic state. Consequently, it becomes easy to control structure and reactivity. We are conducting a theoretical investigation into transition metal-catalyzed reactions and searching for transition state structures, rate-determining steps, and active species.



New Heck catalytic cycle with Pd(II) complex

About Researcher

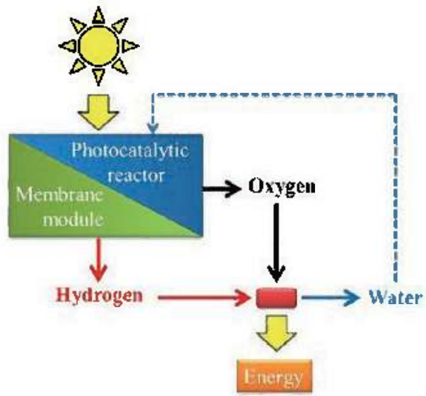
SUMIMOTO Michinori, Ph.D.

Ph.D., 2003, Kumamoto University

WEB ≫ https://ds0n.cc.yamaguchi-u.ac.jp/~rdesign_lb/index.html

Membrane Separation Processes: Fundamentals and Applications

I have been studying membrane materials and membrane processes for the separation of gas and liquid mixtures. **Membrane separation processes** are energy-efficient, simple in operation, and suitable for smaller-scale operation in comparison to conventional separation processes such as distillation and adsorption. Membrane separation can be used for removal of carbon dioxide from natural gas and purification of ethanol from bioethanol. My research interests include the **fundamental transport phenomena** of molecules permeating membranes, the effects of physical and chemical properties of membrane materials on their permeability and selectivity, methods for fabricating thin membranes without defects, and their application to separation and reaction processes in order to lower energy consumption. Current research topics are the development of membranes for separation of hydrogen and oxygen to be used in a photocatalytic **hydrogen production process**, synthesis of a carbon dioxide selective membrane using a facilitated transport mechanism, and transport phenomena through mixed matrix membranes.



An application of membrane gas separation to photocatalytic hydrogen production

About Researcher

TANAKA Kazuhiro, Ph.D.

Ph.D., 1994, Osaka University

Functional Biomaterials for Tissue Engineering, Cell Therapy, and Drug Delivery

Our research interest is in **functional biomaterials** for tissue engineering, cell therapy, and drug delivery. In particular, we have focused on the development of biocompatible nanoparticles, microcapsules, and emulsions containing protein drugs such as vaccine antigens and antibodies.

1. Emulsion carriers for **oral protein delivery**

We have developed a solid-in-oil-in-water (S/O/W) emulsion for oral administration of protein drugs using a surfactant-coated protein. It is known that when the S/O/W emulsions containing insulin are administered orally, the emulsion shows hypoglycemic activity for an extended period.

2. Mucoadhesive patches for oral protein delivery

We have proposed an intestinal patch as an efficient carrier for oral protein delivery. These intestinal patches, which have mucoadhesive and drug-impermeable layers, induce sustained unidirectional protein release toward intestinal mucosa while inhibiting protein leakage from the patches.

Recently, we have been interested in an **antigen delivery system** for intranasal vaccines and studied the development of a novel antigen delivery carrier using nanoparticles or emulsions.

Functional biomaterials developed in our research

About Researcher

TOORISAKA Eiichi, Ph.D.

Ph.D., 2003, Kyushu University

Synthetic and Catalytic Chemistry for Sustainable Organic Synthesis

Our research interests lie mainly in the field of organic synthesis. We focus on projects involving the development of novel catalysts and catalytic reactions for highly efficient organic synthesis, the development of those into a powerful synthetic methodology, and its application to the synthesis of functional materials. Our research is supported by a number of chemical companies. Research currently underway in our laboratory is focused on the following four areas: (1) study and discovery of novel chiral catalysts (organocatalysis and transition metal ion catalysis) for **asymmetric bromination** of organic compounds, (2) development of catalytic reactions (Lewis acid catalysis and Brønsted acid catalysis) for highly efficient synthesis of **heterocyclic compounds**, (3) development of novel catalysts and catalytic reactions for the synthesis of functional resin materials, and (4) molecular design of **new functional resin materials.**

Endless possibility in a world so small it cannot be seen with the human eye

About Researcher

YAMAMOTO Hidetoshi, Ph.D.

Ph.D., 1991, Kyushu University