Handbook

Geothermal Institute, Faculty of Engineering
The University of Auckland, New Zealand

25-27 November
2019

Contents

Welcome

41st New Zealand Geothermal Workshop 2019

Innovation and the Future of Geothermal in a Low Carbon World

We are pleased to welcome delegates to the 41st New Zealand Geothermal Workshop, held at Sir Owen G Glenn building, the University of Auckland.

The theme for the Workshop acknowledges a turbulent new world that we are entering, one that we ourselves have created and will eventually pass to our children. The New Zealand Government, through the Zero Carbon Act, are setting the country on a legally binding pathway to net zero emissions before 2050. Although this is a grand challenge for society, it is also an opportunity to ensure the longevity and prosperity of Geothermal Energy.

In New Zealand, 40% of CO_2 emissions are from road vehicles. Full electrification of this fleet, along with population growth, and replacement of other industrial heating would result in a doubling of electricity demand. Although the most obvious geothermal prospects have already been developed or protected, there continues to be immense interest in deep, supercritical resources. Nearer to the surface, we look towards greater penetration of low-temperature and direct-use technologies. And looking beyond the horizon as other countries ramp up their climate commitments, what opportunities await to export and spread our craft? We hope that the NZGW will continue to grease the intellectual wheels that innovate, elevate, and advertise geothermal in New Zealand and beyond.

The New Zealand Geothermal Workshop commenced in 1979, primarily as an avenue for graduating students of the Geothermal Institute to present their research. This premise continues today.

We hope that this year's workshop provides a moment to reflect on where you think geothermal could be in 2050, and what must be undertaken by our community (and the next generation of practitioners) to reach these goals.

Conveners:

Rosalind Archer, David Dempsey, Mike O'Sullivan, Sadiq Zarrouk

2019 Sponsors

2019 Best Paper Awards

Ngati Tuwharetoa Geothermal Assets Ltd

Best Direct Use paper

New Zealand Geothermal Association

Best New Zealand author

Best student paper

Best student poster

General information

The following information is provided as a guide to the Workshop. If you have any queries, please visit the registration desk.

Registration desk

For any questions, please visit the registration desk during Workshop hours.

If the registration desk is unattended, please call 027 807 9928.

Workshop catering

Lunches, morning and afternoon teas will be served in the Level 0 Foyer, Owen G Building (OGGB), University of Auckland.

Dietary requirements

Vegetarian options are provided with each meal break. Care has been taken to ensure all advised dietary requirements are catered to. If you specified your dietary requirements when registering, please make yourself known to the catering staff.

Mobile phones

During all presentations please switch off or turn your mobile phones to silent.

Presentations

As a courtesy to our presenters, please ensure you arrive at each session venue prior to the start of presentations.

Presenting authors

Presentation slots are 15 minutes long with 3 minutes scheduled for questions. Each session chair will be keeping strictly to time.

If you are scheduled to give a presentation, please ensure your PowerPoint is uploaded well in advance of your presentation time, preferably during the catering breaks or prior to the start of each day. Visit the registration desk for details on how to upload your presentation.

Cameras and electronic recording

No electronic recording of presentations is permitted in any form without the express written permission of Workshop organisers and speakers.

Urgent messages and lost property

Urgent messages for delegates and lost property can be directed to the registration desk.

Messages and lost property will be held there for collection until the conclusion of the Workshop.

Social Events

There are a number of social events available to attendees. If you have not already arranged your tickets to these events, please visit the registration desk.

Workshop Reception

Monday, 25th November, 5.30pm
Level 0, Owen G Glenn Building (OGGB)
Sponsored by Western Energy with WING speakers

This will be a 'drinks and nibbles' event open to all registered Workshop delegates. No ticket required.

Workshop Dinner

Tuesday, 26th November 6.30pm
The Wharf, 2 Queen St, Northcote, Auckland

This years' dinner will be at Auckland's Premier Waterfront Venue. Surrounded by the sparkling waters of Waitemata Harbour and nestled beneath native Pohutukawa trees. Breath taking views of the city skyline and harbour is the perfect backdrop for you to enjoy this incredible location.

Buses: We will have complementary delegate buses leaving outside the conference venue from 6:15 pm. Returning buses will be available from 9:30pm

The Workshop dinner is available to those who have previously registered to attend this event. Please make sure you present your name tag on arrival, as it includes your dinner ticket(s).

If you aren't sure if you have previously registered, please check with the registration desk staff.

Wi-Fi Access

To login:

1. **Select the wireless:** UoA-Guest-WiFi
2. **Enter the username:** geothermal@auckland.wifi
3. **Enter the password:** qulX6Zzg

Auckland information

The following information is provided as a guide to Auckland. If you have any queries, please visit the registration desk.

Emergencies, medical needs and illnesses

If you have an emergency you can contact the police, paramedics and fire department by calling 111 from any landline or mobile phone.

The Workshop Venue is:
Owen G Glenn Building,
2 Grafton Road, Auckland Central.

If you require non-emergency medical attention during the workshop, please inform the registration desk.

Getting around taxis and airport shuttles

There are many taxi companies to choose from in Auckland. We suggest:

Blue Bubble Taxis
00 300 3000
www.cooptaxi.co.nz

Green Cabs
0508 447 336 (free phone)
www.greencabs.co.nz

Super Shuttle
0800748 885
shared airport transfers direct to/from your accommodation www.supershuttle.co.nz

SkyBus 24hrs a day, direct bus transfers to Auckland Airport from downtown Auckland
www.skybus.co.nz

Nearby Services

ASB Bank
Level 1, Owen G Glenn Building (OGGB), University of Auckland, Banking and foreign exchange services

Pharmacy and Post Shop
Level 1 Kate Edgar Information Commons Corner Alfred & Symonds Street

Eat & Drink in Auckland
Where to start? Auckland has more great places to eat and drink than we could hope to recommend. For current reviews visit:

Metro Eats Auckland
www.metroeats.co.nz

Check the Top 50 Restaurants 2016, Cheap Eats and Best Bars lists.

The Urban List
www.theurbanlist.com/auckland

Places to Visit
Visit Waiheke Island for some of the best vineyards in New Zealand, including the University's own award winning Goldie vineyard.

Take a walk on one of Auckland's 50 volcanoes. For a quick trip, visit Mt Eden or One Tree Hill or for a day trip take the ferry out to Rangitoto Island.

View www.aucklandnz.com for more ideas.

Keynote speakers

Patrick Walsh

Vice President, Geothermal Resource, ORMAT

Patrick Walsh is Ormat Nevada Inc.'s Vice President – Geothermal Resource. He served as Ormat's Chief Geologist from 2011 to 2016, and Staff Geologist from 2008 to 2011. In this time, Patrick has had the opportunity to support Ormat's interests in over 17 geothermal projects in 5 countries. While focused on prospect assessment, exploration, resource development, reservoir maintenance, and drilling management, Patrick also provides insight into key geothermal business parameters such as acquisitions, development budgeting, project management, and operations forecasting. He is serving his second term on the Geothermal Resource Council's Board of Directors. Mr. Walsh obtained a Bachelor of Science in Geosciences from The Pennsylvania State University in 1998 and a Master of Science in Geological Sciences from The University of Texas at Austin in 2000. In his 19 years of experience, Mr. Walsh has specialized in geothermal, water and petroleum resource assessment, exploration, and development.

Technical and economic development of high enthalpy upflow and low enthalpy outflow in volcanic and fracture-controlled geothermal systems.

Operating 917 MW globally, Ormat has developed projects and expertise in geothermal systems in volcanic, fracture-controlled, and sedimentary basins. Three systems in the portfolio have significant developed and/or potential upflow and outflow systems. These systems include Steamboat Hills, Nevada; Mammoth, California; and Amatitlan, Guatemala. This presentation will describe these systems, highlight technical and economic aspects of these developments, highlighting the benefits of exploiting geothermal resource. We will also provide an update on a portion of Ormat's Operating portfolio with some lessons learned in various play types if time permits.

The Steamboat Hills Complex, Nevada produces 65 MW with 3 high enthalpy artesian wells, 19 pumped moderate to low enthalpy wells, and 8 injection wells. The system exploits a fracture-dominated system with an apparent magmatic component based on He isotopoic ratios. Mammoth Lakes produces 29 MW with another 30 MW under development exclusively from moderate-enthalpy outflow below a larger magmatic upflow system. Ten production wells are all pumped, and lower injectivity also requires injection pumps to permit injection flow with higher pressure that is maintained below fracture gradients. Amatitlan, Guatemala produces 20 MW from magmatic upflow. The project concession includes an as-yet undeveloped outflow featuring extensive surface manifestations, proven commercial temperature and anticipated fracture-controlled permeability.

Steamboat and Mammoth, 2 systems with developed outflow, have lower temperatures, permitting high flow rates from a single well with pumps (500 to 1400 tph) with temperatures up to 175 C. The pumps avoid flashing, use little or no inhibitor and therefore maintain lower Operations and Maintenance costs and offer nearly 99% plant availability.

Conversley, Amatitlan has had significant scaling issues that require larger amounts of inhibitor and more frequent cleanouts, increasing O&M and resulting in more frequent well replacements. Binary power plants in all three locations allow increased flexibility for temperature decline over the long- life of the projects.

Notes

Katherine Young

Geothermal Program Manager,
National Renewable Energy Laboratory

Katherine Young is the Geothermal Program Manager at the NREL, and has been with NREL since 2008, focusing her research on improving geothermal drilling through innovative use of data and new tools as well as geothermal exploration, regulatory and permitting analyses, and geothermal resource reporting methodologies. Ms. Young has developed innovative tools, such as the Geothermal Reporting Protocol and Optimization Technique, GeoRePORT, the Geothermal exploration and area case histories on OpenEI, a wiki-based, crowd-sourced information sharing Website; and the Regulatory and Permitting Information Desktop (RAPID) Toolkit, a collection of publicly available information about permits and regulations affecting energy and bulk transmission project development. The resource is intended to facilitate communication between project developers and agency personnel, among agencies at all jurisdictional levels, and among all project stakeholders – including the public. Ms. Young has previously worked as a field engineer for Schlumberger Dowell, a geology instructor, and a database software designer, developer, and trainer.

Innovating Geothermal Wells

Geothermal has historically been a niche industry with power installations typically limited to the ring of fire. But with an increased global interest in climate change mitigation, and growth of the renewable industry, interest in geothermal, too, has grown – as a resource for both heat and power. Ms. Young will discuss geothermal's potential in the energy transition and what enabling technologies are on the horizon, particularly in reducing the cost of wells.

Notes

Sara Montomoli

Head of Geothermal Innovation, Enel Green Power

I was born in Italy – Volterra –, and grown up in Pomarance, the municipality where Larderello geothermal power plants are located. I studied Chemical Engineering at Università degli Studi di Pisa, obtaining the master's degree in chemical engineering in 2008. After a short collaboration with Università di Pisa, in the same year I was hired by EnelGreenPower in the Geothermal Operation&Maintenace unit. From 2010 to 2011 I have been responsible of the operation team within the Larderello geothermal area (8 power plants – one of the 4 geothermal geographical areas in which our power plants are divided). From 2012 to 2018 I have been Director of 14 geothermal power plants (included the first hybrid Geothermal&Biomass Cornia2 power plnat) and their related steam network within the Lago geothermal area. Since January 2019 I am responsible of the Geothermal Innovation unit. I am also board member of EGEC (European Geothermal Energy Council) and ETIP-DG (European Technology & Innovation Platform on Deep Geothermal).

Geothermal exploitation in Enel Green Power – a history of sustainable development and new challenges for the future.

Geothermal exploitation started in Italy more than 200 years ago in 1818, when Francesco Giacomo Larderel, a young engineer and entrepreneur of French origin, established his plant in Montecerboli to extract boric acid to produce boron for chemical and pharmaceutical uses. That date marked the day the global geothermal industry came into being. The next great step forward took place almost a century later. It was pioneered by Piero Ginori Conti, the heir to both Larderel's company and his inventive spirit: his idea was to exploit geothermal vapour as a source of energy. On 4 July 1904 he used a simple generator consisting of a dynamo running off geothermal heat to successfully turn on five light bulbs.

It was a turning point for the geothermal industry, which passed from chemical use to energy source. It was also an important marker in the history of electricity and sustainability: for the first time ever, man had generated electricity using the renewable resources from the Earth's interior.

Since then, continual technological innovation has made geothermal energy a sustainable solution used in numerous countries and has given it a special place among the Enel Group's renewable source success stories. Technological excellence in the geothermal sector allows Enel Green Power to take innovative paths and to constantly improve activity on all fronts, from the efficiency of the structures to digitalization processes and environmental positioning. The first geothermal center in South America and the highest in the world was inaugurated in 2017 in Ollagüe on the Andean plateau, the Cerro Pabellón plant in Chile. Also the integration of geothermal energy with power from other renewable sources is one of the most

distinctive characteristics of Enel Green Power innovation. The Stillwater plant in Nevada is the first in the world to combine three different technologies: geothermal, solar thermal and photovoltaic. In Utah the geothermal plant in Cove Fort is boosted with extra power from a hydroelectric generator that reuses the water in the geothermal well. In Castelnuovo Val di Cecina in Italy, Enel Green Power combined the geothermal power plant Cornia 2 with a biomass plant, creating a unique complex, the first of its kind in the world.

Enel Green Power has a strong commitment on encouraging also the development of activities that can give value to the local communities increasing the social acceptability of geothermal power plants. Valuable examples are the beer factory, the cheese factory and the various greenhouses that are improving their business using the geothermal heat. Also initiatives for the CO2 reuse, such as the algae cultivation, are promoted by Enel Green Power.

In a rapidly changing world, where sensitivity to environmental and sustainability matters is growing rapidly, where the attention on CO2 emissions is raising day by day and where regulations are starting to incorporate these issues, it is necessary to enhance these aspects, combining awareness of the future with that of the past. It's a fitting way to remember the pioneering enterprise of Larderel and promote the further development of geothermal industry: two centuries of history and a future of sustainability.

Notes

Novi Ganefianto

Vice President of Exploration and Subsurface Engineering, PT Supreme Energy

Novi has 25 years of geothermal industry experience, working for various geothermal developers, inducing Unocal Geothermal Chevron Geothermal, Star Energy, Thermochem, and Mighty River Power in New Zealand.

He has been involved in exploration, development and field management for many geothermal fields in Indonesia and New Zealand, such as Salak, Darajat, Sarulla, Wayang-Windu, Rotakawa, Mokai, Kawerau and Ngatamariki geothermal fields.

Before joining PT Supreme Energy in 2015, he was the Country Manager for Thermochem Indonesia, which one of his tasks was to project manage the well testing activities during the implementation of the development drilling program currently underway in the Sarulla Geothermal Field. Novi has a bachelor degree in Geology from ITB and a Diploma in Geothermal Technology from the University of Auckland.

Current status and future planning of PT supreme energy geothermal working areas, indonesia

Geothermal development began in Indonesia in 1974 following the establishment of President Decree No.16/1974, which was subsequently strengthened by President Decree No.22/1981, President Decree No.23/1981, President Decree No. 45 in 1991 and President Decree No.49/1991. Under these decrees, PERTAMINA, a wholly government-owned entity, was granted the right to manage the geothermal resources of Indonesia. All of the geothermal fields currently operating in Indonesia (total ~1300 MWe) were developed under this earlier legal framework.

Subsequent laws, passed in 2003 and 2014 (Law 27/2003 and Law 21/2014), significantly changed the legal structure for geothermal development. Geothermal resource management was transferred from PERTAMINA to the Government of Indonesia (GOI) and a competitive tender process was introduced, with regions given authority to grant geothermal licenses (IPB). Following this change in law, numerous privately-owned Indonesian and international companies have been granted geothermal licences however PT Supreme Energy and KS Orka are the only privately-owned companies that are currently actively developing geothermal resources in Indonesia.

PT Supreme Energy was founded on 11 September 2007, having the following subsidiaries:

1. PT Supreme Energy Muara Laboh (SEML), the owner of Geothermal License (IPB) for the Muara Laboh Geothermal Concession Area, located in Solok Selatan, West Sumatra. PT SEML is a consortium of PT Supreme Energy, Sumitomo Corporation and ENGIE.
2. PT Supreme Energy Rajabasa (SERB), having the same consortium as of PT SEML, is the owner of the Rajabasa

Geothermal Prospect located in the South Lampung Regency, Lampung Province.

3. PT Supreme Energy Rantau Dedap (SERD), the owner of Geothermal License (IPB) for the Rantau Dedap Concession Area located in South Sumatera Province. PT Supreme Energy Rantau Dedap is a consortium of PT Supreme Energy, ENGIE, Marubeni and Tohoku Electric.

In 2009, through a tender process, PT. SEML was granted a licence to develop the Muara Laboh Geothermal Concession Area. A Power Purchase Agreement (PPA) with PT.PLN (government owned utility company) was signed on 2 March 2012, followed by drilling of six exploration wells, confirming resource capacity of at least 60 MWe. Resource modelling and power plant design utilizing dual-flash technology led to a decision to proceed with developing 80MWe capacity on the field. Following the signing of the PPA amendment on 10 August 2016, the financing process began which was completed on February 2017.

Development Drilling in Muara Laboh started on the 28th of May 2017 and was completed on the 12th of June 2018. A total of twelve wells were completed during the campaign (nine production and three injection wells). All production wells were completed into a high temperature (>280 °C) and high permeability geothermal reservoir. Well testing has confirmed their capability to flow commercially to support the 80 MWe field development. All wells produce high temperature (>280 °C), near-neutral (pH 6.8) and low-gas geothermal fluid, suitable for carbon steel surface facilities. The new injection wells encountered sufficient permeability in the reservoir to be able to accept all brine and condensate injection. The power plant and steam gathering system construction are well underway, with the Commercial Operating Date (COD) scheduled to occur in Q4 2019.

The Rantau Dedap concession area is located in South Sumatera Province which and was granted to PT SERD in 2010. Following the signing of a PPA in 2012, PT SERD drilled six (6) exploration wells in 2014, delineating a high temperature (>260 °C) reservoir to the southwest (SW) of the field. The Numerical simulation conducted based on the exploration well results suggests that the SW portion of the Rantau Dedap reservoir is capable of sustaining output of approximately 92 gross MWe by the use of utilizing a dual-flash plant supplied by self-flowing, two-phase production wells. Following the signing of the PPA amendment in 2017, the financing process started until it began which was successfully completed in April, 2018.

The fundamental resource development strategy for Rantau Dedap is to produce fluid predominantly from the high temperature (>240 °C), high elevation (>2000 masl) area to southwest, and inject by gravity into the lower temperature (<220 °C) and lower elevation (<1800 masl) outflow zone to northeast. A total of 11 eleven production wells will be drilled, consisting of 8 eight new production wells and 3 three "buffer" wells. The development drilling program and surface facilities construction are currently underway, with the COD is scheduled to occur in Q4 2020.

The Rajabasa Prospect is located at the southern end of the Sumatera Island alongside the eastern coast of Lampung Bay on the volcanic cone of Mount Rajabasa. The occurrence of a high temperature geothermal system at Rajabasa is indicated by numerous fumaroles and associated sulfate hot springs.

PT SERB signed a PPA with PT.PLN on 2 March 2012. Following a long delay due to forestry permitting, PT SERB is now ready for the executing an exploration drilling program as all required permits for exploration have been secured, and all the surface geoscientific studies have been completed.

41st New Zealand Geothermal Workshop

Monday 25 November

8:00	**Registration Open**		
9:30	**Housekeeping**		
9:40	**Welcome and Opening (Lecture Theatre OGGB 4)**		
9:50	**Keynote: Patrick Walsh, ORMAT** TECHNICAL AND ECONOMIC DEVELOPMENT OF HIGH ENTHALPY UPFLOW AND LOW ENTHALPY OUTFLOW IN VOLCANIC AND FRACTURE-CONTROLLED GEOTHERMAL SYSTEMS		
10:30	**Morning Tea**		
	Session 1.1 – Modelling & Simulation 1 Lecture Theatre OGGB 4	**Session 1.2 – Geoscience 1 Lecture Theatre OGGB 5**	**Session 1.3 – Geothermal & Petroleum Case Room 2**
10:50	80 | NON–UNIQUENESS OF GEOTHERMAL NATURAL-STATE SIMULATIONS – Bjarkason	33 | OVERVIEW OF THE GEOSCIENTIFIC UNDERSTANDING OF THE EGS UTAH FORGE SITE, UTAH, USA – Simmons	11 | GEOTHERMAL ENERGY FROM PETROLEUM WELLS IN NEW ZEALAND–BENEFITS AND BARRIERS – Reyes
11:10	19 | INTRODUCING THE VOLSUNG GEOTHERMAL SIMULATOR: BENCHMARKING AND PERFORMANCE – Franz	34 | ORIGIN AND AGE OF FLUIDS AT THE CERRO PABELLÓN GEOTHERMAL SYSTEM, CHILE – Morata	66 | WHAT OPPORTUNITIES ARE EVIDENT FOR GEOTHERMAL WITH THE LOSS OF KIWI GAS? – Rogers
11:30	20 | INTRODUCING THE VOLSUNG GEOTHERMAL SIMULATOR: FEATURES AND APPLICATIONS – Clearwater	46 | SUBSURFACE ALTERATION AND 3D MODELING IN ASAL–RIFT GEOTHERMAL FIELD, DJIBOUTI. – Aden	94 | UTILIZATION OF ABANDONED OIL WELLS IN GEOTHERMAL APPLICATIONS – Jalilinasrabady
11:50	7 | NEW ZEALAND'S COLOMBO PLAN PROJECTS TO DEVELOP INDONESIA'S GEOTHERMAL FIELDS IN 1971 AND 1975. – Hochstein	48 | THE CHARACTERISTICS OF HYDROTHERMAL ALTERATION AT STEAMING GROUNDS IN THE NORTHEASTERN PART OF TATUN VOLCANO GROUP, TAIWAN – Fujisaki	17 | GEOTHERMAL ENERGY UTILIZATION OF ABANDONED PETROLEUM INDUSTRY WELL; CASE: THE POTENTIAL OF HOT WATER PRODUCTION IN TISZATARJAN HUNGARY – Darana
12:10	**Lunch and Poster session:**		
	3 | MILK PASTEURIZATION USING LOW-TEMPERATURE GEOTHERMAL FLUID IN DAUIN, NEGROS ORIENTAL, PHILIPPINES – Quinicot		
	47 | COLOMBIA – A GEOTHERMAL OPPORTUNITY – Aguilera Bustos		
	51 | ASSESSING FLUID FLOW IN LOW-ENTHALPY GEOTHERMAL FIELDS — AN EXAMPLE FROM THE WHATAROA VALLEY, SOUTH WESTLAND, NEW ZEALAND – Janku–Capova		
	55 | INTEGRATION OF DRILLING AND WORKOVER SERVICES IN THE GEOTHERMAL PROJECT LAGUNA COLORADA – Garcia Antezana		
	57 | GEOPHYSICAL IMAGING OF THE LIQUIÑE GEOTHERMAL SITE (39°S, CHILE) BY MEANS OF 3D GRAVITY INVERSION – Elizalde Guerrero		
	60 | GEOTHERMAL DRILLING SYNERGISTIC APPROACH AND STRATEGY IN WEST JAVA – Agus		
	76 | GEOTHERMAL CONCEPTUAL MODEL INFERRED FROM MAGNETOTELLURIC AND WELL LOGGING DATA IN THE SOUTH ILAN PLAIN, TAIWAN – Lin		
	78 | NEW IMPLICATION OF WALL ROCK ALTERATION MINERALOGY IN THE HISHIKARI EPITHERMAL GOLD DEPOSIT, JAPAN – Gonoi		
	89 | OVERVIEW OF HYDRAULIC FRACTURING DESIGN IN GEOTHERMAL ENVIRONMENT – Harahap		
	99 | APPLICABILITY OF THE NA–K GEOTHERMOMETER IN SLATE FORMATIONS OF TAIWAN – Lu		

Monday 25 November

13:10	**Keynote: Katherine Young, National Renewable Energy Laboratory** INNOVATING GEOTHERMAL WELLS		
	Session 2.1 – Modelling & Simulation 2 **Lecture Theatre OGGB 4**	**Session 2.2 – Geoscience 2** **Lecture Theatre OGGB 5**	**Session 2.3 – Silica & Corrosion 1** **Case Room 2**
13:50	42 | AN UPDATE ON THE WAIWERA GEOTHERMAL FLOW SIMULATOR: DEVELOPMENT AND APPLICATIONS – Croucher	81 | HYDROGEOLOGICAL CONTROLS ON STRATOVOLCANIC GEOTHERMAL SYSTEMS – Alexander	45 | MATERIAL CORROSION TEST USING ACID AT VARYING PH AT A GEOTHERMAL FILED IN JAPAN – Yanagisawa
14:10	44 | LEAPFROG 3D TEMPERATURE DISTRIBUTION BASED ON TOUGH2 NUMERICAL MODELING IN ATADEI GEOTHERMAL FIELD, INDONESIA. – Supijo	93 | GEOTHERMAL SUBSIDENCE AND INFLATION IN TAUPO: A COMPARISON OF DETECTION METHODS – Harvey	29 | TWO VIEWPOINTS FOR REMOVAL OF SILICIC ACID FROM GEOTHERMAL WATER TO PREVENT SILICA SCALING – Yonezu
14:30	64 | CHARACTERISTICS OF FLOWS IN PERVASIVELY FRACTURED ANDESITES, ROTOKAWA GEOTHERMAL FIELD, NEW ZEALAND – Kissling	84 | THICK SILICIC VOLCANIC SEQUENCES AT MUARA LABOH AND RANTAU DEDAP GEOTHERMAL FIELDS, SUMATRA, INDONESIA: IMPLICATIONS FOR RESERVOIR ARCHITECTURE AND PERMEABILITY – Mussofan	36 | PROGRESS IN THE CALCIUM SILICATE TECHNOLOGY DEVELOPMENT TO PREVENT SILICA DEPOSITION AND FACILITATE ENHANCED ENERGY RECOVERY FROM A GEOTHERMAL RESOURCE – Johnston
14:50	73 | AN UPDATED CONCEPTUAL MODEL OF THE TOMPASO GEOTHERMAL FIELD USING NUMERICAL SIMULATION – Lesmana	95 | GEOCHRONOLOGY TO REFINE THE STRATIGRAPHY AND STRUCTURE OF THE ROTOKAWA GEOTHERMAL SYSTEM, TAUPO VOLCANIC ZONE, NEW ZEALAND – Milicich	39 | REMOVING SILICA FROM GEOTHERMAL WATER – RE–DESIGN OF THE PILOT PLANT AND INVESTIGATION OF OPERATION AT ELEVATED PRESSURE – Borrmann
15:10	74 | USE OF GRAVITY, MICROEARTHQUAKE, AND TRACER INJECTION TEST DATA IN CALIBRATING THE TIWI NUMERICAL RESERVOIR MODEL – Cinco	58 | SUPERHOT FLUIDS: THE ORIGIN AND FLUX OF NATURAL GREENHOUSE GASES IN VOLCANIC AREAS – Chambefort	27 | ONLINE GEOTHERMAL WELL STIMULATION AND SILICA DEPOSIT REMOVAL – Muller
15:30	**Afternoon Tea**		
	Session 3.1– Modelling and Simulation 3 **Lecture Theatre OGGB 4**	**Session 3.2 – Reservoir Characterisation** **Lecture Theatre OGGB 5**	**Session 3.3 – Silica & Corrosion 1** **Case Room 2**
16:00	98 | EXPERIMENTS WITH VORONOI GRIDS FOR GEOTHERMAL MODELS – Michael	16 | SEISMIC STUDIES OF GEOTHERMAL AREAS IN NEW ZEALAND – Savage	67 | MECHANISM OF SILICA DEPOSITION IN FORMATION AND THE MANAGEMENT OPTIONS INVESTIGATED IN THE LABORATORY STUDY – Siega
16:20	83 | NUMERICAL SIMULATION UPDATE OF DIENG GEOTHERMAL FIELD, CENTRAL JAVA, INDONESIA – Ashat	24 | NOVEL APPLICATION OF CONTINUOUS GRAVITY AND GPS TO UNDERSTAND EFFECTS OF LIQUID SATURATION CHANGES ON YIELDING DEFORMATION – Bromley	82 | FORMATION MECHANISM OF SILICA SCALE IN DIENG GEOTHERMAL POWER PLANT, INDONESIA – Juhri
16:40	86 | MODELLING GEOTHERMAL POWER GENERATION FROM THE WAIOTAPU – WAIKITE – REPOROA GEOTHERMAL FIELDS – Pauline	52 | DATA FUSION FOR GEOTHERMAL RESERVOIR CHARACTERIZATION – Gudjonsdottir	38 | MECHANISM AND KINETICS OF CASIL PRECIPITATION – Fraser
17:00	85 | CONCEPTUAL MODEL AND NUMERICAL SIMULATION UPDATE OF PATUHA GEOTHERMAL FIELD, WEST JAVA, INDONESIA – Ashat		56 | APPLICATIONS OF CALCIUM SILICATES DERIVED FROM GEOTHERMAL RESOURCES – Cairns
17:20 **19:00**	**Welcome Reception**		

Tuesday 26 November

9:00	**Housekeeping**		
9:20	**Keynote: Sara Montomoli, Enel Green Power** GEOTHERMAL EXPLOITATION IN ENEL GREEN POWER – A HISTORY OF SUSTAINABLE DEVELOPMENT AND NEW CHALLENGES FOR THE FUTURE		
10:00	**Morning Tea**		
	Session 4.1 – Drilling and above ground technology 1 **Lecture Theatre OGGB 4**	**Session 4.2 – Geothermal & Society** **Lecture Theatre OGGB 5**	**Session 4.3 – International Updates** **Case Room 2**
10:30	43 | INTEGRATED ENGINEERING ANALYSIS TO SUPPORT SUCCESSFUL UTILIZATION OF CASING DRILLING IN GEOTHERMAL WELLS – Mardiana	32 | MEDIA FRAMING ON SOCIAL ACCEPTANCE OF GEOTHERMAL DEVELOPMENT IN INDONESIA – Yogandari	Industry and Government Updates
10:50	62 | BREAKTHROUGH ON A ROTARY STEERABLE SYSTEM FOR GEOTHERMAL DRILLING IN A WEST JAVA FIELD – Agus	53 | VOLCANOES AS A GATEWAY FOR YOUNG PEOPLE TO THE GEOTHERMAL WORLD – Otero	Industry and Government Updates
11:10	49 | EXPERIMENTAL AND NUMERICAL STUDY OF GEOTHERMAL WELLBORE HEAT EXCHANGER IN ABANDONED GAS WELLS: A CASE STUDY FROM TAIWAN – Hsieh	70 | AN HOLISTIC APPROACH TO IMPACT ASSESSMENT: REVITALISING THE PRESENCE OF MĀORI VALUES FOR CULTURAL SUSTAINABILITY IN GEOTHERMAL DEVELOPMENT – Taute	Industry and Government Updates
11:30	8 | MODIFICATION OF UNIT 1 COOLING TOWER (CT) TO IMPROVE THE CT PERFORMANCE IN STAR ENERGY GEOTHERMAL (WAYANG WINDU) LTD – Zein	10 | GEOTHERMAL ENERGY AND ETHICAL RISK ASSESSMENT – Krieger	Industry and Government Updates
11:50	21 | COMMON CHARACTERISTICS OF PUMPED WELLS IN GEOTHERMAL POWER PROJECTS – Yearsley	5 | THE DIGITAL UPGRADE – A NEW OPPORTUNITY FOR GEOTHERMAL ORGANIZATIONS? – Rumberg	Industry and Government Updates
12:00	**Lunch**		
13:10	**Keynote: Novi Ganefianto, PT Supreme Energy** CURRENT STATUS AND FUTURE PLANNING OF PT SUPREME ENERGY GEOTHERMAL WORKING AREAS, INDONESIA		
	Session 5.1 – Drilling and above ground technology 1 **Lecture Theatre OGGB 4**	**Session 5.2 – Intyernational Projects** **Lecture Theatre OGGB 5**	**Session 5.2 – Geothermal Resources** **Case Room 2**
13:50	79 | PREDICTING SUCCESS OF WELL DISCHARGE AND AIR COMPRESSION OF TIWI WELLS USING AF/AC RATIO METHOD – Bravo	102 | A COMBINED APPLICATION OF HIGH–RESOLUTION THERMAL INFRARED AND MAGNETIC DRONE–BASED SURVEYS OVER LARGE AREAS FOR GEOTHERMAL AND ELEMENT EXPLORATION IN WESTERN CANADA – Eyre	15 | OHAAKI RESOURCE ASSESSMENT IN THE UNITED NATIONS FRAMEWORK CLASSIFICATION FOR RESOURCES (UNFC–2009) AND PROPOSAL TO CLASSIFY ALL NZ GEOTHERMAL SYSTEMS – Van Campen
14:10	13 | MANAGING THE CYCLING EFFECT ON WELL EPT–L/1 – Cici	18 | CLIMATE– AND WEATHER–RELATED FACTORS IN MAIBARARA GEOTHERMAL OPERATIONS – Delfin	101 | GREENHOUSE GAS EMISSIONS FROM NEW ZEALAND GEOTHERMAL FIELDS IN CONTEXT – Mclean

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14:30	23 | CONDENSATION INDUCED WATER HAMMER, NEW ZEALAND GEOTHERMAL STEAMFIELD PIPING CASE STUDIES – Koorey	63 | PERTAMINA GEOTHERMAL ENERGY BUSINESS OPERATION: AN UPDATE ON JOINT OPERATION CONTRACT – Gunawan	6 | STRATIGRAPHIC RESERVOIRS: A SIGNIFICANT FUTURE RESOURCE IN THE U.S IN ADDITION TO EGS AND UNDISCOVERED HYDROTHERMAL RESERVOIRS – Allis
14:50	40 | EXERGY ANALYSIS OF THE SOUTHERN NEGROS GEOTHERMAL POWER PLANT, PHILIPPINES – Bacus		59 | GEOTHERMAL: THE NEXT GENERATION – Chambefort
15:10	**Afternoon Tea**		
15:40	**Industry updates coordinated by the NZGA** **Room: Lecture Theatre OGGB 4**		
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18:30	**NZGW Conference Dinner** **THE WHARF**		
22:00			

Wednesday 27 November	
8:50	**Housekeeping**
9:00	**NZGA Welcome**
9:10 - 10:30	**Country and Government Updates**
10:30	**Morning Tea**
11:00 - 12:40	**Industry Updates – NZGA**
12:40	**Lunch**
13:30 - 15:00	Industry Updates – NZGA
15:00	**Afternoon Tea**
15:20 - 17:00	Industry Updates – NZGA

Abstracts

3 | MILK PASTEURIZATION USING LOW TEMPERATURE GEOTHERMAL FLUID IN DAUIN, NEGROS ORIENTAL, PHILIPPINES

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Keywords: *Geothermal Direct Use, Low-enthalpy, Lumped-System Analysis, Pasteurization*

A geothermal vat pasteurizer is presented to exploit geothermal energy for direct use in Upper Bulak, Dauin in Negros Oriental. This pasteurization system includes one main vat pasteurizer with an involute water guide. The pasteurizer is equipped with an agitator mechanism with four hemispherical propellers. The geothermal fluid is channeled through a pipe, and because of the involute pathway, the geothermal fluid flows in a circular motion through the small cylindrical reservoir. This drives the movement of the propellers causing the agitator to rotate inside the pasteurizer. Hence, this geothermal vat pasteurization system is an efficient tool to utilize the heat from the source and use the fluid movement to drive the agitator to stir the milk for maximum heat distribution.

A lumped system analysis is used to estimate the time the raw milk reaches the required temperature before clocking the milk for the pasteurization process. This analysis is verified by the actual recorded time of 3 minutes during the conduct of the study. The characteristics of the geothermal water in terms of temperature, pH, and the flow rate is studied. The characteristics of both the raw and pasteurized milk that uses the geothermal pasteurizer are analyzed. The results indicate that the geothermal resource can reach the required temperature and can hold it for the entire pasteurization process. The results of this study provide a good reference for geothermal direct use applications in the Philippines.

Poster

5 | THE DIGITAL UPGRADE – A NEW OPPORTUNITY FOR GEOTHERMAL ORGANIZATIONS?

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Keywords: *Digitization, Digitalization, Digital Transformation, Digital Utilization, Organizational Development*

Digitalization has been identified as an ongoing trend with significant effects on societies, associations and companies. The way these organizations deal with the fast development of SMAC (social, mobile, analytics, cloud computing) technologies can be a determining factor for their competitivity in the future.

Though digitalization is a scientific field since decades and not a new development, the current digital wave creates challenges and opportunities for the global Geothermal community.

The authors of the paper report on best practices and lessons learned from the digital transformation of the International Geothermal Association (IGA) and covers the many facets that digitalization may offer to other associations wanting to add value to their membership and to capitalise on the many opportunities the digital world offers. Amongst others the following transformative changes and its impacts will be presented:

- how new digital technologies changes the way members get informed, communicate and participate,
- how this changing behaviour requires a new value proposition with smart services and data access, while the same time volume and velocity of data generation increased significantly,
- how these aspects require a new organizational agility with digital operations, services, structures and mindsets.

The International Geothermal Association (IGA) is a worldwide organization that promotes and contributes to the geothermal research, development and utilization since 1988. Being a scientific, educational and cultural organization with non-political, non-profit and non-governmental status, the IGA aims introducing Geothermal to the world as one of the main renewable sources.

Session 4.2

6 | STRATIGRAPHIC RESERVOIRS: A SIGNIFICANT FUTURE RESOURCE IN THE U.S.

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Keywords: *stratigraphic reservoirs, sedimentary resources, heat flow, permeability, basins, Basin and Range, Cove Fort.*

If there is to be renewed growth in geothermal power generation in the U.S. that competes with the growth in wind and solar photovoltaic (PV) power, developments need to be on a scale of ~100 MW. Stratigraphic reservoirs are scalable because of the conductive thermal regime, and the predictable characteristics of the reservoir units on a basin scale once a successful confirmation well has been drilled. However, based on economic modelling by Mines et al. (2014), the target depth range for these reservoirs is 2 – 4 km and temperatures need to be at least 150°C to 200°C. Reasonable assumptions for reservoir and power station characteristics yield a levelized cost of electricity of 10c/kWh. If recent technological advances in drilling for tight oil and gas can be adapted then it should be possible to significantly reduce the cost and make geothermal more competitive. Deep, lateral groundwater flow in high-permeability stratigraphic units in the eastern Basin and Range Province has swept heat and lowered basin temperatures. Two examples from Utah are examined and demonstrate exploration strategies need to integrate subtle basin-scale groundwater movement with the thermal regime in order to identify the best regions for locating viable stratigraphic reservoirs. In view of the challenging time for new geothermal projects in the U.S, it is essential that government-funded research focus on development issues for both enhanced geothermal systems and stratigraphic reservoirs.

Session 5.2

7 | NEW ZEALAND'S COLOMBO PLAN PROJECTS TO DEVELOP INDONESIA'S GEOTHERMAL FIELDS IN 1971 AND 1975

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Keywords: *Geothermal exploration, productive fields, Java, Bali, Indonesia*

The aim of the New Zealand/Indonesian Geothermal Colombo Plan Project (1970) was to assess the geothermal potential of five selected geothermal fields on Java and Bali and to rank them for further development. The exploration of the five prospects were undertaken by several Indonesian/New Zealand field teams using geological, geophysical and geochemical surveys between 1971 and 1977. These were undertaken by Indonesian Volcanological Survey and New Zealand government experts from the DSIR. Four potentially productive fields were found: Kamojang, Darajat, Salak-Awibengkok, all located in Western Java, and Danau Bratan (Central Bali). The Cisolok-Cisukarame prospect was found not to be suitable for development.

The survey (and subsequent drilling) led to the discovery of three types of our geothermal systems: Type I: vapour-dominated (Kamojang and Darajat); Type II: liquid-dominated (Salak-Awibengkok and Danau Bratan); Type III: low temperature outflow system (Cisolok-Cisukarame). Halfway during the drilling project at Kamojang, the productivity of the first (small diameter; 6in./152mm) exploration wells at the end of 1974, led to the proposal seconded by New Zealand aid, to extend the Kamojang project. Pertamina came in to assist with the production drilling and contributed to the design of the power house starting in 1978 due to New Zealand's deteriorating financial aid in the late 1970s. The government of Indonesia, through Pertamina and PLN contributed some NZ$10 million towards civil works. The total project was estimated to be NZ$30 million.

Later developments of Darajat and Salak-Parabakti by US companies under licence by Pertamina, together with upgrading Kamojang, (110 MWe) produced a total electricity output of about 850 MWe. This paper is a recognition of the success of the 1970 Indonesian/New Zealand Aid project and its participants from both countries.

Session 1.1

8 | MODIFICATION OF UNIT 1 COOLING TOWER (CT) TO IMPROVE THE CT PERFORMANCE IN STAR ENERGY GEOTHERMAL (WAYANG WINDU) LTD

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Keywords: *air flow, Amarillo, cooling tower, gearbox, Marley, recirculation, Star Energy, velocity*

Unit 1 Cooling Tower (CT) in Wayang Windu Geothermal Power Plant has been operating since 2000. Extensive works have been conducted by Star Energy Geothermal (Wayang Windu) team in order to improve the performance of the CT while assuring excellent operational reliability. The first project in 2011 was replacing the CT fan stack with a higher version. Data from a Unit 1 CT performance test revealed a decrease of approach temperature by as much as 1.44°C, an increase of range temperature by as much as 1.92°C, and an increase of CT efficiency by as much as 5.17%. The impact was equivalent to a net generation improvement of 1.44 MW. The second project, carried out from 2014 till 2017, involved replacing the existing low reliability CT gearbox with a more reliable gearbox and increasing the number of fan blades. The CT upgrading project

improved the CT thermal performance and the impact was equivalent to a net generation improvement of 0.40 MW.

Session 4.1

10 | GEOTHERMAL ENERGY AND ETHICAL RISK ASSESSMENT

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Keywords: *geothermal, risk assessment, acceptable risks, ethics*

From ancient times, people have been exploring the planet for some useful materials. This search has been more than successful: coil, oil and gas became very important world's commodities. Their use however has not done any good to the ecological equilibrium. Today we are exploring other alternative energy sources and one of them – geothermal energy – presents the enormous undiscovered energy deposit our planet has to offer.

No matter what kind of resources we use, our continued reliance on the renewable energy should be safe first. Though replacing fossil fuels with geothermal could be beneficial in many ways, it could also lead to negative outcomes. It is in our responsibility to regulate the technology in an ethical way and assess the consequences so that welfare of the individuals and the society are considered.

The paper is based on a master thesis successfully defended at the Ruhr-University Bochum in Bochum, Germany in June 2018. The goal is to identify, analyze and evaluate the objective risks in different geothermal technologies according to their harm potential by means of historical evidence analysis and analog records methods. Risks are assessed regarding their causes, consequences and likelihoods for which the comparison-based evaluation is used. The research is embedded in the ethical framework: since geothermal risks are generally imposed on other people rather than personally taken the essential conditions of risk acceptability are characterized. The paper reveals what potential geothermal risks should we be aware of and which of them could result in graver harms. The outcome of the risk assessment makes it possible to answer the question what risks could be deemed acceptable from an ethical point of view and what not.

Session 4.2

11 | GEOTHERMAL ENERGY FROM PETROLEUM WELLS IN NEW ZEALAND: BENEFITS AND HURDLES

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***Keywords:** petroleum wells, heat extraction, Taranaki.*

Deriving geothermal energy from petroleum wells in New Zealand is in line with the government's initiative to reduce greenhouse gas emissions by 2030 and attain carbon neutrality by 2050. It is also a pragmatic progression for coping with the depletion of petroleum reserves in Taranaki. Onshore Taranaki contains 40% of petroleum wells in New Zealand, where deep wells can access temperatures as high as 150°C ± 20°C, based on estimated bottom hole temperatures (BHT), and 175-200°C based on solute chemistry. More than 20 countries have studied and considered petroleum wells as sources of geothermal energy and more countries are setting-up installations for direct heat use or power generation. The technical and economic hurdles, as well as different approaches to reservoir modelling should be considered for any petroleum to geothermal conversion. Some of the primary differences include the role of water in the reservoir; physical and geological properties including temperature, permeability, flowrates, and heat sources; surface installations; production time frames; fluid characteristics; and environmental impact. Harnessing geothermal energy from petroleum wells is at the nexus of two mature energy-related industries in New Zealand, with the requisite local expertise and international connections, so there is a high likelihood that such initiatives can progress in Taranaki from concept to working reality in a few years.

Session 1.3

13 | MANAGING THE CYCLING EFFECT ON WELL EPT-L/1

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***Keywords:** Cycling, multiple feed zone, throttling, well head pressure drop.*

The cycling effect is an impact that shows that the minimum pressure required by a well to remain stable in production is not achieved. The root cause of the cycling effect in a well is the presence of multiple feed zones which have difference pressure, enthalpy and permeability. This root cause can be concluded from data acquisition such as a PTS Shut-In survey and down-hole sampling. In the case of Well EPT-L/1, the cycling effect causes the well to not produce. It will always experience a pressure drop if produced with a minimum pressure of 8 barg in conditions of up to 60% throttling and when the pressure is less than 8 barg, the pressure in Well EPT-L/1 will slowly reduce. Thus, the operational pressure to produce the well should be a minimum of 8 barg.

Session 5.1

15 | OHAAKI RESOURCE ASSESSMENT IN UNFC-2009 FRAMEWORK AND PROPOSAL

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***Keywords:** geothermal, resource assessment,*

Ohaaki, regulation, resource management, sustainability

Ohaaki resource assessments are reviewed over its long exploration and production history. The recently IGA-adopted UNFC-2009 resource classification framework and geothermal specifications are used to categorize these resource assessments and analyse changes over time, in the context of changes to NZ regulations and electricity market.

With the lessons from such a review, a proposal is presented to use the same UNFC-2009 based method to classify all NZ/Waikato geothermal systems as a basis of future resource management. Historic data is used to illustrate this and a proposal is presented how to gather data for an update.

Session 5.2

16 | SEISMOLOGICAL STUDIES OF GEOTHERMAL SYSTEMS IN THE TAUPŌ VOLCANIC ZONE

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Keywords: *Microseismicity, Anisotropy, Brittle-ductile transition, Ambient noise, Temporal variations*

In the last decade, in partnership with Mercury NZ Limited (formerly Mighty River Power), Victoria University of Wellington postgraduate students have used seismic data from New Zealand's geothermal fields to elucidate the structure and geomechanical properties of several geothermal systems in the Taupō Volcanic Zone. Recent projects have focussed on the Rotokawa and Ngatamariki fields, but earlier studies looked at Kawerau.

Double difference earthquake locations reveal that under Kawerau the majority of seismicity is shallower (4 km maximum depth) than in the surrounding regions (6-7 km). This suggests that the major heat source is situated beneath the centre of the field and that at levels deeper than 4 km the ground is too hot to support brittle failure.

Between 2012 and 2015, matched filter methods doubled the number of earthquakes detected in Rotokawa and Ngatamariki to about 9000. The focal mechanisms of almost 1000 of those events were inverted to determine the prevailing stress field. At Ngatamariki, the new locations exhibit a strong spatio-temporal association with borehole drilling and stimulation. Areas of high b-values (a measure of the ratio of the numbers of small to large earthquakes) correspond to areas of elevated pore fluid pressure and a broad distribution of fractures. Focal mechanism inversion yields a normal faulting stress state with a NW/SE axis of minimum compressive stress (S_3), but distinct regions vary from the average. Shear wave splitting also yields NE/SW fast directions, consistent with the presence of stress-aligned cracks and NW/SE extension. Changes in delay time and Vp/Vs ratios correlate with changing volumes of production. Changes in isotropic shear velocity were measured from stacking noise cross-correlations. There were faster velocities in regions of injection, and gradual increases in shear-wave velocity from 0.06% to 0.08% over a year, but it remains difficult to distinguish the effects of rainfall changes and production. We observed abrupt decreases in velocity by as much as 0.07% in Ngatamariki immediately after regional and local earthquakes, which returned to normal over a period of several weeks.

Session 3.2

17 | GEOTHERMAL ENERGY UTILIZATION OF ABANDONED PETROLEUM INDUSTRY WELLS; CASE STUDY: THE POTENTIAL OF HOT WATER PRODUCTION IN TISZATARJAN HUNGARY

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Keywords: *Geothermal, direct use, abandoned petroleum industry well*

Abandoned petroleum industry wells can be harmful to the environment by effects such as the leakage of oil, natural gas and brine into soil and drinking water (Will Downey, 2016). Despite the possibility of several dangerous effects they still have some potential to be useful. One of the potential uses is the extraction of geothermal energy from this kind of well. By using an abandoned hydrocarbon well to extract geothermal energy, besides saving the environment, it also can save the cost of drilling for the project. The project cost can be reduced by up to 60% (Toth et al, 2019). However, this utilization technique requires several conditions such as a good thermal gradient. In Hungary due to the thin crust, the heat flow makes it possible to make use of geothermal energy. In the study area, the temperature of the sediment can reach 60-70°C with the thermal gradient of approximately 6°C/100 m (Less Gyorgy, 2011). Thus, the temperature will increase with depth (Jordan Hanania, Kailyn Stenhouse, 2015). The well in the study area has 2,794 m MD and it has five good aquifer zones from 867 m to 1310 m. Based on the theory and the uniqueness of the area, this abandoned hydrocarbon well meets the conditions for having geothermal energy potential. Due to those factors, the utilization of geothermal energy from this well can be achieved by mining the hot water. Based on calculations, the well can give a maximum temperature of hot water of approximately 70°C. Thus, the abandoned hydrocarbon well in the study area can be a productive geothermal resource, especially hot water production.

Session 1.3

18 | CLIMATE- AND WEATHER-RELATED FACTORS IN MAIBARARA GEOTHERMAL OPERATIONS

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Keywords: *Maibarara, Philippines, climate, weather, environment, geothermal operations.*

Implementing mitigating strategies of energy facilities to anticipated increases in extreme weather events and climate variability requires documenting which climatic factors affect facilities and understanding the process by which they impact specific equipment and operations. Such knowledge is vital if adaptations are to be effective in reducing potential losses in operational disruptions, business continuity and company profitability. In Maibarara, the effects of air temperature, wind patterns, rainfall, thunderstorms, and typhoons on two relatively new generating units – the 20MW Maibarara-1 (M1) commissioned in 2014 and the 12 MW Maibarara-2 (M2) in 2018 – are documented.

Though far from exhaustive, our study shows that increases in air temperature, even when seasonal, have the most direct, continuous, and substantive consequences, especially on their impact on cooling water and condenser performance. Extreme weather events like severe thunderstorms and typhoons also cause disruptions that can be significant but in a far less sustained manner. Moreover, the effects

of weather and climatic factors on geothermal operations are mediated by the physical lay-out of the Maibarara project and its general environmental setting.

Session 5.2

19 | INTRODUCING THE VOLSUNG GEOTHERMAL SIMULATOR: BENCHMARKING AND PERFORMANCE

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Keywords: *Volsung, Simulator, TOUGH2, Benchmarking, Performance, Parallel Computing*

In this paper we introduce the Volsung Geothermal Reservoir Simulator software package. At its core is a very fast numerical reservoir simulator based on the finite volume method (FVM). Its computational backbone is based on a hybrid method, where most of the numerically intensive calculations are performed on a CPU and only the memory bandwidth-limited linear solve operations are outsourced to an inexpensive, consumer-grade graphical processing unit (GPU). This approach enables vast performance enhancements when compared with traditional CPU-based systems while avoiding the hardware and software complexity of distributed memory architectures found in other high-performance-computing solutions.

We have validated Volsung versus test models from the Stanford 1980 Geothermal Model Intercomparison Study. In addition, we created simple test models to compare Volsung to results from the TOUGH2 simulator for selected problems of interest. Tests include a dual-porosity simulation problem which uses the Multiple Interacting Nested Continua (MINC) formulation, simulations using different equations of state (water, non-condensible gas and salt) and simulation runtime comparison. In all cases Volsung successfully reproduced the expected model results and achieved large speedups versus TOUGH2 for production size models.

Session 1.1

20 | INTRODUCING THE VOLSUNG GEOTHERMAL SIMULATOR: FEATURES AND APPLICATIONS

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Keywords: *Volsung, modelling, TOUGH2, wellbore, surface network, simulation*

In this paper we describe features and applications of the Volsung Geothermal Reservoir Simulator software package. Volsung includes a reservoir simulator, a wellbore model, a surface network simulator and a 3D graphical user interface (GUI) for building models, running simulations and visualizing model outputs. It is designed to make it easier to use numerical models in the decision process for managing geothermal fields. Volsung reduces model development times, simplifies the modelling process and enables sophisticated simulations designed to meet the modern day needs of geothermal operators. This paper describes features of Volsung that underlie these improvements, including: grid generation, conceptual model implementation, coupled wellbore and surface network simulations, data visualization, calibration to microgravity, modelling tracers (including salt and non-condensible gas), automatic steady-state detection, modelling faults and remote simulation with GPUs. These features and planned future developments are discussed in the context of how to get better value from geothermal reservoir modelling efforts.

Session 1.1

21 | COMMON CHARACTERISTICS OF PUMPED WELLS IN GEOTHERMAL POWER PROJECTS

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Keywords: *fluid utilization, productivity index, allowable drawdown, gas breakout, static head, dynamic head.*

Pumped wells in geothermal power projects share common characteristics, including the requirement for sufficient dynamic water level in the well above the pump to preclude gas breakout on the suction side of the pump. This dynamic water level is a function of resource temperature, static water level, flowrate, and well productivity, the interrelationship for which is explored in this paper.

A broad overview of existing pumped-well geothermal power projects is presented, including the range of fluid utilization (flowrate divided by power output). Discussions are presented on pump hydraulics and the influence of resource temperature and static water level on allowable drawdown and the corresponding minimum well productivity indices for a given power output.

The overarching purpose of this paper is to present together in one place the key elements of geothermal pumped wells that will aid the reader in understanding fundamental characteristics of pumped wells in existing power projects as well as potential expansions or greenfield sites.

Session 4.1

23 | CONDENSATION INDUCED WATER HAMMER, NEW ZEALAND GEOTHERMAL STEAMFIELD PIPING CASE STUDIES

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Keywords: *Condensation induced water hammer, piping.*

The production and transport of steam and hot water from geothermal fields needs careful design and operational management to avoid condensation induced water hammer (CIWH). CIWH occurs when a steam space collapses upon mixing with cooler steam condensate or water. The resulting hammer event can be catastrophic. This paper details a number of cases where CIWH has occurred in New Zealand geothermal fields. Causes, events, and risk mitigations are discussed.

Session 5.1

24 | NOVEL APPLICATION OF CONTINUOUS GRAVITY AND GNSS TO UNDERSTAND EFFECTS OF LIQUID SATURATION CHANGES ON YIELDING DEFORMATION

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Keywords: *deformation, subsidence, geophysics, gravity monitoring, Tauhara.*

Continuous microgravity monitoring and repeated micro-gravity measurements have been trialled at the centre of a site of anomalous deformation in the Wairakei-Tauhara geothermal system. When combined with continuous data from GNSS (GPS), horizontal strain data across

a monitored crack, and subsurface pressure-temperature data from shallow monitor bores, the gravity data provides additional information on possible mechanisms that may be driving changes in localized deformation rates over time.

The overall shape of the deformation anomaly remains unchanged, while rates continue to vary smoothly with time. Deformation (i.e. subsidence) mechanisms involving changing conditions in two boiling (2-phase) aquifers, at about 50-80m and 125-175m depth respectively, are postulated. An additional driving mechanism involving incremental yielding and repeated load changes (from passing trucks) is also explored.

Highly compressible hydrothermal clays are hosted within a buried hydrothermal eruption crater, which is ~200m deep near the centre of the deformation zone (based on continuous drill-core) and inferred to be ~200m wide (based on Geerstma fitted parameters to its shape). Sliding on the clay-lined crater walls may account for the shape consistency over 20 years. Significant transitions in clay yielding parameters (yield stress) and pressure decline from cooling groundwater inflow at different depths within the upper groundwater and intermediate-level boiling aquifers, can account for the observed compaction rate variations. Transient loading changes may also partly explain the ongoing deformation through incremental yielding.

Session 3.2

27 | ONLINE GEOTHERMAL WELL STIMULATION AND SILICA BASED DEPOSIT REMOVAL

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Keywords: *Online Chemical Cleaning. Silica Scaling, Geothermal Well Stimulation,*

The blocking of reinjection wells by silica based deposits reduces well permeability. This can limit the production of the geothermal power plant and is a major cost to the plant owners to remedy. Conventional well stimulation techniques usually all require the well to be taken out of service and have other disadvantages including significant health & safety risks, high cost of implementation, corrosion and well stressing. An alternative approach where the well does not need to be taken out of service has been developed. The solution combines chemicals and application techniques, derived from understanding how scaling deposits form, and discerning deposition pathways specific to the well, brine chemistry, temperatures, and kinetics. This synthesis facilitates the formulation of tailored treatment chemicals that react with the geothermal silica scale at temperature. Significant and sustained restoration of well permeability has been observed in a number of applications using this new technique and it thus offers the industry an alternative solution that has substantial benefits over traditional approaches.

Session 2.3

29 | TWO VIEWPOINTS FOR REMOVAL OF SILICIC ACID FROM GEOTHERMAL WATER TO PREVENT SILICA SCALING

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Keywords: *Removal of silicic acid, Geothermal water, Silica scale, Prevention method*

As a prevention method of silica scales at geothermal power plants, removal of silicic acid from geothermal water was studied from two chemical viewpoints: removal of supersaturated polysilicic acid and removal of all monosilicic acid by the addition of cethyltrimethylammonium bromide (CTAB) and calcium chloride accompanying pH adjustment, respectively. As the polymerization of silicic acid proceeds and polysilicic acid grows, the removal efficiency of polysilicic acid is higher. At the addition of 10^{-4} M CTAB, most of the polysilicic acid was removed. For removal of monosilicic acid, the addition of the same amount of Ca^{2+} as monosilicic acid and the following adjustment to pH 12 around 90℃ is the best condition to precipitate all of silicic acid as a calcium silicate hydrate from geothermal water. In addition, aluminum, which affects the formation of silica scale, is also removed by the both methods.

Session 2.3

32 | MEDIA FRAMING ON SOCIAL ACCEPTANCE OF GEOTHERMAL DEVELOPMENT IN INDONESIA

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Keywords: Social Acceptance, Public Perception, Media, Geothermal Development.

Social aspect is one of the challenges faced in accelerating geothermal development in Indonesia. Media is one way to find out public opinion about Indonesia's geothermal social acceptance. The role of the media is to disseminate and even educate about business development and government policies and interact with the aspirations of the community to achieve common interests between the central government, regional governments, local communities and geothermal developers. Media users have their respective opinions so have the potential to build one or several communities. Communities that have the same opinion will potentially develop public opinion that has an influence and even impacts on the image and reputation of the development of geothermal energy.

This paper aims to analyze the thoughts and behavior of local people regarding the development of geothermal energy through articles in the media, found through media monitoring, to evaluate the spread of news about geothermal energy in order to have a positive image in the eyes of the people so that the acceleration of geothermal development in Indonesia can be achieved.

Session 4.2

33 | THE GEOSCIENTIFIC UNDERSTANDING OF THE UTAH FORGE EGS SITE

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Keywords: *Utah FORGE, EGS, geology, groundwater hydrology, heat flow*

The current geoscientific understanding of the Utah FORGE site has been obtained from synthesis of numerous independent datasets, including new geological, geophysical, and geochemical surveys, plus drilling and logging of three new wells, the deepest being 58-32 which penetrates to 7536 ft (2248 m) depth.

The stratigraphy consists of two broad rock types, comprising basin fill sediments and crystalline basement rocks mostly made of Miocene granitoids. The contact between these rock types forms an inclined plane, which dips ~20° west and which likely represents a large-scale normal fault that has been rotated during extension. Anomalous heat flow comprises localized hydrothermal convection east of the Opal Mound fault and regional conduction (~70°C/km, well 58-32) west of the Opal Mound fault. The modern stress regime is extensional, characterized by normal faulting and a maximum horizontal compressive stress oriented approximately N25°E.

Well 58-32 penetrated the basement at 3176 ft (968 m), which consists of granitic rock containing plagioclase, K-feldspar, and quartz. Between 1700 and 7536 ft (518-2248 m), the temperature profile increases linearly with a maximum bottom hole temperature of 197°C. The FMI log imaged ~2000 natural fractures, with predominant north-south, east-west, and northeast-southwest orientations that strongly resemble fracture patterns exposed in the Mineral Mountains.

Analysis of about 100 thermal gradient and deep exploration holes show how convective and conductive heat transfer are partitioned. Convective heat transfer is a small-scale feature restricted to Roosevelt Hot Springs, whereas conductive heat transfer is a large-scale feature that is regionally developed in the crystalline basement rocks in and around the EGS reservoir. The groundwater hydrology and chemistry reflect the thermal structure with hydrothermal upflow being confined to east of the Opal Mound fault. Where the rising hot water gets to shallow level, it forms a westward outflow zone that disperses down the hydraulic gradient through shallow alluvium.

Session 1.2

34 | ORIGIN AND AGE OF FLUIDS AT THE CERRO PABELLÓN GEOTHERMAL SYSTEM, NORTHERN CHILE

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Keywords: *Cerro Pabellón, Andean Cordillera, Chile, fluid geochemistry, stable isotopes, dating.*

The Cerro Pabellón geothermal system in the Central Andean Volcanic Zone hosts the first geothermal power plant in South America (48 MW), and is located in northern Chile at 4500 m a.s.l. The geothermal area is hosted within a NW-SE graben structure, and is defined as a blind high-enthalpy geothermal system. Here we present the results of a geochemical and isotopic study that aims to understand the origin and age of the geothermal fluids at Cerro Pabellón. Brine and condensate samples obtained from production wells were analyzed for dD, d18O and d13C. In addition, apparent ages of the geothermal fluid samples were constrained using 3H and 14C methods. dD-d18O values indicate a meteoric origin of fluids, which probably underwent fluid-rock interaction at temperatures of about 250°C. An andesitic water component can be inferred considering a lighter meteoric endmember. d13C values are also consistent with a magmatic input on fluids for the gaseous components. Tritium (3H) and radiocarbon (14C) analyses were carried out to assess the age and residence time of geothermal fluids. Taking into account the inherent limitations of these methods, a probable age of at least several thousands of years is estimated. These results should be expanded and complemented with further data to better understand the recharge dynamics of the Cerro Pabellón system and evaluate the long-term sustainability of the power plant.

Session 1.2

36 | PROGRESS IN THE CALCIUM SILICATE TECHNOLOGY DEVELOPMENT TO PREVENT SILICA DEPOSITION AND FACILITATE ENHANCED ENERGY RECOVERY FROM A GEOTHERMAL RESOURCE

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Keywords: *Geothermal, separated water, nanostructured calcium silicate, silica sinter, binary, heat exchanger, enhanced energy recovery, fertilizer, building, paper.*

We are continuing to successfully develop and implement our proprietary nanostructured calcium silicate, CaSil, technology at pilot plant scale to demonstrate how we can prevent the polymerisation and precipitation of silica from separated geothermal brine supersaturated in dissolved silica, which undesirably results in the formation of intractable silica sinter deposits in pipes, heat exchangers and reinjection wells. Our objective is to provide an attractive alternative approach and new technology to obviate the silica deposition problem and at the same time enhance the amount of heat energy recoverable and electricity generated in binary cycle plants, as well as reducing maintenance costs.

Our approach captures the silica entities dissolved at supersaturated levels in geothermal brine following steam/water separation by precipitating a proprietary nanostructured calcium silicate material, before these entities can polymerise, precipitate and deposit as an intractable sinter. The calcium silicate particles remain suspended in the brine flow and do not form such a sinter. Silica deposition is avoided. This enables binary plant heat exchange temperatures, considerably below those currently determined by the silica saturation index, to be used without the risk of silica deposition. The recoverable heat energy and electricity generated can be enhanced accordingly.

The calcium silicate particles are recovered continuously in a proprietary separator to provide CaSil products as a concentrated slurry, or with further processing as a filter cake or dry powder, depending on the application. Following efficient CaSil particle separation, the resulting cooled geothermal brine exiting the binary plant heat exchangers can be reinjected without risk of silica deposition.

By controlling the chemistry, different CaSil products can be produced. We are progressing CaSil applications in the building, paper, coatings, absorbent, mining and environmental remediation industries.

The presentation will provide an overview of our pilot scale implementation of the CaSil technology and calcium silicate applications development work.

Session 2.3

38 | MECHANISM AND KINETICS OF CASIL PRECIPITATION

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Keywords: *Calcium silica hydrate, silica formation, scaling prohibitor, Wairakei*

Silica formation is a problem in geothermal power generation from wet steam resources, especially in binary plants. Our proprietary method has been successfully proven in removing silica by forming nano-structured calcium silicate hydrate (CaSil) at pilot plant scale. CaSil particles do not adhere to pipes and can be removed prior to re-injection to provide a useful product.

The CaSil process has shown to be effective in our pilot plant located at the MB Century site and sourcing brine from the Wairakei binary cycle power plant, Taupo, New Zealand. If this process is to be applied widely, the kinetics and mechanism of the CaSil precipitation need to be fully understood to optimise the process for different brine compositions and recovery procedures.

The precipitation reaction of our proprietary CaSil is facile and difficult to monitor, as there is no consistent accompanying pH or colour change. Using batch methods and filtration, combined with AAS, UV-Vis spectrophotometry and SEM, we investigated the Ca to Si ratio in the filter cake product and residual filtrate generated from reaction mixtures using different SiO_2 and Ca concentrations, different Ca to Si ratios and being produced at different temperatures.

Our results so far showed that the CaSil forming reaction is robust and leads to useful and recoverable products under a variety of different synthesis parameters. CaSil precipitation is preferred over SiO_2 formation in most typical plant operating ranges therefore it provides a proprietary way of capturing dissolved silica species before a problematic silica deposition can take place.

Session 3.3

39 | REMOVING SILICA FROM GEOTHERMAL WATER - RE-DESIGN OF THE PILOT PLANT AND INVESTIGATION OF OPERATION AT ELEVATED PRESSURE

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Keywords: *Scale formation, silica scale, silica, calcium silicate hydrate, nano-structured calcium silicate hydrate, calcium carbonate, calcite, calcite scale, geothermal energy.*

The nano-structured calcium silicate hydrate (CaSil) technology has been developed as a solution for the formation of silica scale from geothermal brine. It has been matured from laboratory scale to pilot plant stage. The CaSil technology is successful in reducing silica in geothermal water to safe usage and re-injection levels, even at low temperatures.

However, while the initial version of the pilot plant built was useful as a proof of concept, it had several shortcomings. Namely it was work intensive, allowed little control over the products collected, and the separation process for recovery of CaSil from the brine was only designed to work at atmospheric pressure. Work on the first proof of concept plant proved that the process is very sturdy; none of the shortcomings had any significant impact on the plant operation.

In this paper we present our pathway towards the next iteration of pilot plant, which will address many of the issues encountered in the old plant. We are also outlining further research towards using the separator technology under elevated pressure.

Session 2.3

40 | EXERGY ANALYSIS OF SOUTHERN NEGROS GEOTHERMAL FIELD, PHILIPPINES

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Keywords: *Exergy, Utilization efficiency power plant, Southern Negros, Reservoir Modeling.*

Exergy analysis is important for identifying the sources of ineffeciency in a thermal process and for determining options for optimizing the system (Szargut et al., 1988). In a common geothermal power plant set-up, the overall second law (exergy/utilization) efficiency of the process is obtained from the actual electric power generated by the available exergetic power from the produced geothermal fluids at the wellheads.

This work calculates the second law efficiency of the geothermal system using exergetic power from the geothermal reservoir, instead of the wellhead. In Southern Negros Geothermal Project (SNGP), the utilization efficiency is 28.8 % based on an available exergy of 670 MWe at the reservoir. Reservoir parameters that are used for exergy analysis are obtained through numerical reservoir modeling. An optimization and sustainability assessment of the resource shows that highest utilization efficiency (geothermal heat source) is obtained at a 190 ºC reinjection temperature.

Session 5.1

42 | AN UPDATE ON THE WAIWERA GEOTHERMAL FLOW SIMULATOR: DEVELOPMENT AND APPLICATIONS

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Keywords: *Reservoir models, numerical modelling, flow simulator*

Waiwera is a new open-source, parallelised geothermal flow simulator, developed initially as part of the Geothermal Supermodels research programme. Recent progress on Waiwera development has included implementation of a parallelised MINC method for simulating fractured media, a zone system for easier specification of model parameters over designated parts of the model mesh and user-customizable simulation output including output from sources. Waiwera has adopted a new, modern build system and also uses a completely new unit-testing system, enabling easy installation and testing on a range of platforms.

As well as describing these new features we also demonstrate Waiwera's performance on test problems and geothermal reservoir models.

Session 2.1

43 | INTEGRATED ENGINEERING ANALYSIS TO SUPPORT SUCCESSFUL UTILIZATION OF CASING DRILLING IN GEOTHERMAL WELLS

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Keywords: *casing drilling, static modeling, dynamic modeling, geothermal*

Casing drilling has become a common operation for drilling a well nowadays. Instead of using a drill pipe to transfer the energy from the surface to the drill bit, this operation uses casing, so when the bit reaches the end of the section, the casing is already there to protect the well.

One of the problems in drilling a geothermal well in Indonesia is the difficulty of running in-hole the 13 3/8-in casing after drilling a 17 1/2-in section. The openhole exposure may trigger the wellbore to collapse, creating an obstruction to conveying the casing to the final depth. To solve this problem, a nondirectional casing drilling technology was proposed as the solution. The main component of this technology is the drillable alloy PDC casing bit, which is attached to a standard casing that is rotated at the surface. The casing can be fully rotated while applying weight to cut through the obstruction. A comprehensive engineering analysis was performed prior to the job to support the operation.

The casing drilling system successfully set the 13 3/8-in casing 314 m deeper than the initial point of the casing running obstruction. The drilling and reaming capability of the casing bit helped in cutting through all the formation filling the predrilled hole. The cementing process was executed well, with good integrity to the surface. Since then, this operation has become an effective standard practice for our team and has been performed in more than eight wells.

As a way forward, this paper also provides a feasibility study of a fully directional casing drilling technology to be applied in geothermal wells to improve the drilling efficiency. This study includes the readiness of the tools and main engineering aspects: hydraulics and mechanical (torque and drag, casing wear, fatigue, pipe stress, and vibration).

Session 4.1

44 | LEAPFROG 3D TEMPERATURE DISTRIBUTION BASED ON TOUGH2 NUMERICAL MODELLING: A NEW APPROACH

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Keywords: *Leapfrog Geothermal, TOUGH2, Numerical Modelling, Atadei Geothermal Field*

Atadei geothermal prospect area is located in Lembata Regency, East Nusa Tenggara, Indonesia. The estimated reservoir temperature based on ammonia geothermometer is about 221°C, with the upflow zone in three separate locations, namely: Watuwawer, Lewo Kebingin, and Lewokeba. The earlier exploration stage produced minimal subsurface data. Nevertheless, an interpretation of subsurface conditions and the lateral extent of the geothermal area was developed by previous researchers. This includes an interpretation of reservoir geometry; the fluid contained (i.e., steam caps formation), fluids flow pattern, and some structural geology that may control permeability and reservoir depth. Based on these published data, we have created a TOUGH2 numerical model of Atadei geothermal field to add substantial information regarding the reservoir characterization and to avoid inaccurate interpretation during the early exploration stage. This paper aims to explore a new approach regarding integration between TOUGH2 and Leapfrog Geothermal. Reservoir simulation results using TOUGH2 numerical modeling are then integrated into the Leapfrog Geothermal in order to get a more robust 3D model of the temperature distribution of the Atadei geothermal field.

Session 2.1

45 | THE MATERIAL CORROSION TEST ON PH ADJUSTMENT CONDITION BY ACID AT GEOTHERMAL FIELD IN JAPAN

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Keywords: *material corrosion rate, two-phase fluid, acidic fluid, pH, Cr equivalent, carbon steel*

We carried out a pH adjustment test at the acidic hot water line at Kakkonda geothermal field in November 2017. And we compared the results with the material corrosion prediction equation using a Cr equivalent amount, as proposed by Kurata et al. (1992).

In the field test, the temperature was 145 ° C, the initial base case pH was 5.15, and then the pH was adjusted to 3 and 4 with sulfuric acid or hydrochloric acid. The test duration was 5 hours and K-55, TN80SS, TN80Cr13 and TN110Cr13S were used for the corrosion test. After the corrosion test, antimony and arsenic scales were attached to the test material and the corrosion rate was calculated after removing the scale.

According to the prediction equation, the corrosion rate at pH 4 was about 2 times that at pH 5.15 and 3 to 4 times that value at pH 3. But the measured value at pH 4 was about 1.2 to 1.6 times that at pH 5.15. And at pH 3, carbon steel and low alloy steel showed a high corrosion rate, but stainless steel showed lower values. The corrosion rate in the case of the addition of hydrochloric acid was higher than for sulfuric acid.

Session 2.3

46 | SUBSURFACE ALTERATION AND 3D MODELLING IN ASAL-RIFT GEOTHERMAL FIELD, DJIBOUTI.

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***Keywords:** Asal-rift, Dalha basalt, Stratoid series, Asal series, quartz index, 3D modelling.*

The study area (Asal-rift geothermal field) is one of the most prosperous geothermal fields and tectonically active area in Djibouti. Almost all of the studied area is covered by volcanic rocks, Thermal manifestations are found in the area. This paper describes the result of X-ray diffraction mineralogical analysis in order to characterize hydrothermal processes and thermal evolution using cutting samples from new geothermal wells (three directional wells).

The formation of hydrothermal alteration minerals is usually dependent on the temperature, permeability, pressure, fluid composition and the duration of hydrothermal activity. The lithologic encountered succeed from oldest to youngest; 1) Dalha basalt Series, this unit consists of a sequence of lava flows estimated to have been formed between 8.9 to 3.8Ma, 2) Afar Stratoid composed mainly of basalt, which as formed between 4 to 1Ma, 3) Asal Series, less than 1Ma consisting of porphyritic basalt, scoriaceous basalt and hyaloclastite in the southeastern part of Asal-rift geothermal field. Mineralogical examination revealed six zones of hydrothermal alteration downward from unaltered zones, followed by smectite zones, mixed layer zones, chlorite zone, chlorite-epidote zone and chlorite-actinolite zone. The hydrothermal alteration zoning with increasing depth resulted from interaction of geothermal fluids with the basaltic host rock.

Three dimensional magnetotelluric (MT) inversion of Asal-rift using leapfrog geothermal was performed to obtain the resistivity structure on the field. The result of the interpretations shows three main resistivity structures. Thin and high resistivity layer is present at the top followed by low resistivity (conductive cap), below there is a high resistivity layer (resistive core).

Session 1.2

47 | COLOMBIA – A GEOTHERMAL OPPORTUNITY

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***Keywords:** Colombia, New Zealand, cooperative relationship, geothermal potential, raise awareness, capacity building.*

Colombia has increased its interest in using geothermal resources as part of the solution for energy transition. This is motivated by clear evidence of considerable geothermal potential for power generation and the existence of low and medium enthalpy systems as possible source for direct use and other uses. The Colombian geological and tectonic setting facilitates the presence of geothermal systems associated with volcanoes and sedimentary basins. Numbers highlight the geothermal potential in Colombia. There are at least 20

active volcanoes with hydrothermal features and geothermal gradients from oil wells reveals values up to 65°C/km. Preliminary estimations show that about 20% of energy demand could be supplied using geothermal resources. These numbers contrast with the use of low temperature resources limited to bathing and the absence of geothermal power generation in Colombia. Currently, electricity generation capacity comprises approximately 70% hydro and 30% fossil fuels, such as natural gas and coal. These facts certainly make Colombia a great geothermal opportunity.

New Zealand and Colombia has strengthened their cooperative relationship in the recent years. An example of this is the crucial role New Zealand played as a supporter of the peace agreement that ended about sixty years of civil war in Colombia. This is now bringing access to unexplored geothermal areas and an atmosphere convenient to develop geothermal projects. Today, the challenges lie mainly in creating a legal and regulatory framework to incentivate geothermal projects, and taking actions for raising awareness about the benefits of geothermal uses and capacity building around geothermal. Transfer of experiences, knowledge and technology between New Zealand and Colombia in geothermal development could be significant for Colombia to become a world-class geothermal country.

Poster

48 | THE CHARACTERISTICS OF HYDROTHERMAL ALTERATION AT STEAMING GROUND IN THE NORTHEASTERN PART OF TATUN VOLCANO GROUP, TAIWAN

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Keywords: *geothermal, silicified rock, fluid inclusion, sulfur isotope, Tatun*

Geological and geochemical research was conducted to clarify characteristics of hydrothermal alteration of steaming ground located near Mt. Huangtsui, northeastern part of Tatun Volcano Group.

Steaming ground has been altered by acidic hydrothermal alteration to form silicified rocks, which are massive at the Sih-Huang-Ping (SHP) and occurred along NE trending fault zone in the Huang-Shan (HS). The fault zone at the Huang-Shan is accompanied by quartz veins. Alunite zones are developed surrounding the silicified zones, especially at Huang-Shan. The sulfur isotopic ratio of alunite from the Huang-Shan is high and indicates a hypogene origin. Although the hot springs from the Sih-Huang-Ping are steam-heated water at present, volcanic acid fluid with Cl-SO4 type is present in the Huang Shan.

The fluid inclusion temperatures of quartz from hydrothermal breccia at the Huang-Shan show boiling and higher homogenization temperature whereas those from quartz veins show boiling but lower temperatures.

Session 1.2

49 | EXPERIMENTAL AND NUMERICAL STUDY OF GEOTHERMAL WELLBORE HEAT EXCHANGER IN ABANDONED GAS WELLS: A CASE STUDY FROM TAIWAN

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Keywords: *Abandoned oil and gas well, Geothermal energy, Numerical simulation, Wellbore heat exchanger*

Deep abandoned gas wells can be retrofitted to convert into geothermal energy extraction wells. For example a geothermal wellbore heat exchanger (GWHE), a closed-loop geothermal energy extraction system, can be used to harvest the heat energy from a high-temperature sedimentary rock formation. The purpose of this study is to investigate the performance of the GWHE system in a deep abandoned gas well by using a field experiment and numerical simulation.

A three-thousand-meter deep abandoned gas well located in northwestern Taiwan is selected to conduct a field experiment of the GWHE. This test well is retrofitted by a workover job to ensure the wellbore integrity. The tubing used for the GWHE system is coated with an insulation material in order to avoid heat loss in the outflow. The field test successfully collects experimental profile of the output temperature. The experimental data is used for the history matching in the numerical study.

A numerical model is built based on the configurations of the field experiment. A thermal simulator, STARS, is used in this study. The numerical model is validated by matching the experiment data from the field test. After the history match is done, the validated model is obtained and can be used to predict the performance of the GWHE system.

Our simulation results show rhat the performance of the GWHE system is strongly sensitive to the pumping rate, the formation temperature gradient and the formation temperature. The high-temperature sedimentary rocks can continuously contribute heat energy to the GWHE system even though the output water temperature has a slow decline.

Session 4.1

51 | ASSESSING FLUID FLOW IN LOW-ENTHALPY GEOTHERMAL FIELDS – AN EXAMPLE FROM THE WHATAROA VALLEY, SOUTH WESTLAND, NEW ZEALAND

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Keywords: *heat flow, thermal conductivity, thermal diffusivity, radiogenic heat productivity, geothermal gradient, fluid flux, permeable fractures, Alpine Fault.*

Geothermal production in New Zealand is confined to high-enthalpy fields in the central North Island. The rest of the country would benefit from increased attention to low-enthalpy fields for direct use. The Whataroa Valley in South Westland is an example of a non-volcanic area with a high geothermal gradient (125 ± 55°C km^{-1}) and heat flux (up to 460 mW m^{-2}), produced by uplift along the Alpine Fault and the combined effects of rock and groundwater advection.

Laboratory measurements show that the thermal properties of the schist bedrock in the hanging-wall of the Alpine Fault cannot by themselves account for the subsurface temperatures in the Whataroa Valley. Rather, the anomalously high heat flow is likely caused by fluid circulation. A new wavelet-based method of identifying anomalies in temperature logs and correlating them between logs acquired at different times during drilling of the 893 m-deep DFDP-2B borehole in the Whataroa Valley allows the identification of fractured zones and implies fluid fluxes of order of 10^{-7} to 10^{-6} m s^{-1}.

A fibre-optic cable in DFDP-2B has also been used to study post-drilling thermal equilibration. Variations about the steady-state temperature profile reflect large-scale flow patterns. Indications of temperature changes of ~2°C following regional seismicity imply that fractured reservoirs are sensitive to large-magnitude (>M6) earthquakes.

The approaches to determining the hydraulic properties of fracture zones that we have developed in the Whataroa Valley could be used to assess the thermal state of other low-enthalpy geothermal fields. Laboratory measurements of thermal conductivity provide the baseline for assessing the conductive component of heat flow. Filtering signals from downhole temperature measurements discriminates long-wavelength anomalies (10^1 to 10^2 m) as aquifers and short-wavelength anomalies (10^0 m) as individual fractures. By analysing measurements acquired following a thermal disturbance, the fluid flux in these fractures can be quantified.

Poster

52 | DATA FUSION FOR GEOTHERMAL RESERVOIR CHARACTERIZATION

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Keywords: *Geologic modeling, Rock properties, Gravity data, Bayesian inference, Krafla Iceland.*

This study performs Bayesian inversion of geophysical (gravity) data to generate probabilistic 3D subsurface models. Probabilistic models describe the uncertainty of model predictions, which is beneficial for managing risk

during decision making such as well position targeting. We select Krafla geothermal system in Iceland as a case study for the application of three-part framework. The method combines a prior geologic model of the area based on primary geologic data obtained from wells, statistical analysis of petrophysical properties (density and porosity) based on available databases and additional measurements, as well as available gravimetric measurements data. A Markov chain Monte Carlo sampling scheme, implemented in the geological modelling software GeoModeller, is used to invert for subsurface lithology and density. Due to the non-uniqueness of gravity data, many possible models of subsurface density distribution could account for the measured data. The a priori uncertainty of the lithological model largely controls the uncertainty of the posterior results for lithology and density. This shows that reliable prior geological constraints are important in Bayesian inversion. In this case, the lithological model consists of layers of high-density lava flows and low-density hyaloclastites underlain by high-density basement intrusions. Rock density depends also significantly on the extent and type of hydrothermal alteration particularly for hyaloclastites where density tends to be higher with increased extent of alteration. More realistic prior density probability density functions (pdf's) especially accounting for hydrothermal alteration for hyaloclastites result in more realistic model output.

Session 3.2

53 | VOLCANOES AS A GATEWAY FOR YOUNG PEOPLE TO THE GEOTHERMAL WORLD

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***Keywords:** outreach, evaluation, exhibition, volcanoes, youth, Chile*

The Andean Geothermal Center of Excellence (CEGA) Outreach Unit has been testing different ways to bring the issue of geothermal energy to different audiences for years, with a focus on young people and the media. Our work includes books, videos, talks, murals, exploration kits for girls and more. During the first semester of 2019, CEGA developed a free interactive exhibition about volcanoes in one of the main subway stations in Chile, covering topics such as volcanoes forms, dangers and benefits through mixed media: virtual reality, augmented reality, scenographies, and the guidance of a team of geologists who accompanied the visitors - children and adolescents - during the tour, sharing research experiences and their passion for volcanoes with the audience. Although the central theme of this exhibition – "Journey to the center of the volcano"- revolved around volcanoes, our team conceived it as an excuse to relieve the issue of geothermal energy among the target audience, noting that the positive side of the volcanoes was the enormous amount of energy that could be provided to a country with the greatest unexploited potential of geothermal energy. The evaluation instruments applied to a sample of visitors, revealing whether the use of volcanoes as a hook to open the conversation about geothermal energy is effective.

The application of the evaluation instruments (surveys) and the analysis of results is still a work in progress, and we are willing to present its results during the New Zealand Geothermal Workshop, along with the materials of the exhibition which are all licensed under Creative Commons.

Session 4.2

55 | INTEGRATION OF DRILLING AND WORKOVER SERVICES IN THE GEOTHERMAL PROJECT LAGUNA COLORADA

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***Keywords:** Integrated Drilling Services, Workover, Drilling, Geothermal Project, Sol de Mañana Geothermal Field.*

The National Electricity Company (ENDE) of Bolivia in compliance with its obligations and responsibilities in the electric sector and its role in the energy productive chain is carrying out the Geothermal Project Laguna Colorada in the "Sol de Mañana" field, and has the purpose to supply renewable energy to the National Interconnected System (SIN), and contribute in the economic development of the country.

Taking advantage of the geothermal potential in the "Sol de Mañana" area, it will be the first project of its kind in Bolivia and one of the first in South America due to the extreme working conditions.

ENDE embarked on the challenge of drilling 25 new geothermal wells (vertical and directional) with an approximate depth of 2000 m. Furthermore, it requires two rigs with a winterization system to avoid problem of the freezing of the equipment due to the low temperatures in the area.

The project also contemplates doing workovers to run slotted casing in 4 existing wells and 1 minor workover. In addition, civil engineering work includes the following activities: a) Construction of water pits, b) Construction of rig foundation and cellars, c) Constructions of pads and d) Maintenance of access roads, internal roads and pads during drilling works.

ENDE has decided to use an Integrated Services contract model, where the principal contractor is responsible for managing the drilling operations and managing 40 different services subcontracts including the workovers.

ENDE plans to change the way it administers the project from an economic, operational and contractual point of view to improve drilling performance and reduce the Non-Production Times (NPT). This will be the first Integrated Services Project in Latin America and the highest in the world 5000 m above sea level.

Poster

56 | APPLICATIONS OF CALCIUM SILICATES DERIVED FROM GEOTHERMAL RESOURCES

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Keywords: *Nano-structured calcium silicate, silica scale, cement.*

We have developed a process to remove dissolved silica from geothermal brines in the form of a proprietary calcium silicate hydrate material (CaSil). By decreasing the level of dissolved silica in the brine below the silica saturation index, we can effectively reduce the formation of intractable silica sinter within pipework and associated equipment. The formed CaSil material does not adhere to pipework and can be recovered from solution, allowing the brine to be reinjected without risk of silica deposition in the reinjection well.

The recovered calcium silicate has a low bulk density and a high surface area, with the calcium component of the CaSil remaining chemically available. These properties make the CaSil amenable to incorporation into concrete materials based on Portland cement. The CaSil/cement composite materials are lightweight and have the potential to be used as construction materials.

This paper will discuss the properties of the composite materials and their potential uses.

Session 3.3

57 | GEOPHYSICAL IMAGING OF THE LIQUIÑE GEOTHERMAL SITE (39°S, CHILE) BY MEANS OF 3D GRAVITY INVERSION

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***Keywords:** Geothermal resources, Geophysical method, Bouguer gravity inversion, Liquiñe, Chile.*

The Liquiñe geothermal site is characterized by an anomalous number of geothermal hot springs (with in-situ measured temperatures ranging between 35-75 °C), which are spatially related to the main NS lineaments of the Liquiñe-Ofqui Fault System (LOFS) and NW-SE Andean Transverse Faults (ATF). Country rocks are dominated by granitoids and scarce mylonitic gneisses. The lateral continuity of most of the mapped outcrops and structural elements are interrupted by dense vegetation and soil cover, which highlights the necessity to perform further geophysical campaigns aimed to constrain the structural control on thermal hot springs. In this work we present a gravimetric survey developed along the Liquiñe valley. NW-SE and N-S profiles, obtained in an area of ~36 km2, allowing us to define the subsurface morphology of the basement. To invert the Bouguer anomaly, we used the open source SimPEG software (https://simpeg.xyz/) to constrain a 3D density model within the extension of the gravimetric survey. Our results show two main Bouguer gravity anomalies were detected, the first one related to two main NS lineaments of the LOFS, which also correlates with the thermal spring manifestations within the Liquiñe village. This Bouguer anomaly is interpreted as the consequence of highly fractured rock zones, increasing permeability. The second major Bouguer gravity anomaly is related to a topographic relief, consistent with a recognized proximal ATF trace. An increase of the basin thickness from south to north, with a thickness of a ~10 m to a maximum of ~200 m, respectively. Furthermore, these observations are also supported with the 3D density model, for depths up to 300 m, which draws a picture of a complex three-dimensional structural system.

Poster

58 | SUPERHOT FLUIDS: THE ORIGIN AND FLUX OF NATURAL GREENHOUSE GASES IN VOLCANIC AREAS

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***Keywords:** Deep geothermal gas, natural greenhouse gas, magmatic source, Taupo Volcanic Zone*

What are the sources and pathways to the surface of naturally emitted gases from volcanic-hosted geothermal systems? Subduction zones are a major conduit for the loss of volatiles, and New Zealand is one of the most active arc systems on Earth. Yet, the amount of gas emitted across the central North Island's volcanic region is poorly constrained. Recent research in New Zealand's Taupō Volcanic Zone has overturned a twenty-year paradigm by showing that shallow (~5 km) magmatic intrusions may ***not*** be the basis for surface expressions of gas and heat in New Zealand's gas-rich geothermal systems.

We thus hypothesise that geothermal gases have deep roots located where zones of partial melt (>8 km) meet crustal discontinuities. These discontinuities (e.g. faults or accommodation zones) act as highways to bring subduction and magmatic gases to the surface.

We will use a combination of melt and fluid inclusion and mineral noble gas isotope analyses, with surface gas and flux measurements, to trace the origin, transport, and interaction of gases within the Taupō Volcanic Zone crust. Such as a doctor with a stethoscope we want to investigate the breathing of the volcanic area in the great Taupo-Rotorua area.

Here we are presenting this new and exciting project funded by the Royal Society Te Aparangi Marsden Fund from June 2019 to June 2022, highlighting the key research objectives and the relevance and linkages of this project.

We believe this project presents a great opportunity to better understand geothermal natural emission, offering a potential t_{2019} (time reference for future surveys) baseline for future utilisation and exploration as well as emission control.

Session 2.2

59 | GEOTHERMAL: THE NEXT GENERATION

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Keywords: *Deep geothermal, supercritical, exploration, thermochemistry, engagement.*

New Zealand is endowed with generous geothermal resources. Currently untapped, NZ's deeper, supercritical geothermal resources have the potential to provide a near-unlimited source of renewable energy, with ten times more energy than conventional geothermal. New Zealand's unique tectonic setting with its active rifting arc produces voluminous magma and outstanding heat flow. It delivers exceptional opportunities for geothermal development and has placed New Zealand among the leaders in geothermal energy technology for the past 60 years. Our present level of scientific understanding, however, is insufficient to offer industry-ready solutions for NZ. Our multidisciplinary programme aim to resolve the critical, underpinning geological, geochemical and technological challenges – unknown in conventional geothermal – to enable future NZ generations to sustainably use supercritical resources for electricity generation and high-temperature industrial applications, while minimising carbon emissions.

This new research programme – building on over a decade of research – aims to minimise exploration and technological risks by detailing heat transfer at significant depth; interactions between New Zealand rocks and fluids at supercritical conditions; modelling system sustainability; and delineating the potential of these resources.

We assembled New Zealand and overseas geophysicists, geologists, experimental geochemists, modellers, as well as economic and Māori strategic investment advisors. Here we present the main objectives, relevance and future linkages of this challenging new science endeavour.

Session 5.2

60 | SYNERGISTIC APPROACH AND STRATEGY FOR GEOTHERMAL DRILLING IN WEST JAVA

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Keywords: *ECD, BHA, Surveying Strategy, stuck pipe, Dog Leg Severity (DLS), Rate of Penetration (ROP)*

With the current downturn of the oil business, geothermal projects remain stable and will ramp up in line with the Indonesian government commitment to provide 35,000 MW electricity by 2019.

After 5 years absence from the geothermal business, Schlumberger is putting back its footprints in the geothermal business by providing an integrated drilling services to Star Energy, one of the key geothermal players in Indonesia. A collaborative engineering approach was implemented by various members of the drilling team in Schlumberger to produce integrated planning, execution, and evaluation, aimed at achieving a safe and successful drilling operation.

Schlumberger integrated drilling services delivered a successful drilling operation that enabled Star Energy to achieve an actual production level exceeding the planned value.

Poster

62 | BREAKTHROUGH ON A ROTARY STEERABLE SYSTEM FOR GEOTHERMAL DRILLING IN A WEST JAVA FIELD

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Keywords: *Rotary Steerable System (RSS), geothermal, BHA, Surveying Strategy, stuck pipe, Dog Leg Severity (DLS), Rate of Penetration (ROP).*

Geothermal wells are often deviated and most of the directional work is generally performed in the intermediate hole section (17 ½"), conventionally using a mud motor. However this has some limitations, such as a small RPM range available for cleaning the hole while rotating and the risk of getting stuck due to pack-off (especially in the presence of total losses while sliding (particularly for inclinations around 35 degrees and above) in the formations of high heterogeneity encountered in the volcanic environment).

To overcome these drilling challenges, a Rotary Steerable System (RSS) has been utilized, specifically a RSS Xceed900. This is a "point the bit" system which 'directs' the bits in the desired direction, either through bending a shaft or having a built in offset, as opposed to a "push the bit" system, which utilizes "pads" to allow steering. This is the first time a "point the bit" RSS has been used in a geothermal well, worldwide.

To allow the successful deployment of this new technology in a geothermal application, a thorough technical/commercial analysis and several simulations and iterations were performed, which included:

- Gyro and Magnetometer drilling modes due to the expected cross-magnetic interference from the formation.

- IDEAS (Integrated Dynamic Engineering Analysis System - Schlumberger proprietary software) simulations to ensure both directional and dog-leg capabilities in the anticipated drilling conditions.
- Well plan optimization targeting a dog-leg severity (DLS) below 3 deg/30m.
- Flow rate optimization during aerated drilling together with survey considerations (downlink).

The actual field results can be summarized as follows:

- Higher on bottom ROP (15%).
- Optimization of parameters for hole cleaning - RPM 100-140, flow rate 900-1100 gpm.
- Minimization of back reaming.
- Optimization of Hi-Vis pills usage.
- Smoother T&D trend (including micro dog-leg avoidance).
- Implemented surveying strategy and QuikSurvey application.

The RSS Xceed900 showed several benefits that offset its higher cost compared to conventional mud motors in directional wells. This technology proved, in meeting specific drilling challenges, to be a viable alternative to mud motors for improving both performance and hole cleaning.

Session 4.1

63 | PERTAMINA GEOTHERMAL ENERGY BUSINESS OPERATION: AN UPDATE ON JOINT OPERATION CONTRACTS

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***Keywords:** JOC, Salak, Darajat, Sarulla, Chevron, Star Energy, Binary Cycle.*

Pertamina Geothermal Energy (PGE) as a subsidiary of Pertamina (Persero), which is engaged in the geothermal business, is authorized by the Indonesian Government for access to several working areas. Some of these work areas are managed by PGE directly and the others are managed by contractors in form of a Joint Operation Contract (JOC). Until now there has been five JOC that are still running, namely: JOC Salak (West Java), JOC Darajat (West Java), JOC Wayang Windu (West Java), JOC Sarulla (North Sumatra), and JOC Bedugul (Bali).

From 2017 until mid-2019, there were several important changes in the management of JOC, including: the changes of JOC Salak and JOC Darajat management contractors in 2017, and the reaching of the Commercial Operation Date (COD) of 3 power plant units @110 MW by Sarulla JOC contractor, which increased installed capacity of geothermal power plants in Indonesia to 1,948.5 MW in 2017-2018.

Session 5.2

64 | CHARACTERISTICS OF FLOWS IN PERVASIVELY FRACTURED ANDESITES, ROTOKAWA GEOTHERMAL FIELD, NEW ZEALAND

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***Keywords:** fracture flow, permeability anisotropy, fluid dispersion, Rotokawa*

In New Zealand's high temperature geothermal systems, fluids flow dominantly through fractured rocks with low matrix permeability. It is important to understand the nature of these fracture systems, and how fluids flow through them, so that the geothermal systems may be more efficiently and sustainably used to generate electricity. Here we present fluid flow calculations in several distinct discrete fracture models, each of which is broadly consistent with the fracture density and high dip magnitude angle distributions interpreted from borehole image logs at the Rotokawa Geothermal Field, a New Zealand andesite-hosted reservoir.

Our initial flow calculations are carried out using a cubic flow law, which is derived directly from Darcy's linear relationship between fluid velocity and pressure gradient for flows between smooth parallel plates. For comparison, we then follow with calculations using the Forchheimer flow law, which includes an additional term to account for the friction due to fracture wall roughness.

Most models show pervasive connectivity at reservoir scales, with fluid flow and tracer transport predominantly along the mean fracture orientation. As expected, the models show that permeability anisotropy increases as the standard deviation of the dip distribution decreases, with the fracture system eventually forming into distinct unconnected groups so that across-dip permeability (and hence fluid flow) drops to zero. The models also confirm that significant dispersion of fluid will occur as it is transported through a fractured reservoir. The amount of dispersion shows a broad inverse relation to the permeability anisotropy and reaches a maximum for a uniformly distributed population (unrealistic for Rotokawa) where fracture dip magnitudes vary from horizontal to vertical. Our calculations using the Forchheimer flow law with a subset of the fracture population models show that, as expected, the flow rates drop rapidly as the friction reaches a threshold value and, more surprisingly, the permeability anisotropy decreases at the same time.

Session 2.1

66 | WHAT OPPORTUNITIES ARE EVIDENT FOR GEOTHERMAL WITH THE LOSS OF KIWI GAS?

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***Keywords:** energy supply, gas, geothermal, electricity, spot price*

The New Zealand Government's April 2018 decision to stop petroleum exploration bidding outside Taranaki will reduce the amount of energy that the oil and gas sector will produce in New Zealand. This will create an increasing shortfall in supply of indigenous gas production against current demand of 200 PJ/a (56 TWh/a).

This paper will outline what opportunities are likely to be available for geothermal companies on the back of these changes as a supply/demand gap emerges. It will show that as the gas market shrinks, different gas customers will take different decisions on what capital investment best fits their business.

Small high value gas markets will remain with gas while electric generation, industrial heating and commercial uses will shift to alternatives.

As geothermal electricity generation currently solely provides baseload generation, the challenge for geothermal will be to replace mothballed gas baseload and diversify into higher margin peaking services.

Session 1.3

67 | MECHANISM OF SILICA DEPOSITION IN FORMATION AND MANAGEMENT OPTIONS INVESTIGATED IN LABORATORY STUDY

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Keywords: *silica, scaling, formation*

Managing silica scaling in plant surface facilities, injection wells and near-wellbore formation is a major challenge in geothermal field operations. Determining which management option is appropriate depends on the overall understanding of the mechanism of silica deposition both at the surface and within the reservoir formation. Factors driving silica deposition in plant facilities and injection wellbores seem to be well understood and hence effective control of scaling has been implemented by several geothermal plant operators, such as the use of pH-modification technology. The mechanism of silica deposition in a near-wellbore formation however is not as well understood.

A series of autoclave experiments were conducted to study silica scaling in a near-wellbore formation. These experiments were mostly designed to investigate water-rock interaction of acid-dosed brine with greywacke and its influence on silica deposition. These tests have been used to understand things such as the effects of adding chemical inhibitor and filtrate injection from a silica extraction plant. This paper discusses the autoclave testing methodology and how the results of the study provide better understanding of the mechanism of silica deposition in the reservoir formation, including how the autoclave testing can be used to assist with pre- and post-development risk mitigation.

Session 3.3

70 | AN HOLISTIC APPROACH TO IMPACT ASSESSMENT: REVITALISING THE PRESENCE OF MĀORI VALUES FOR CULTURAL SUSTAINABILITY IN GEOTHERMAL DEVELOPMENT

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Keywords: *Maori values, Indicators of sustainability, Cultural sustainability, Environmental sustainability, Social sustainability, Economic sustainability, Impact assessment, Geothermal development, Geothermal energy production, generation, and utilization, Rūaumoko.*

The geothermal resources of Aotearoa New Zealand's[1] Taupo Volcanic Zone (TVZ) provided warmth and ample cooking capabilities for the first Māori who settled in the region. Today, a wealth of Māori values associated with geothermal resources exist within many Māori communities of the TVZ. These Māori geothermal values can be thought to be separated into three components that reflect the different types of concerns and interests to Māori. The first component, being the spiritual component, was derived from the many Māori myths that describe the origins of the TVZ's geothermal resources and the super-natural implications associated with improper use of such resources. The values held within this spiritual component govern Māori behaviour and respect towards geothermal resources. The second component, which concerns the values associated with cultural practices and customs, emerged from the long-standing historical uses and practical benefits of geothermal resources. Finally, in today's context where a multi-worldview spectrum of stakeholders exists, and a competitive field of economic goals typically overrides cultural sustainability goals, the third component, which concerns Māori political values, has emerged to ensure that Māori do not lose out on opportunities in Aotearoa's economic growth through geothermal development. The three resulting components of Māori geothermal values are, customary, spiritual, and political, and are presented herein. In revitalising the representation of Māori values within today's 'western-traditional' impact assessment context, the three components are positioned alongside western values such as environmental, societal, and economical parameters. This parallel consideration of Māori values and western values contributes to a more holistic overview of the geothermal development sector.

Session 4.2

73 | AN UPDATED CONCEPTUAL MODEL OF THE TOMPASO GEOTHERMAL FIELD USING NUMERICAL SIMULATION

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Keywords: *Tompaso, TOUGH2, natural state, conceptual model*

Recent geoscience studies and well data suggest that the Tompaso geothermal field may have two separate reservoirs. The first reservoir is

located around the LHD-27 well cluster in the Pinabetengan area and it has supplied 2×20 MWe at units 5 and 6 of the Lahendong power plant since the year 2016. The second prospect is located around the Tempang area, which is associated with the Soputan fault. A new conceptual assessment of the Tompaso area is presented based on a numerical reservoir model which was constructed using the TOUHG2 simulator and the EOS1 equation of state. The reservoir model includes two high-temperature upflows at the base of the model, including one below the Masam Crater and one below the Toraget area. The locations of these upflows were chosen based on the apprearance of alteration zones. A natural state model was developed based on downhole pressure and temperature data from ten wells.

Based on this natural state model, an alternative conceptual model was proposed where the second geothermal prospect area was added. In the first prospect area, the updated conceptual model has the geothermal fluid coming from the upflow zone located below the Masam Crater and then moving north-northeast towards the Kawangkoan area. In the second prospect, the updated conceptual model has geothermal fluid flowing from an upflow zone under the Toraget area and expected moving to the northeast towards the Passo area.

Session 2.1

74 | USE OF GRAVITY, MICROEARTHQUAKE, AND TRACER INJECTION TEST DATA IN CALIBRATING THE TIWI NUMERICAL RESERVOIR MODEL

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Keywords: *Tiwi, reservoir model, numerical modeling, geothermal model, precision gravity, microearthquake, tracer injection, conceptual model*

The Tiwi Geothermal Field, operated by Philippine Geothermal Production Company, Inc. (PGPC) in Albay, Philippines, has been in production since 1979 and the numerical model of the reservoir has been adequately matched to the collected production and injection history, including changes in subsurface pressure and temperature data as well as discharge enthalpies. The numerical reservoir model is based on the TOUGH2 simulation code and uses a double porosity formulation, with various levels of matrix block sub-division (MINC'ing) in the reservoir section.

In addition to matching the usual production and downhole survey data, matching of the changes in gravity, which have been precisely measured across the field for the past 40 years, is also routinely conducted. It has proven to be useful in providing additional insights into the reservoir processes taking place, particularly related to phase change, movement of the steam-water interface in the reservoir and the degree of mass influx, either from external aquifers or internally from matrix to the producing fractures. The matrix to fracture interactions are controlled in the model by parameters such as the fracture spacing, degree of MINC'ing of the matrix blocks and the permeabilities of the matrix and fractures.

Another geoscientific data set that is used to constrain the model is microearthquakes (MEQs). These are very low intensity earthquakes that can only be detected by precision instruments. Some of the MEQs are induced by injection, and to a lesser extent by production. We believe the distribution of these events indicates where rock-fluid heat exchange is occurring, and the existence and/or stimulation of the fracture network. Production and geochemical data during the past 20 years indicates a strong connection between edgefield injection wells in the southeast Naglagbong sector (where about 70% of the total brine is injected) and production wells in the South Kapipihan sector. Both the data and the model indicate that the injection in Naglagbong provides long-term pressure support to South Kapipihan with no negative thermal effects. The great depth and lateral extent of the MEQ activity readily explains this favorable behavior, as the result of a large volume of hot, fractured rock that allows for ample heat exchange before the injected brine reaches the production wells. The model has been adjusted to account for this volume, with consequences for reservoir volume and reserves.

More recently, a binary project has been proposed which will lower injection temperatures. Although the match in the model to pressure and temperature changes in the area has been generally good, it was found by tagging the injection water that the velocity of fluid movement in the model was not consistent with available tracer test results. To improve the calibration of the model and make it more consistent with tracer arrival times and concentration trends, it was necessary to add a streak of high permeability blocks that corresponds to a mapped fault (Cale Fault) to act as a conduit of fluids between the injection and production wells used in the tracer test.

The inclusion of both production and geoscientific data in calibrating the numerical model of Tiwi has resulted in improvements in the history matching and the simulation of

reservoir processes, increasing confidence in the model's output and the use of the model to provide input to resource development decisions.

Session 2.1

76 | GEOTHERMAL CONCEPTUAL MODEL INFERRED FROM MAGNETOTELLURIC AND WELL-LOGGING DATA IN SOUTH ILAN PLAIN, TAIWAN

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Keywords: *magnetotelluric, well-logging.*

The Ilan Plain is located in the northeastern part of Taiwan. Geologically, it is the southwestward extension of the Okinawa Trough, which is a part of the subduction system with the Philippine Sea Plate being hidden under the Eurasian Plate. Based on the surface geothermal manifestations and higher temperature gradient, this area is a hot spot for the developments of geothermal resources in Taiwan.

An exploration well based on the geophysical model, mainly through the magneto-telluric method, was drilled in 2016 but failed to get the expected result. The failed outcome suggests that the cap layer represented by the low-resistivity zone in the traditional resistivity model may be unsuitable for metamorphic areas.

The aim of this study is to first reaffirm the previous MT results with well-logging data and additional MT data, then examine any other possible factors other than the clay cap that could create the resistivity anomaly, and finally build a better geological model in this metamorphic terrane. Our preliminary analysis confirms the MT outcome and proposes three possible scenarios of resistivity variation for better modeling.

One interpretation is that the low resistivity zone may be caused by a sandstone layer containing plentiful iron sulfide, e.g. pyrite, instead of a clay cap. Mixing with different resistivity components from the groundwater and the amount of carboniferous materials in the formation are also possibly affecting the resistivity. Further work needs to be done to identify the most likely factors to explain the resistivity disparity.

Poster

ICELAND DRILLING

78 | NEW IMPLICATION OF WALL ROCK ALTERATION MINERALOGY IN THE HISHIKARI EPITHERMAL GOLD DEPOSIT, JAPAN

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***Keywords:** Hydrothermal alteration zoning, interstratified clay mineral, chlorite, epidote, Hishikari epithermal gold deposit.*

This work seeks to establish a new alteration mineral zonation in the Hishikari mine for more efficient exploration. Detailed analysis of wall rock alteration was conducted by means of microscopic observation, X-ray diffraction and electron probe micro analysis. Samples used here were collected from four underground cross cuts and five drill cores to cover mainly the Honko and Sanjin deposits.

As a result of analysis, dominant alteration minerals identified were chlorite-smectite interstratified mineral (C/S) and/or illite-smectite interstratified mineral (I/S). These are common in cross cuts and drill cores. However, some areas of the southern part of the deposit have dominated chlorite with minor illite. In the same region, epidote was remarkably recognized.

Epidote is a mineral which occurs at higher temperatures than chlorite and illite in general and can be a potential as a new index mineral for the division of alteration zoning. Previous fluid inclusion studies in Hishikari mine reported that some higher homogenization temperatures were recorded in the Sanjin deposit than in the Honko and Yamada deposits. The presence of epidote is consistent with these study, suggesting that this mineral will be useful especially in the Sanjin deposit.

Chlorite compositions were analyzed by EPMA. The comparison with the data of the previous study suggest chlorites of the Sanjin have higher formation temperature than the Honko and the Yamada.

Poster

79 | PREDICTING SUCCESS OF WELL DISCHARGE AND AIR COMPRESSION OF TIWI WELLS USING THE RATIO OF AREAS OF FLASHING TO CONDENSATION (AF/AC) METHOD

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***Keywords:** Air Compression, Well Discharge, Af/Ac Ratio Method,*

The Tiwi Geothermal Field has a number of production wells that have difficulty in being re-discharged when they cease flow, resulting in loss of production. The wells are usually allowed to build up pressure and are then discharged to the sump to stimulate production but this may take quite a long time and is not always successful. An air compressor has therefore been mobilized to Tiwi to stimulate wells that are no longer able to self-discharge.

The downhole temperature and pressure data from the wells have been used along with the Af/Ac (Area of flashing to Area of condensation) ratio method (Sta. Ana, 1985) to help predict the likely success of self-discharge and air compression. In one of the test wells, the correlation predicted success for self-discharge, as Af/Ac was >0.85 based on the pressure and temperature survey and shut in wellhead pressure, but when the well was opened, it was unable to flow. The compressor was then used to stimulate the well to a higher wellhead pressure, which then resulted in a successful flow. The flow test results provided additional data and suggesting modifications to the Af/

Ac ratio method to be able to account for: (1) surface discharge pressure effects as the well was flowed to a surface piping system which had higher back pressure than either flowing the well vertically or horizontally to an atmospheric test rig, (2) how the "Area of flashing" is defined below a wellbore obstruction or the total depth to consider for wells with shallow obstruction, and (3) the correct wellbore temperature survey to use for well leaking to the surface. After applying these corrections to the candidate well, the results then agreed with the threshold ratio of 0.85 described in the correlation.

In other test cases, recently reworked wells were successfully flowed to the system sooner than planned. The Af/Ac ratio method was used in evaluating if air compression was likely to be successful in stimulating the wells, which led to calculating a target pressure to achieve the 0.85 threshold ratio.

Session 5.1

80 | NON-UNIQUENESS OF GEOTHERMAL NATURAL-STATE SIMULATIONS

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Keywords: *Natural state, steady state, uniqueness, convergence, reservoir modelling, TOUGH2.*

A numerical simulation representing the natural-state of a geothermal system commonly involves finding an approximate solution to a mass and energy balance equilibrium problem; that is, solving a steady-state simulation. Solving this type of natural-state simulation problem is often problematic, and geothermal simulators regularly struggle or are unable to achieve a reasonable steady-state solution for a given geothermal model. When a simulator achieves a steady natural state, it is often assumed that the simulated natural state is unique for the chosen model parameters. However, this uniqueness assumption may be wrong as there might be multiple equilibrium solutions for a single natural-state model. Using a model based on a working model of the Wairakei-Tauhara geothermal field, we demonstrate how multiple equilibrium or steady-state solutions can be achieved for a fixed set of rock properties and model boundary conditions. The different steady-state solutions are found by varying the initial conditions used to initialize the transient to steady-state simulations which model the natural-state. For the presented example, we were able to find four different steady-state solutions to a natural-state problem. These four simulated natural-states had natural-state temperatures which, in parts of the model, could disagree by up to 122°C: a model discrepancy which is substantially greater than expected temperature observation errors. This uniqueness problem, therefore, complicates natural-state model inversion or calibration.

Session 1.1

81 | HYDROGEOLOGIC CONTROLS ON STRATOVOLCANIC GEOTHERMAL SYSTEMS

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Keywords: *Stratovolcanoes, hydrogeology of geothermal systems*

High-temperature geothermal systems associated with stratovolcanoes (also known as composite cones) can be found at locations around the world. For example, in Indonesia, most successful geothermal developments have been completed on the lower slopes of (or adjacent to) stratovolcanoes where there are surface manifestations of a hydrothermal system.

Understanding the hydrogeology of a stratovolcano provides insight into the feasibility of developing a geothermal resource for power generation. This paper presents global examples of successful development of stratovolcanic geothermal systems, and focuses on the key hydrological and geological characteristics necessary for development of stratovolcanic geothermal systems including surface manifestations, recency of eruption, depth to basement, depth to heat source, and groundwater flow.

Session 2.2

82 | FORMATION MECHANISM OF SILICA SCALE IN DIENG GEOTHERMAL POWER PLANT, INDONESIA

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Keywords: *polymerization, silica scale, iron, Dieng*

Severe silica scale problem has occurred in Dieng geothermal power plant since the start of its operation. Silica scale is formed in surface pipeline systems, and this requires acidification of the brine using sulfuric acid to address the problem. In order to understand the formation mechanism of silica scale inside the brine pipeline, the polymerization behavior of silicic acid in geothermal water, and the precipitation of scale and its characteristics, were investigated in an on-site batch experiment.

The polymerization of silicic acid was investigated by spectrophotometry to determine monosilicic acid (SiO_2(M)) and by ICP-OES to determine total silicic acid (SiO_2(T)). Under neutral pH condition, SiO_2(M) concentration decreased rapidly from 1,000 to 350 ppm, while SiO_2(T) decreased moderately from 1,000 to 350 ppm. This suggests that silica precipitation follows the rapid growth of polysilicic acid. Even under acidic pH condition, polymerization

proceeds: SiO_2(M) concentration decreased from 1,000 to 600 ppm. However, SiO_2(T) concentration was kept almost constant. This suggests that addition of sulfuric acid was not able to completely stop the polymerization of monosilicic acid, but only retarded the growth of particles (reaction between polysilicic acids).

Trace metal concentrations such as iron (Fe) and/or aluminum (Al), reported to promote the formation of silica scale, were determined by ICP-OES. Under neutral pH condition, a decrease in Fe concentration was observed coinciding with the decreasing SiO_2(T) concentration. This suggests that Fe concentration in the brine is playing a role in the deposition of silica under neutral pH condition by accelerating the growth of polysilicic acids. On the other hand, both the Fe and SiO_2(T) concentration in the brine remained constant after acidification by sulfuric acid. This suggests that Fe ions were prevented from binding into the polysilicic acid under acidic condition. Furthermore, the XRD and XRF analyses show that the scale is mainly composed of amorphous silica with high concentration of Fe.

Session 3.3

83 | NUMERICAL SIMULATION UPDATE OF DIENG GEOTHERMAL FIELD, CENTRAL JAVA, INDONESIA

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Keywords: *numerical model, Dieng geothermal field, conceptual model, TOUGH2.*

Dieng Geothermal Field has been operated for 17 years with installed capacity of 60 MW. Next target, Dieng field will be developed for additional 2x55 MW. For development purposes, numerical model is used to evaluate initial permeability and temperature distribution and to forecast future reservoir performance as well. After 2013, several geoscience surveys and well testing have been conducted in order to estimate the changes of reservoir behavior during production and to update the conceptual model. Several numerical models of Dieng have been developed in 2006 and 2013 by using single porosity approach. Generally, the single porosity models give more optimistic result in forecast simulation and to account this issue dual porosity approach were implemented in the model. The recent numerical model is built by using TOUGH2 with EOS1. This paper describes the possibility and sustainability for the next 2x55 MW development. Several PT shut-in surveys data and production well histories were used to validate the model. During forecast simulation, the model was also coupled with Excel based wellbore model.

Session 3.1

84 | THICK SILICIC VOLCANIC SEQUENCES AT MUARA LABOH AND RANTAU DEDAP GEOTHERMAL FIELDS, SUMATRA, INDONESIA: IMPLICATIONS FOR RESERVOIR ARCHITECTURE AND PERMEABILITY

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Keywords: *Sumatra, Tectonism, Silicic Volcanism, Basin, Caldera, Muara Laboh, Rantau Dedap, Petrography, Alteration, Image Log, Reservoir, Permeability.*

Thick silicic tuff sequences and silicic intrusives are found in deep wells drilled at the Muara Laboh and Rantau Dedap Geothermal Fields, Sumatra, Indonesia. Petrographic and petrophysical investigation of cuttings, core, gamma ray and image logs were used to understand the silicic stratigraphic controls on reservoir permeability. Regional geologic constraints and limited U-Pb zircon ages show that silicic explosive volcanism most likely occurred mainly during the Miocene to Plio-Pleistocene, and locally continuing into the Holocene. Wells in both fields show that silicic tuff sequences reach thicknesses of 500 to >1000 meters, and silicic intrusive complexes intrudes to reservoir depths. In Muara Laboh, thick silicic tuffs are found in a basin generated between major strike-slip fault segments. The dominant rock type is variably welded to non-welded silicic ash-flow tuff with a variety of devitrification textures. A long-lived sheared and altered granite-granodiorite-microdiorite intrusive complex representing multiple magmatic episodes (96 to 20 Ma) occurs in the SW sector of the field. In Rantau Dedap, similar silicic tuff sequences are found as caldera fill deposits overlain by debris flows. A weakly altered, poorly deformed granite to granodiorite intrusive complex occurs at depth. The silicic volcanics have high resistivity in image logs, fine fragmental textures (tuffs) to massive textures (intrusives), and high gamma ray counts (65 to 200 API) in both fields. Fracture intensity of the thick silicic tuff sequences increases with welding, primary devitrification, and possibly the thickness and cooling history of individual eruptive units. Major feed zones are associated with faulted lithological contacts and very limited at thick silicic tuffs in Muara Laboh. Fluid entries at Rantau Dedap are most abundant in the relatively thin Upper Rhyolite Tuff and underlying Dacite Tuff, and near the basal contact of the thick Lower Dacite Tuffs with intrusions. Permeable zones are encountered at the margin of the intrusive complexes in both fields.

Session 2.2

85 | CONCEPTUAL MODEL AND NUMERICAL SIMULATION UPDATE OF PATUHA GEOTHERMAL FIELD, WEST JAVA, INDONESIA

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Keywords: *Conceptual Model, Numerical Model, Patuha, Steam dominated reservoir.*

Patuha geothermal field is located about 50 km southwest from Bandung, West Java Province, Indonesia and developed by state owned company PT Geo Dipa Energi (Persero). The field has been in operation since September 2014 with plant capacity of 55 MW. Several geoscience surveys had been carried out from 1983 until 1998. The drilling was started by Patuha Power Limited with a slim hole campaign in 1996 (17 wells) continued by drilling large and standard diameter wells until 1998 (14 wells). Since 2014, several geoscience additional activities have been carried out, such as geological mapping, geochemical survey, reprocessing geophysical data and micro earthquake survey. Integrated analysis of those geoscience data combined with all wells data are used to update Patuha conceptual model. The 3D conceptual model from all data also has been developed to give comprehensive information in the subsurface existing area and development plan area in the north Patuha. Based on the updated conceptual model, numerical model has been developed by using TOUGH2 with EOS1 and dual porosity approach. The numerical model has been validated by natural state. This paper describes the implementation of Patuha reservoir simulation to support the field development plan.

Session 3.1

86 | MODELLING GEOTHERMAL POWER GENERATION FROM THE WAIOTAPU – WAIKITE – REPOROA GEOTHERMAL FIELDS

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Keywords: *Waiotapu, Waikite, Reporoa, numerical model, geothermal power generation*

The Taupo Volcanic Zone in New Zealand is a cradle of geothermal systems, of which some, such as Waiotapu, are renowned as geo-tourism destinations. Due to its cultural significance, Waiotapu is classified as a protected geothermal system, where no geothermal production is allowed. Geothermal systems with hydrological linkage to Waiotapu such as Waikite and Reporoa are also treated differently than other systems. The Waikato Regional Plan classified Waiotapu – Waikite as protected systems and Reporoa as a research system (Waikato Regional Council, 2019).

The natural state numerical model developed by Kaya et al. (2014) was used to investigate possible strategies from Reporoa area under different production and reinjection scheme for optimum power generation while monitoring the pressure near the surface features to avoid any induced changes in the thermal activity and avoid the adverse effect of development. Investigations were done both on the production side, such as the amount of power generation, location, depth and number of production wells, and also on the injection side, such as the location, depth and number of injection wells, including injection rate. The configuration of production and injection wells was also tested. A monitoring well was located between Reporoa and Waiotapu with the purpose of safeguarding Waiotapu from any potential changes due to production activity.

Based on the test results, the recommended scenario is to set up a 25 MW production in Reporoa, with five production wells and one injection well. The production wells have a maximum steam flow of 47 kg/s from each well, and all injection wells inject both brine and condensate at 100% injection rate. According to our modelling study, the goal of preserving surface manifestations in Waiotapu area is achievable.

Session 3.1

89 | OVERVIEW OF HYDRAULIC FRACTURING DESIGN IN GEOTHERMAL ENVIRONMENT

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***Keywords:** Reservoir Stimulation, Hydraulic fracturing, Fracturing design.*

Unlike hydrocarbon reservoirs, geothermal reservoir boundaries are somewhat vague. New wells often encounter low or even zero permeability formations. Poor or low permeability is the biggest concern for the field operators in geothermal industry. Instead of abandoning the well, the application of stimulation technique such as hydraulic fracturing can be applied to minimize this problem and revitalize the non-productive well. This technology was an adaptation of best practices in petroleum industry. A couple of promising results of improvement in production and injection capacities from previous field application in a geothermal environment have been reported. Modifiable parameters such as injection rate, concentration of proppant, proppant distribution, pump schedule and effect of certain fluid, all have very important role in the design of the hydraulic fracturing program. This paper will discuss some of the field application of this technique in geothermal environment, which instead of abandoning the well, led to future consideration of hydraulic fracturing as a means of stimulating well performance. Furthermore, drilling make-up well project could be postponed.

Poster

93 | GEOTHERMAL SUBSIDENCE AND INFLATION IN TAUPO: A COMPARISON OF DETECTION METHODS

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***Keywords:** aerial, survey, photogrammetry, New, Zealand, drone, UAV, UAS, subsidence, PSInSAR, Sentinel-1*

Remote sensing data from aerial surveying and satellite is of interest for environmental monitoring and was recently trialed by Waikato Regional Council (WRC) in New Zealand. This study investigates known areas of ground subsidence in Taupo, New Zealand using aerial imagery and satellite data. Results confirm subsidence is ongoing, and demonstrate the use of remote sensing methods including photogrammetry and Persistent Scatterer Interferometric Synthetic Aperture Radar (PSInSAR) to quantify vertical surface change over time. The methods have a wide range of applications of interest to geothermal development, including reservoir modelling, and monitoring vegetation, geothermal surface features, surface subsidence and inflation.

Session 2.2

94 | UTILIZATION OF ABANDONED OIL WELLS IN GEOTHERMAL APPLICATIONS

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Keywords: *Geothermal, Abandoned oil wells, Utilization, Efficiency.*

Abandoned oil wells have several possible applications as geothermal resources. Selecting the most viable application depends on characteristics of individual oil wells and the general condition of the region for the development. In this study, the potential for the possible utilization such as low temperature power production (binary power cycle), desalination of water, pseudo hot-springs and spas, geothermal district heating (GeoDH) and agricultural applications will be reviewed. Moreover, retrofitting abandoned oil wells for geothermal utilizations can reduce the reliance on fossil fuels and also eliminates mining, processing and transportation process for the power production.

According to Geothermal Energy Association (GEA), an economically competitive geothermal power plant can cost as low as 3400US$ per kilowatt installed. While the cost of a new geothermal power plant is higher than that of a comparable natural gas facility, in the long run the two are similar over time (CEC). This is because natural gas construction costs account for only one third of the total price of the facility, while the cost of the fuel at a natural gas facility represents two thirds of the cost. The initial construction costs of a geothermal facility, in contrast, represent two thirds or more of total costs. So, although initial investment is high for geothermal, natural gas and geothermal are still economically comparable over a long term. Considering the drilling costs more than 40% (Carolyn. K) for a geothermal powerplant development, retrofitting high potential abandoned oil wells can make it the cheapest one among all options including renewable energies.

Session 1.3

95 | GEOLOGICAL EVOLUTION OF THE ROTOKAWA GEOTHERMAL SYSTEM, NEW ZEALAND

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Keywords: *Taupō Volcanic Zone, New Zealand, U-Pb dating, geochronology, Rotokawa geothermal system*

New data from the Rotokawa geothermal system (central Taupō Volcanic Zone), has constrained the magmatic, structural and hydrothermal evolution of the hottest utilised geothermal system in New Zealand. U-Pb zircon geochronology data on buried lithologies at Rotokawa provide constraints on the 3-km-thick sequence of volcanic products. The oldest volcanic rock dated is a Tahorakuri Formation ignimbrite, with an eruption age estimate of 1.84 ± 0.04 Ma. This and other old ignimbrites onlap the Rotokawa Andesite lava pile, up to 1.2 km thick, that rests on Mesozoic basement

greywacke. Between ~1.8 and 0.7 Ma, there is a magmatic hiatus, with the next oldest being a rhyolite lava dated at 720 ± 90 Ma. At 350 ka, the area was buried by ignimbrites of the Whakamaru Group. Ignimbrites and sediments of the Waiora Formation were then emplaced over a 150 kyr period. Extensive rhyolitic lava bodies of the 90 ± 10 ka Oruahineawe Formation show evidence suggesting both extrusive dome and shallow intrusive emplacement. Mostly lacustrine sediments of the Huka Falls Formation and pyroclastic deposits of the 25.4 ka Oruanui eruption then cap the system. Rotokawa is typical of high gas and high enthalpy New Zealand geothermal systems with a deep chloride water reservoir and an excess steam phase. As a result, the volcanic and sedimentary succession has been variably altered, to abundant quartz, chlorite and calcite, with common but variable adularia, epidote, calcite and illite at depth.

Session 2.2

98 | EXPERIMENTS WITH VORONOI MESHES FOR GEOTHERMAL MODELS

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Keywords: *Geothermal modelling, Voronoi grids, regularization.*

Various modellers have used Voronoi meshes in their geothermal models, constructed by first triangulating the region of interest and then connecting the centres of all the triangles to form a polygonal mesh. A Voronoi mesh has the nice property that the lines joining block centres are orthogonal to the block boundaries. However in some cases the Voronoi meshes used have an undesirable feature of including one or more very small sides in some blocks. In the current study we implement an algorithm for regularising Voronoi meshes, offsetting the orthogonality condition against the secondary aim of having all sides of a block being of the same size.

The method is demonstrated on a test problem of an injection/production doublet and on a mesh used in a previous modelling study.

Session 3.1

99 | APPLICABILITY OF THE NA-K GEOTHERMOMETER IN SLATE FORMATIONS OF TAIWAN

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Keywords: *Na-K geothermometer, argillite/slate formations, water-rock interaction, tNa/K(albite-muscovite)*

More than 2/3 of hot springs in Taiwan are located in the Central Range metamorphic terrane, where argillite, slate, phyllite and black schist are predominated. Rapid uplift and erosion generate a higher geothermal gradient. The meteoric water infiltrated downward, was heated, then rose to the surface as hot springs by regional faults or fractured systems.

The SiO_2 geothermometer has been proved to be suitable in the argillite/slate formations of Taiwan (Chen, 1985; Huang et al., 2018). However, the applicability of the Na-K geothermometer has been debated for a long time. The widely used formula proposed by Fournier and Truesdell (1973) isn't suitable in argillite/slate formations, because K-feldspar is absence. Chen (1985) proposed an albite-muscovite equilibrium formula of the Na-K geothermometer for argillite/slate formations. However, the 60-days argillite-fluid interactions showed that the Na-K geothermometer has a reverse relationship with experimental temperature (Huang et al., 2018).

In this paper, we advocate that the reverse relationships of Na-K geothermometer and experimental temperature in Huang et al. (2018) may be affected by reaction time and redox state. The good correlation of Na/K and silica temperatures from well fluids implies that the Na-K geothermometer is worth considering.

A new empirical formula of Na-K geothermometer is proposed by the fluids from deep production wells and based on quartz geothermometers above 180°C in this study.

$\log(Na/K)=2.474*103T^{-1}-3.7267 \quad R^2=0.71$

From which the $T_{Na/K}$ (°C)

$$227°C > T > 180°C,\ T(°C) = \frac{2474}{\log \frac{Na}{K} + 3.73} - 273.15$$

Most of the calculated errors between T_{Na-K} and T_{quartz} we proposed are less than 8°C in the Chingshui, Tuchun, and Lushan geothermal fields. Poor coefficient of determination (R^2 value) may be due to the equilibrium involved with H+ and complex clay mineral interactions.

Poster

101 | GREENHOUSE GAS EMISSIONS FROM NEW ZEALAND GEOTHERMAL POWER GENERATION IN CONTEXT

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Keywords: *Carbon dioxide, CO_2, methane, CH_4, greenhouse gas, geothermal, emissions.*

Conventional geothermal systems are complex natural features, usually comprising a deep heat source such as a magma chamber, and above this a convecting system of hot water/steam. There are often natural features at the surface indicating the presence of these geothermal systems underground, including fumaroles, hot springs, geysers and steaming ground. There are many geothermal fields in New Zealand, mostly associated with volcanism within the extensional Taupo Volcanic Zone of the North Island.

From these geothermal surface features, there is a significant natural flux of CO_2 and methane (CH_4) through the ground surface and into the atmosphere. These gases are transported to the surface by hot geothermal fluids, though the original source of the gases is not yet known and is the subject of current research by GNS. When geothermal fields are developed for electricity generation, CO_2 and methane are released during the power generation process, while the natural flux of these gases is thought to diminish.

CO_2 and methane emissions data during plant operation (combined as CO_2-equivalent) are presented for the major geothermal plants in New Zealand. There is a focus on the most recent emissions for the calendar year 2018, followed by a review of how these emissions have changed over the period 2010-2018. The tendency of geothermal emissions intensity to decrease over time is shown, as well as the effect of plant/operational changes. The geothermal emissions intensity is compared to typical values for other clean energy sources, and also to fossil fuels.

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102 | A COMBINED APPLICATION OF HIGH-RESOLUTION THERMAL INFRARED AND MAGNETIC DRONE-BASED SURVEYS OVER LARGE AREAS FOR GEOTHERMAL AND ELEMENT EXPLORATION IN WESTERN CANADA

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Keywords: *Drone, UAV, geophysics, magnetics, thermal infrared, geothermal, Canada*

In Canada, geothermal and element exploration is challenging due to thick vegetation cover, steep topography, and the presence of hundreds of meters of glacial overburden masking geothermal expressions. Consequently, unique exploration techniques sometimes need to be deployed. Remote sensing thermal infrared surveys and magnetic surveys can be a useful tool for mapping geothermal anomalies and thus aid in characterizing the underlying geothermal system. However, the resolution-to-cost relationship of airborne/satellite surveys often do not match the needs for geothermal prospecting over a large area. In November 2018, Borealis GeoPower employed an unmanned aerial vehicle (UAV or drone) to conduct the first combined drone-based thermal and magnetic survey over a ~22 km^2 area to investigate their Terrace, British Columbia, geothermal project, located near the hottest hot spring in Canada. Over 47,000 georeferenced thermal images were taken; image processing techniques were consequently applied to orthorectify and mosaic the images to obtain a thermal map with sub-meter (~0.5 m) resolution. The high-resolution of the magnetic data enabled enhanced mapping of small magnetic features that would typically go undetected in surveys with lesser resolution. The combination of drone-based thermal and aeromagnetic surveys effectively identified unreported geothermal outflows and subsurface geological structures, demonstrating the usefulness of these techniques for geothermal exploration.

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