PROFESSOR RANJITH PATHEGAMA GAMAGE

Buried **treasure**

Shedding light on alternative deep Earth resources, **Professor Ranjith Pathegama Gamage** is an expert in fundamental and applied rock mechanics – a key field in the battle to combat climate change – and energy extraction from deep Earth

What do your current roles as Director of Deep Earth Research and the Head of Geomechanics Engineering at Monash University entail?

The Deep Earth Energy Research group consists of eight academic staff and over 30 PhD students and 10 postdocs. The primary aim of the group is to help facilitate collaborative fundamental and applied research on feasibility assessment and technical problems that currently impede progress in the development of alternative deep Earth resources. Such deep Earth resources include new low-emission hydrocarbon alternatives (including underground coal gasification, coal-bed methane, shale gas and tight-sand gas); renewable energy sources (such as geothermal energy); options for geological waste containment (including carbon dioxide (CO_2) storage and nuclear waste disposal); and future metals integral to renewable energy technologies.

Can you describe some of the advanced experimental facilities at your disposal for deep Earth research?

I have established state-of-the-art testing facilities in Monash's Deep Earth Energy Research Laboratory (DEERL). The first of its kind in Australia for this specialisation, the Laboratory serves as a national focal point for such research. Some of the AUD $18 million-worth of equipment in DEERL (macroscale high-pressure testing chambers) is unique in Australia. Monash University has therefore achieved an international reputation as a 'power house' of large-scale advanced testing facilities for deep Earth explorations. These advanced facilities can be effectively used to conduct research on coal seam gas, shale gas and deep geothermal recovery under complex geological conditions.

With reference to potential benefits and limitations, can you discuss carbon capture and storage (CCS)? Do you think CCS is viable as a large-scale option for climate change mitigation?

CO_2 emissions into the atmosphere due to fossil fuel usage during power generation and other industrial processes can be largely reduced (around 90 per cent) through CCS and therefore it is clearly a large-scale option for climate change mitigation. However, predicting the long-term safety of CO_2 storage in oceans or deep underground is still very difficult. That is where my team is placing quite a lot of effort. Our vision is for a future where deep geological CO_2 sequestration systems provide a fully functioning, immediate and affordable option for controlling the impacts of global warming.

Are there examples you could provide of your current investigations exploring innovative methods to make CO_2 sequestration more practically viable?

According to our findings, injection of nitrogen into the coal seam during sequestration will reverse CO_2-induced swelling to some extent (20-30 per cent), which enhances CO_2 injectibility. In addition, proper control of the injection and production well arrangement in the coal seam will significantly increase process efficiency.

In addition, my group provided the first confirmation that supercritical CO_2 can significantly reduce permeability in coal seams and similar deep Earth porous media. This is a key finding; it opens up new research directions toward the use of supercritical CO_2 flow through deep underground reservoirs (coal seams, shale basins, saline aquifers and oil beds). It also promises important advances in CO_2 injection for enhanced recovery of coal seam gas.

Where are you hoping to concentrate your efforts over the next few years?

Climate change legislation, along with regulations to limit greenhouse gases, has led to natural gas competing with oil and coal; ranking now as the third largest of the world's energy sources. Among these sources, natural gas is the cleanest and most hydrocarbon-rich, and has high energy conversion efficiencies for power generation.

The greatest challenge is very low recovery of gas. Because of extremely low permeability values in shale gas reservoirs, appropriate permeability enhancing techniques are necessary for adequate recovery. Of all these techniques, hydraulic fracturing (hydro-fracturing) of the reservoir rock by injection of high pressure fluid is the most effective and commonly used. However, conventional enhancement of permeability for hydro-fracturing poses significant environmental challenges.

I want to focus on the development of environmentally friendly techniques for shale gas extraction, through critical experiments in modified hydraulic fracturing. These innovative techniques (use of waste CO_2 as an input to the shale gas industry) need in depth research to identify an optimum mechanism with all necessary rigour and clarity.

Deep in thought

With the aim of making Australia a world leader in renewable energy technologies and carbon dioxide emission reduction, the Deep Earth Energy Research group at **Monash University** is developing techniques to both extract energy sources and bury carbon deep underground in a clean, sustainable and environmentally friendly way

AT MORE THAN four times the world average, only Bahrain, Bolivia, Brunei, Kuwait and Qatar have higher per capita carbon dioxide (CO_2) emissions than Australia. Recognising this situation, the Australian Government is providing domestic actions and partnering with other countries to build capacity in order to reduce emissions and adapt to the impact of climate change. However, more research across a broad range of fields and sectors is required if mitigation strategies, as well as switching coal to natural gas, are to prove successful.

Led by Professor Ranjith Pathegama Gamage, Professor in Geomechanics and Australian Research Council (ARC) Future Fellow in Resources Engineering, the Deep Earth Energy Research group is conducting investigations into both extracting energy – such as oil, coal and gas – from the Earth in a more environmentally friendly way and also storing atmospheric carbon underground; two essential components of any serious climate change mitigation strategy.

ENERGY EXTRACTION

Largely triggered by the economic success of US shale gas extraction, many countries including Australia are now exploring the possibility of tapping into their own reserves. However, there are still concerns regarding groundwater contamination, earthquakes, use of large volumes of water and the release of methane into the atmosphere. Consequently, Ranjith and his research team have been investigating ways to minimise the environmental impact of shale gas extraction and improve its efficiency.

Current methods use water to fracture shale, but the Monash team is exploring a waterless method, using supercritical CO_2 or nitrogen as an alternative. Using these non-aqueous fracture fluids could mean reduced contamination and improved extraction efficiency, thus transforming shale gas into an economically attractive and, importantly, green energy source.

Current objectives include finding the optimum energy required to initially form network cracks and subsequently extend it, as well as investigating the rock-fluid interaction, flow and diffusion in the resulting fractured shale system.

NEW MINING TECHNOLOGY

The mining industry is seeking innovations in science and technology in breaking rocks for mineral extractions to meet the world's growing energy needs, reduce energy consumptions and minimise environmental impacts. Blasting is currently the common practice for hard rock mining, followed by further crushing. Extraction of minerals depends on crushing rock, and around 6 per cent of Australia's electricity is consumed in this energy-intensive process. Blasting often produces large rock blocks of up to a few metres, leading to complications of handling and secondary blasting. Ranjith aims to develop new science for a more efficient engineering approach of rock breakage – one that is environmentally and economically sustainable.

SEQUESTRATION

CO_2 sequestration involves the collection of the gas in large quantities from fossil-fuel power plants, and then liquefying and subsequently storing it, where it will remain for millennia. However, while the concept is clear, efficient sequestration remains incredibly challenging.

Biological, oceanic and shallow geological sequestration have all been considered, but it is generally agreed that the most promising method is deep geological sequestration in large underground reservoirs, despite the fact that the technique has yet to be proven technically and economically viable.

Key to the success of such a technique is the underground reservoir's ability to effectively take in and retain CO_2. Governed by the characteristics of the material that constitutes

Macroscale core flooding testing rig.

Deep geothermal testing chamber.

INTELLIGENCE

DEEP EARTH ENERGY EXTRACTIONS AND CARBON STORAGE

OBJECTIVES

To undertake collaborative fundamental and applied research on feasibility assessment and technical problems that currently impede progress in development of alternative deep Earth resources, including new low emission hydrocarbon alternatives, renewable energy sources, options for geological waste containment and the future metals integral to renewable energy technologies

KEY COLLABORATORS

The University of Sydney, Australia

Tsinghua University; **Peking University**, China

Indian Institute of Technology, India

Cambridge University; **Imperial College London**, UK

Pennsylvania State University, USA

Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen University, Germany

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RANJITH PATHEGAMA GAMAGE is a professor in Geomechanics and an ARC Future Fellow in Resources Engineering at Monash University. He heads one of the premier research groups in Australia for carbon dioxide sequestration and development of new sustainable technologies for extraction of natural gas from coal seams, shale and tight geological formations, and is responsible for important breakthroughs in these fields.

Largest core flooding equipment.

A convincing thesis

Professor Ranjith Pathegama Gamage's Discovery project, funded by the Australian Research Council, has resulted in team member Dr Samintha Perera winning the prestigious 2014 Rocha Medal. The Medal is awarded annually for the world's best PhD thesis in the field by its peak body: the International Society of Rock Mechanics (ISRM). This is just the fourth time the medal has been awarded to an Australian, and the first since 1998. "Capturing this prestigious award is evidence of the strength and talent in my research group, and of its well-deserved international reputation," Gamage reflects.

the reservoir, sealing units, and their expected response to environmental and chemical changes brought about by the process, confirming this viability is a primary concern of Ranjith and his collaborators.

FIT-FOR-PURPOSE FACILITIES

Assisting his team in this important work, Ranjith has established Monash's Deep Earth Energy Research Laboratory (DEERL). A unique facility, the Laboratory is equipped with the world's largest testbed for simulating conditions as deep as 12 km down, with pressures up to 300 MPa, temperatures of 450 °C and sample sizes as large as 1 m^3. Alongside established equipment, Ranjith has also developed a number of advanced experimental devices specifically for investigating geological CO_2 sequestration, including a novel large-scale advance triaxial testing device and large-scale core flooding device. Researchers from over 12 universities across Australia, as well as high profile industry representatives and the ARC, have helped develop this equipment and utilised the facility for their own work.

In conjunction with experiments in the Laboratory, advanced numerical simulations of the full CO_2 injection and sequestration process are used by the group to better understand storage capacities and the mechanical and fluid-flow behaviour of various reservoir and sealing rocks at the pressures, temperatures and chemistries relevant to geological CO_2 storage.

INFORMING POLICY

Ranjith and his team have made the most of their excellent resources to produce research with significant impact on Australian policy concerning geological storage of CO_2. One of the most interesting areas in which they have made progress is in determining the suitability of unmineable deep coal seams for sequestration. Results produced through experiments and numerical modelling have highlighted the sorbed-CO_2 storage capacity of various coal types. "We were the first to investigate the swelling such injection induces in the seams – a crucial issue affecting the flow of CO_2 and its containment for sequestration," adds Ranjith.

Their conclusions show that coal seams are very good sink candidates for permanent CO_2 storage. They also found that injection strategies that utilise multiple injection wells and pulsed injection best enhance the storage capacity of sequestration reservoirs and that periodic flushing of the reservoir with N_2 gas can help maintain injectibility, as Ranjith elaborates: "Our innovations include combining nitrogen with CO_2 to modify permeability associated with gas adsorption". However, significantly more research is required to overcome challenges faced with respect to the influence of CO_2 adsorption on coal structure and permeability.

Other potential sequestration media and topics of the Deep Earth Energy Research group's focus come in the form of saline aquifers (geological formations consisting of water-permeable rocks saturated with salt water); depleted oil and gas reservoirs; basaltic formations (formed through basaltic lava rapidly cooling); and soils.

ENGINEERING SOLUTIONS

Furthermore, the Monash scientists have been exploring some practical difficulties associated with sequestration. For example, one issue concerns the material used for sealing and capping a sequestration well before abandoning it. "Standard Portland-based well cement might not be suitable for an environment with acidic media," Ranjith comments. "Hence we developed a cement that can withstand such conditions. Called Geopolymer, our cement shows superior performance to that of Portland cement, and we believe it can hold without degradation."

By investigating a wide spectrum of potential media and engineering challenges, the researchers hope to provide a full understanding of sequestration for policy makers. And with their parallel studies into the environmentally friendly extraction of energy from the Earth, it is clear that the Monash team will continue to provide solutions to some of the most difficult engineering challenges that climate change mitigation poses.

Professor Ranjith Pathegama Gamage is looking for investors/partners to develop new methodologies for extraction of energy from deep earth and less energy intensive mineral extractions techniques. He is forming an innovative industry consortium of oil, gas and mining engineering. Please contact him if you wish to join.

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