CSEM's
Materials Monthly
August 2007
Making materials matter
THE AUSTRALIAN NATIONAL UNIVERSITY

HotRot

and putting some science into the black art of composting

At the start of winter, ANUgreen began an ambitious 12 month trial of an industrial-scale compost facility called the HotRot. The trial aims to transform a significant part of the university's waste stream into valuable, sweet-smelling compost, cut down our greenhouse gas emissions and save a lot of money. While it's still early days, the first results are promising. However, it's been realised that at the core of the industrial compost process there's a big scientific black hole on what's driving the waste transformation. Microbiologists in the Schools of Botany and Zoology and Biochemistry and Molecular Biology are hoping to fill this hole.

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Vol VIII, Issue VII

Materials Monthly is produced by the ANU Centre for Science and Engineering of Materials

The numbers are so compelling it's a wonder that other universities (and similar sized organisations) aren't setting up their own composting factories. Around a third of the waste generated at ANU is in the form of food and other organic material. It amounts to several hundreds of tonnes of stuff that has to be carted to the tip and disposed of each year. The direct cost to the ANU is over one hundred thousand dollars each year in petrol, handling and tip fees, but there's also a lost opportunity in exporting our organic waste while importing topsoil, fertilisers and compost for our garden landscapes.

Enter the HotRot 1512; a 12 metre long by 2 metre wide metal tube that can take over 2 tonnes of garden, animal bedding, and kitchen waste every day. The raw waste material is fed in at one end and is mixed with wood chip (most of which is animal bedding from the JCSMR) to provide an appropriate moisture content and porosity. The waste is then moved through the system using an auger that mixes and aerates the material throughout the

Dr David Carpenter (left), from ANUgreen, and Dr David Gordon, from the School of Botany and Zoology, discuss the university's latest step towards sustainability, the HotRot composter (seen the in the background).

decomposition process. Microbial activity in the vessel pushes the temperature up to 60^{0}C, and the residence time of material in the system is roughly 14 - 21 days.

Raw organic waste goes in one end, and a strong ammonia-smelling pre-compost

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The HotRot being lowered into position earlier this year. It's based in the Gardener's Soil Yard (near the Big Dish).

In July, ANU staff and students were given a tour over the facility.

HotRot

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mix falls out of the other. The output is then allowed to sit in a heap for a few weeks while it cools down, and it's then mixed with other garden waste streams to create a high quality mixed mulch that's stable, toxin free and contains none of the pathogenic microbes present in the original waste.

Well, that's the theory anyway. While most of the time everything chugs along nicely, because the waste inputs are highly variable, occasionally for reasons that are not altogether clear, the process goes sour, and the desired transformation doesn't take place. Instead of a clean crumbly product, the output is a greasy and rank mix that has limited use and signals that the production line needs cleaning out and starting again.

"The trial is still in its early days," says Mr Barry Hughes, the Waste and Recycling Coordinator at ANUgreen. "The recipe of what we mix with what is the tricky bit and we're still experimenting with this.

"One of the variables we have to deal with is Canberra's cool climate in winter. That means that the food waste we receive often hasn't rotted as much as it might in warmer times. In effect the cool temperatures serve to keep the waste relatively fresh."

Adding science to the mix

And, of course, rotting is what drives the whole compost transformation. The HotRot tank is merely an empty vessel engineered to maximise the activity of a diverse community of microbes that actually drive the process of decomposition. And here's where everyone got a bit of a surprise: despite the fact that composting is as old as history, little is known about the community of microbes that actually drive the process.

As decomposition occurs a pungent ammonia - laced odour is released. ANUgreen devised its own bio-filter, with assistance from R5 Solutions (NZ), consisting of soil filled tanks (seen here) to reduce the smell. So far it seems to have worked but the real test may come in summer.

"Despite the growing importance of these composting technologies, relatively little is known about the microbiological processes and community dynamics that drive them," says Dr David Gordon from the School of Botany and Zoology. Dr Gordon, together with Dr Gwen Allison from the School of Biochemistry and Molecular Biology, has been in discussions with ANUgreen about establishing a research program to investigate the microbes at the core of HotRot.

A elevated walkway and access ports allows the compost process to be easily monitored as it progesses.

"The engineering of these plants and their operation is largely based on manipulation of physical factors that can potentially enhance microbial activity such as the particle sizes of materials entering the system," he explains. "This ensures that there is adequate aeration and mixing of the material, and maintaining temperatures that are within the range that will yield effective pathogen reduction and microbial metabolic activity.

"Until recently, classic microbiological methods were only able to investigate a small fraction of the total microbial diversity in a community – those that could be cultured in vitro.

"More recently, nucleic acid-based molecular techniques have enabled researchers to characterise the composition and activity of a variety of microbial communities by targeted analysis of particular genes, for example, the species-specific region of the 16S rRNA gene, and those genes involved in sulphur-reduction. This has facilitated a better understanding of the microbial community and functional dynamics.

"While there have been a few studies of the composition of the microbial community of compost, these studies have focussed on laboratory-scale and not industrial-scale composting systems, and are largely descriptive in nature. It's surprising that little research has been directed at understanding the microbiological community that drives the composting process, because this knowledge is essential for the rational manipulation of industrial systems enabling improved efficiency and economy."

A golden opportunity

Dr Gordon believes the HotRot facility offers an excellent opportunity to dig deep into the microbiology that drives the process.

"Commercial composting is a growing industry with enormous environmental and economic potential," says Dr Gordon. "However, growth in this industry is limited by many factors, including a lack of understanding of the basic microbiological processes. We know of no attempt to

From putrescence to product

Rotting, smelly food scraps and organic waste (labelled putrescibles) are tipped in at one end, dark black, soil-like material falls out at the other. The fertiliser quality of the output is excellent. Food is not only high in nitrogen but contains appreciable amounts of other trace elements. Compost produced from food and putrescible waste will contain approximately twice as much nitrogen as waste produced solely from woody green waste.

Once composted, the product is dry, crumbles easily, and most of the input material is degraded. The bulk density of the material will be approximately 250-400kg/m3 and the moisture content in the range of 10-30%.

Depending on the processing time, a mass reduction of 60-80% may be expected. This is mirrored by a corresponding volume reduction of around 60-70%.

The composting process will achieve temperatures in excess of 60oC. Temperatures of this order ensure effective pathogen control while maintaining an efficient processing environment. Final product pathogen levels well below 200 MPN (for faecal coliform bacteria) and the elimination of Salmonella bacteria can be expected within a processing time of ten to fourteen days.

More information: www.hotrotsystems.com/NZAusPacific/index.cfm

Organic rubbish (collected in specially marked bins) is tipped in at one end, and a compact, valuable resource comes out the other end.

understand and modify the microbial community of industrial composting facilities; which is a bit surprising because commercial systems like HotRot offer a golden opportunity for experimental manipulation that is not possible in many other microbial systems.

"It takes two to three weeks for the decomposing material to pass through HotRot, and the microbial communities will obviously change enormously as the material moves through the tube. These changes will occur as a consequence of changes in nutrient availability and temperature, both of which will be driven in part by the absolute amount of microbial biomass. Our goal is to monitor changes in the microbial community using a nucleic acid-based community level analysis and viable cell culturing for enteric and other gram-negative bacteria.

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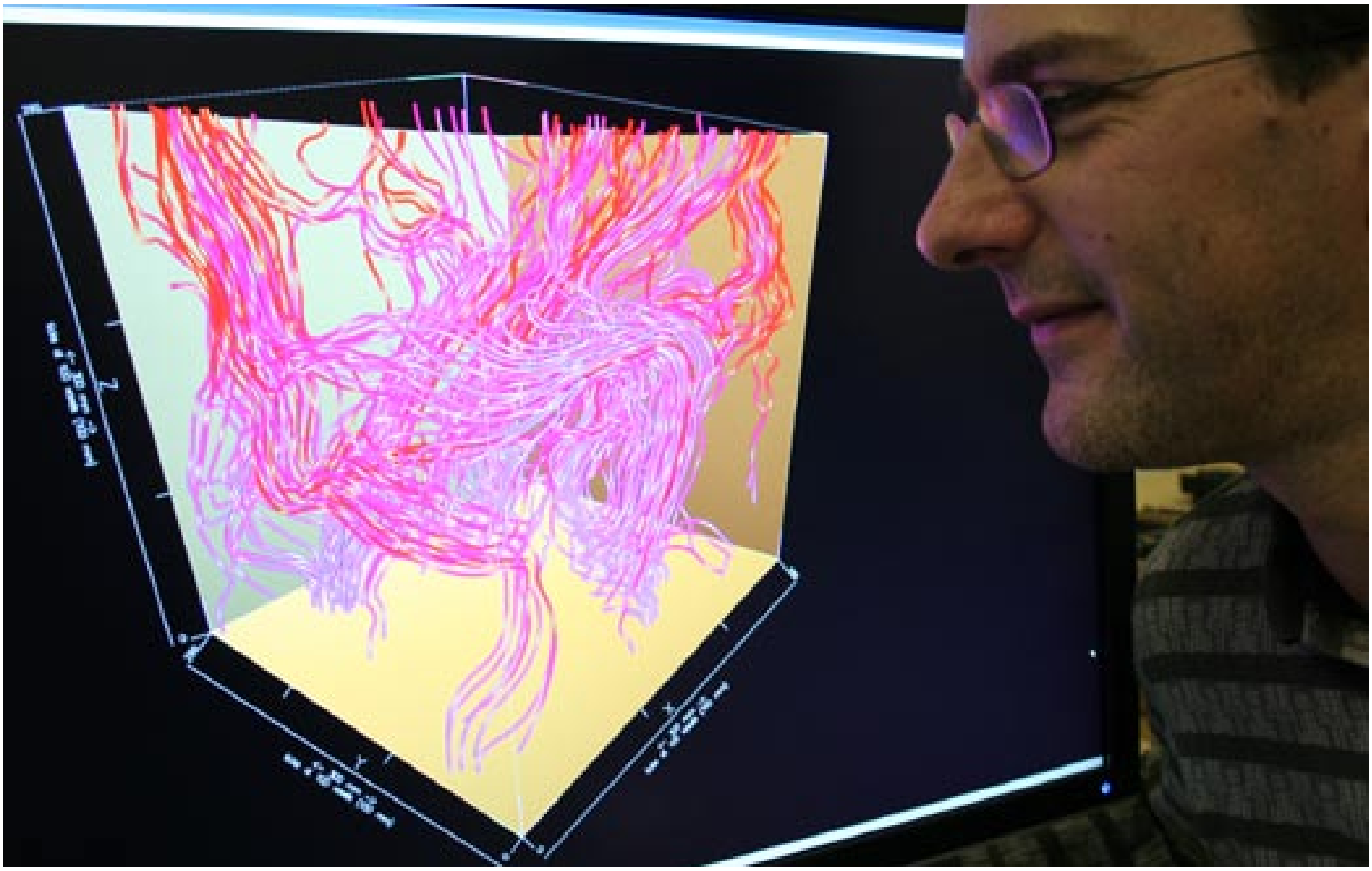
Access ports along the length of the HotRot allow for easy monitoring and sampling. "It's an excellent system with which to experiment with," says Dr Gordon.



Dr Christoph Arns examines a visualisation of fluid flow through Castlegate sandstone based on a solution of the Navier-Stokes equation using lattice Boltzmann techniques. The visualization was provided by Ajay Limaye (ANU Vislab), using his software package Drishti.

Go with the flow

Modelling complex materials

How does oil, water, gas, or nuclear waste flow through porous rocks? It's far from merely being an academic question. In the petroleum industry, for example, billions of dollars are spent each year making laboratory measurements on core materials in an effort to understand how oil is stored and might be retrieved. And the manner in which contaminants move through earth materials is critical to the design of nuclear waste facilities that will need to be functional over many lifetimes. With oil the aim is to get fluid flowing quickly. With contaminants the aim is to minimise the flow.

So how to do you understand a complex disordered materials like porous rock? You begin by taking what you think is a representative sample from a rock core and then you measure it in as many different ways as you can. You pump a fluid through the sample to measure its resistance to flow. You apply an electric field across your sample to measure its electrical conductivity. You push against it with a microscopic force to calculate its elasticity. You collect data on its pore space using nuclear magnetic resonance (NMR) spectroscopy. And you image the sample using X-rays to create a representation of its microstructure.

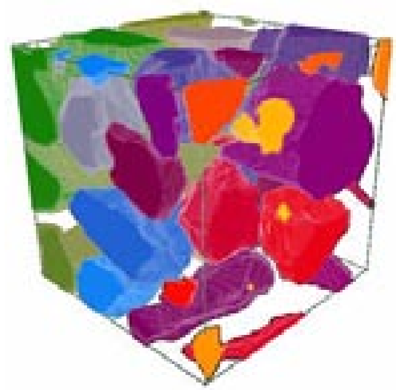
Every experimental measurement gives you an additional piece of information on the form and function of the material but the challenge is then integrating what you know and scaling the results up to create useful knowledge applicable in the real world.

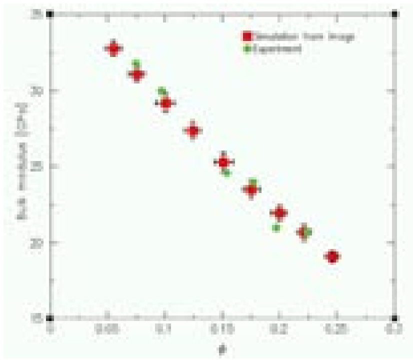
"Not many people work in the area of drawing the various threads together," says Dr Christoph Arns. "Most researchers have expertise surrounding one form of analysis which provides useful insights in one area. Often what they discover is very powerful in describing a material at one scale but may have limited value when applied at a larger scale.

"My area of research is based on integrating information from a variety of different characterisations by making numerical measurements. And I'm in a very lucky position because I work with an outstanding NMR researcher and have excellent co-researchers working with our micro X-ray CT facility. These two characterisation technologies are some of the most effective ways of understanding complex materials, and the researchers I'm working with are among the world's best in these fields."

Dr Christoph Arns is a Senior Research Fellow in the Department of Applied Maths (RSPSE). He's a physicist turned petroleum engineer turned computational physicist.

"Petroleum engineering is all about developing ways to improve the extraction of hydrocarbons from oil-bearing rocks," explains Dr Arns. "That almost inevitably leads you towards ways of better understanding complex materials because this is what oil bearing rocks are."





A model of a block of sandstone (left) was used to predict the elasticity of the material. Predictions closely match actual measurements.

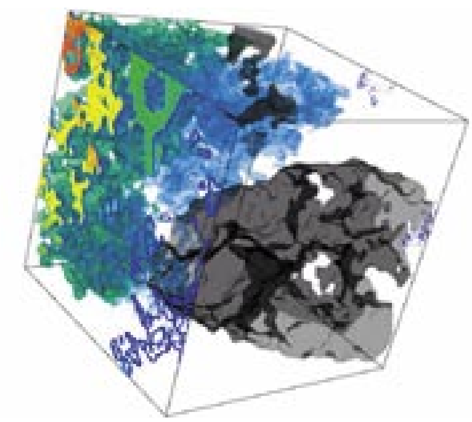
Dr Arns has been working for many years on the computational modelling of physical properties of complex materials. He has developed an innovative suite of software that can derive a range of important morphological and physical properties directly from 3D digitised tomographic images (created with Applied Maths' micro X-ray CT facility). These include conductivity, diffusivity, fluid permeability, dispersion of a neutral tracer, elastic properties and NMR relaxation/diffusion response.

"The predictions we have made from our computer simulations are in good to excellent agreement with independent laboratory measurements across a wide range of pore volume fractions," says Dr Arns. "This includes agreement in permeability measurements across four orders of magnitude in permeability."

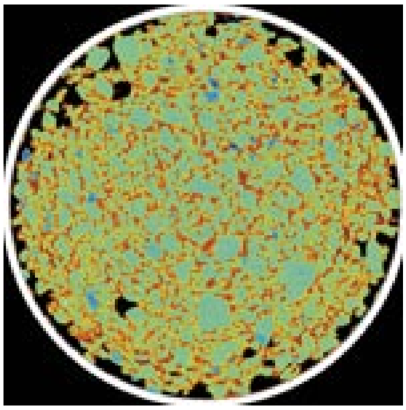
"In general, here at Applied Maths we have demonstrated that by combining microtomographic images with numerical calculations that we can accurately predict properties of complex materials. We've recently applied this methodology to a range of petroleum reservoir rocks with excellent results and used the detailed pore scale information available from the images for an analysis of pore-pore diffusion coupling, and tracer dispersion and local flux.

"This is significant, as it allowed us to find morphological parameters on the basis of Xray-CT images, which correlate well with macroscopic physical properties.

"Existing methodologies for estimating the macro properties of disordered materials are limited to overly simplistic representations of microstructure," observes Dr Arns. "For example, hydrocarbon recovery from reservoir rocks and contaminant dispersion in soils are currently estimated on the basis of laboratory-scale measurements and applied to the field scale. However, large anomalies



Intensity image of a tracer spreading through a small microporous section of a carbonate sample after an injection. The intensity is high in the microporous region (reddish colours), where convection is small and the tracer has to escape by molecular diffusion.



An X-ray slice through a rock sample (encased for flooding) and subsequent measurement.

are observed between what's predicted and what's actually measured. These anomalies are an expression of uncertainty related to the inability to adequately capture pore-scale features of materials, specifically the rock microstructure and rock-fluid interactions. This limits our capacity to make accurate predictions of macroscopic properties from morphological information, which could be gathered for example by a geologist to arrive at a large scale picture of a reservoir.

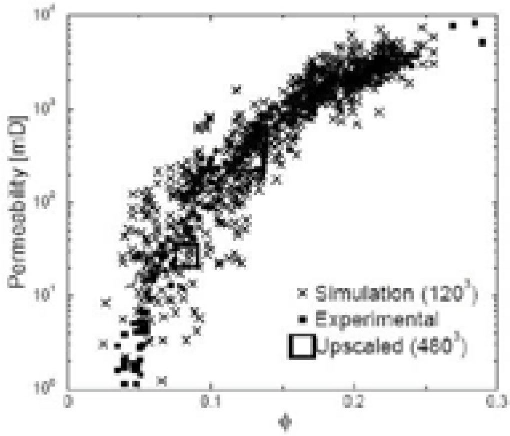
"A detailed understanding of correlations of physical properties and morphological descriptors under static structure will also help us, if we consider a dynamical change of the structure itself.

"We expect that numerical modelling of reactive flow on the pore scale should lead to improved estimates of permeability changes caused by a range of subsurface processes. This will significantly lower the risk of enormously costly mistakes in the development of oil fields.

"Of similar significance is the potential impact of pore-scale understanding of contaminant migration and reactive flow for groundwater remediation strategies. We'll be able to generate more accurate numerical modelling where field data cannot be obtained, for example in modelling the risk of storing hazardous materials. Therefore our research has both a significant economic and environmental dimension to it."

The research being undertaken by Dr Arns is strongly interdisciplinary in its nature, and depends on inputs and interactions with a broad range of scientists.

"NMR spectroscopy is one very important technique for understanding pore volumes and narrow constrictions in porous materials including length scales not accessible by Xray-CT imaging," explains Dr Arns. "Professor Paul Callaghan at the Victoria University of Wellington, New Zealand, is a world leader in this discipline, and he has been a long term collaborator, providing quality NMR data for this work.



Excellent match for permeability between simulation and experiment using a sample of sandstone over 4 orders of magnitude.

"The other main technology that is contributing to this research is the micro X-ray CT facility. Running a facility such as this requires a range of skills, and I rely on my colleagues to supply me with segmented images and their topological partitions of morphologically interesting samples. Adrian Sheppard, Arther Sakellariou, Tim Senden, Robert Sok and Mark Knackstedt are all involved in this.

"And, as you might expect, computing the enormous data sets involved in this numerical modelling requires tremendous computing power. Consequently, we're heavy users of the ANU Supercomputer Facility. It's close proximity and the willingness of its staff to work and interact with us is an important part of our success in this work."

Understanding and successfully modelling complex materials like oil bearing rock is a daunting task. Few places in the world could bring together the various skills and technologies to make it happen. Applied Maths is one such place.

"Applied Maths is a great place for this type of research," says Dr Arns. "It's a supportive and friendly place, open to new ideas and always ready to interact with others when it means adding value to the science."

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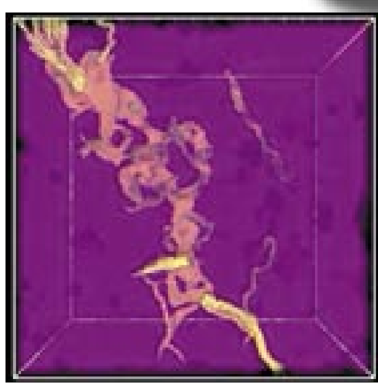

Preferential flow paths through a carbonate rock. In low velocity regions of the pore space a potential contaminant could spend a long time before rejoining a main flow path.

HotRot

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"The primary question to be answered is whether variation in the microbiota of material entering the system, or the 'seed' community, affects the downstream efficiency of the composting process.

"In these systems, material is added at one end and comes out the other - everything flows in one direction. We hypothesise that the composition of the microbial community that is freshly added to the system will vary enormously from day to day. Initially, this variation may not matter, as the resources that will be first exploited will be those that are most easily digested, such as the simple sugars. However, as material proceeds through the system it becomes increasing resistant to decomposition and successful decomposition will depend on particular microbial species being present. These species may not always exist in the material entering the composting system.

Access all ports

"Now, we're proposing to sample the system at regular intervals over spring and summer," explains Dr Gordon. "We'll take samples from the access ports that lie along the length of the system, one of reasons that this is such an easy system to investigate.

"The samples will be processed using culture-dependent and culture-independent methods. Conventional microbiological sampling methods for viable cells will use a variety of selective media and conditions. DNA will be isolated from the same samples and standard molecular techniques will be used to characterise the microbial community.

"We'll also undertake basic chemical analyses of the decomposing material for its carbon, potassium, total nitrogen and microbial nitrogen content using standard chemical analyses and DAPA determination (microbial derived nitrogen)."

In addition to this chemical and biological data, the system is set up to record temperature and humidity at a number of points along the length of the tube. ANUgreen also keeps careful records of the mass and type of materials being fed into the system.

This data will then be interpreted together with the microbiological and chemical results to determine if and how variation in materials entering the system changes the composting process. Data analysis and interpretation relevant to 'composting outcomes' will then be discussed in collaboration with R5 Solutions, the manufacturers of the system.

Barry Hughes digs into a steaming pile of the finished product. After passing through the HotRot this material sits in a heap where temperatures rise to around 70^{0}C. The heap is allowed to cool for some three weeks, and then it's mixed with other garden waste to create a quality compost.

An ANU first

"This is the first large-scale food-waste composting trial undertaken by any institution in the ACT," says Dr David Carpenter, Sustainability Manager at ANUgreen. "It's capable of diverting between 250 and 400 tonnes of food and other organic waste from land fill every year. In so doing it will create substantial savings in transport, water, topsoil, fertilisers and greenhouse gas emissions. It's estimated we could be saving up to around 500 tonnes of CO_2 being emitted per annum."

So HotRot looks like being a winner from every direction. And with a little science added to the mix, the black art of composting might become an innovation we see taking off all around the country.

ANUgreen is the University's environmental management program. It's run by the Facilities and Services Division, and was established in 1999.

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Materials Monthly comes out 10 times a year (February to November). We welcome your feedback and contributions. Please let us know if you wish to be added to our electronic or postal mailing lists.

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