Handbook

Copthorne Hotel and Resort
Bay of Islands, New Zealand

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23-26 November
2020

Contents

Welcome

42nd New Zealand Geothermal Workshop 2020

We are pleased to welcome delegates to the 42nd New Zealand Geothermal Workshop, held at the Copthorne Hotel in the beautiful Bay of Islands. We are thrilled that international attendees, while unfortunately unable to join us in NZ are with us online. This year's location is a novel one for the workshop – it provides everyone a great chance to see Top Energy's Ngawha development, and to visit the Waitangi Treaty grounds which are considered by many the birthplace of modern New Zealand.

2020 has been a year like no other – however the energy sector is an essential lifeline for New Zealand. So despite the challenges of the COVID-19 pandemic our country's geothermal generation continued to play a key role in providing baseload renewable energy to the nation. This will have required innovation and ingenuity from so many across the sector. 2020 has also been characterised by "NZ Inc." continuing to reach across national borders (now virtually) to support global geothermal development.

We hope the workshop is a time to pause, to reflect, and to become energised about the future of geothermal in New Zealand – whether that is in direct use for process heat or other applications, or fuelling hydrogen production, or developing new resources in new areas for electricity generation to propel New Zealand closer to 100% renewable electricity. What will our vehicle fleet look like by 2030? How many of you will be driving electric?

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, however we hope the event is a forum for the entire geothermal community to connect and collaborate.

We are grateful to all attendees, speakers and sponsors for their commitment to the workshop in 2020. Large events in the current climate involve uncertainties beyond "business as usual" event planning.

Thank you for your support in 2020!

Conveners:

Rosalind Archer

David Dempsey

Mike O'Sullivan

Sadiq Zarrouk

2020 Sponsors

2020 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

Wi-Fi Access

Please note that the venue wifi in the exhibition space is not the same network as the session rooms. Please use the below instructions to login to each space.

To login to Wi-Fi in Exhibition Space (Waitaha Room):

- Select the network connection *"waitahawireless"*
- Type in the password: **bo1wa1taha**
- Connect
- Open your internet browser, this will start your session

To login to Wi-Fi in Main Conference Hall (Treaty Rooms):

- Select the network connection *"Copthorne Wireless"*
- Open your internet browser
- The Reivernet/Copthorne home page will open and it will ask you to make a selection – choose 'Visitors'
- Type in the code: **NZGW20**
- This will then start your time

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 Waitaha Room.

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.

Cameras and electronic recording

No personal electronic recording of presentations is permitted in any form without the express written permission of Workshop organisers and speakers. Sessions will be recorded and available via the virtual conference platform until 23 December 2020.

Virtual Conference Platform

If you have misplaced your login details for the virtual conference platform please email geothermal@auckland.ac.nz for assistance.

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.

Welcome Reception and Powhiri

Monday, 23rd November, 5.30pm
Waitangi Treaty Grounds

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

Top Energy Field Trip

Friday, 27th November, 9:30am

The Top Energy Field Trip is available to those who have previously registered to attend this event.

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

Duke of Marlborough Hotel, Russell

Workshop Dinner

Wednesday, 25th November 6.15pm
Duke of Marlborough Hotel, Russell

Refreshing Rascals and Reprobates since 1827. Located on the waterfront of Russell in the Bay of Islands, the Duke of Marlborough Hotel offers an outstanding restaurant, accommodation and event venue. Holding New Zealand's first liquor licence, this historical beauty has been lovingly restored and offers her visitors a great place to relax, unwind and watch the world go by.

Ferry: We will have complementary ferry service departing from the Copthorne Wharf at 6:15pm. Return service will be available at 10:30pm. Should you wish to join the dinner late or depart early you will need to purchase a trip from the public ferry providers from Paihia or Russell Wharfs.

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.

Keynote speakers

Andrea "Andy" Blair

Upflow | President of the International Geothermal Association

Andy is the President of the International Geothermal Association (Germany) and co-founder of Upflow, a geothermal science, research and innovation company that builds expert teams to provide intelligent solutions to global industry. The nexus between science, business and community is where her expertise sits. She has a deep understanding of the drivers relating to the business of science, and a proven ability to turn scientific ideas into economic gains.

In her previous role as Business Development Manager at GNS Science (NZ) she was responsible for leading and coordinating sub-surface geothermal geoscience contracts worldwide for over 10 years.

Awarded the role of Geothermal Business Development Lead for New Zealand (2017-2020), Andy was tasked with driving commercial investment in geothermal industrial direct use projects. The desired outcome was the development of large projects with significant positive impacts on local economies, communities, and the environment.

Andy has experience in leading strategic planning and tactical thinking across several industries including governance roles that required strategic investment decision making. This includes chairing the commercial arm of a Māori organisation with a significant geothermal asset base (~$500m).

A co-founder and Global Chair of Women in Geothermal (WING) (2013-2020), Andy grew the organisation from 83 members to over 1800 members in 48 countries worldwide, making it the single largest geothermal association in the world. A not-for-profit organisation, WING has grown into a global movement of people, both men and woman, supporting the empowerment and advancement of women within the industry.

Andy is a Director for the Geothermal Resources Association (US), Advisory Board Member for The Rogue Bore geobrewery and Co-Chair of the Regional Skills Leadership group.

Global geothermal movements: what's happen in the world of geothermal, current focus, latest thinking, and global trends.

Andy will talk to the latest technologies, workstreams and thinking happening in international markets and how the International Geothermal Association intends to play a leadership role. She will provide insights into regional activities, the issues and opportunities, and provide some commentary on New Zealand's role in the global future of geothermal.

Notes

Daniela Blessent

Universidad de Medellin
Professor of Environmental Engineering

Daniela Blessent graduated from the Politecnico di Torino (Italy) in 2004 in Environmental Engineering. During her studies, she spent one year (2002-2003) at the Federal Polytechnic of Lausanne (Switzerland). She obtained a PhD in Earth Sciences in 2009, at Université Laval (Quebec, Canada), with focus on hydrogeological numerical modeling of fractured geological media. She then worked as a professor at Polytechnique de Montreal (Canada) from 2010 to 2012. Since 2013, she has been working at the Universidad de Medellin (Colombia) as professor in the Environmental Engineering department. Her research activities currently benefit from multiple international collaborations, in particular thanks to the international project IGCP636 "Geothermal resources for energy transition", which is part of the UNESCO International Geoscience Programme. Since January 2020, she is the president of the Colombian Geothermal Association (AGEOCOL).

Geothermal research in Colombia: lessons learned and future perspectives.

A research group focused on geothermal energy has been established in 2014 as an initiative between Universidad de Medellín (Colombia) and Institut national de la recherche scientifique (Québec, Canada). Seven years later the group has been awarded the Best Research Programme of the Universidad de Medellín during the X Innovation and Creativity Fair held at the end of September 2020.

The research work started with the assessment of the geothermal potential of a study area close to the Nevado del Ruiz volcano. Groundwater and heat transfer numerical modeling was used as a tool to simulate temperature at depth, based on thermal and hydraulic measurements of rock properties. An hydrogeochemical study has also been started recently. The studies conducted provided new insights into the construction of conceptual and numerical models for fractured geological media.

Perception of geothermal energy has also been analyzed through online and face-to-face surveys conducted in two areas of the country, in the Nevado del Ruiz and Azufral volcanoes. Feasibility of shallow geothermal energy installations have also started to be investigated.

The performed activities allowed the creation of a solid research network, fostering participation in geosciences of young researchers, students, and women. The extensive participation of scientists from several countries, the enrollment of undergraduate and graduate students, and the numerous outcomes highlight the key role of international collaboration and visibility for Colombia, where geothermal development is at its beginning.

To support the development of the geothermal industry in Colombia, it is important to promote outreach activities and to include courses on geothermal energy in both geoscience and engineering academic programs, since the geothermal field is multidisciplinary and it requires a proper communication among different disciplines, including social sciences.

Notes

Russell Shaw

TOP ENERGY GROUP
Chief Executive

As an electrical engineer with over 25 years' experience in the utility sector, Russell has significant experience in strategy, management, risk and operations with extensive knowledge of asset management, performance improvement and engineering. Prior to joining Top Energy in 2008, Russell was General Manager for Operations at WEL Networks where he led WEL's Asset Management, Procurement and Field Services groups of over 150 staff. Prior to this Russell was a partner with UMS Group, a global utility management consulting group. Russell is a Chartered Electrical Engineer, has an honours degree in Electrical and Electronic Engineering, an MSc in Engineering Business Management and is a Fellow of the Institute of Engineering and Technology and Engineering NZ. He is also a member of the NZ Institute of Directors.

Ngawha Geothermal Field Development

Russell Shaw, Chief Executive of Top Energy Group will present a paper detailing the development of the geothermal field at Ngawha from the early Ministry of Works developments through to the present day.

The paper will particularly focus on the most recent developments with the commissioning of the 15MW OEC3 in 2008 and the planned commissioning of the 32MW OEC4 in November 2020. Recent field modelling techniques will be reviewed as will well testing results. There will also be a discussion on the Non Condensable Gasses (including CO_2) which occur in the field and how these have changed over the past 20 years of geothermal generation.

Notes

The Future of Hydrogen for NZ

Linda Wright

Chief Executive,
New Zealand Hydrogen Association

Throughout her 20-year career Linda has been at the forefront of driving innovation and change across the sustainability, solid waste and renewable energy sectors.

Linda has an extensive global network across the hydrogen value chain and understands intimately the value proposition for renewable hydrogen, and in New Zealand in particular. In 2016 Linda founded a private sector consortium to progress the delivery of hydrogen infrastructure, which supported by the Government, transitioned to become the New Zealand Hydrogen Association in 2018. Linda is the Chief Executive of the Association and is committed to delivering its objectives of facilitating the delivery of hydrogen solutions both domestically and for export.

Linda has been involved in progressing technical aspects of hydrogen production, storage, demand and end-use scenarios and she is currently developing strategic alliances with private sector entities to deliver a range of hydrogen projects across New Zealand. She is also engaged with international partners to advance the role that

hydrogen can play in the transition to a low emission future and to position New Zealand at the forefront of the global hydrogen economy.

Notes

42nd New Zealand Geothermal Workshop

Monday 23 November			
3.00	**Registration Open**		
5.30-7.00	**Welcome Reception | Waitangi Treaty Grounds**		
Tuesday 24 November			
8.00	**Registration Open**		
8.30	**Housekeeping**		
8.45	**Welcome and Opening**		
9.00	**GLOBAL GEOTHERMAL MOVEMENTS. WHAT'S HAPPEN IN THE WORLD OF GEOTHERMAL, CURRENT FOCUS, LATEST THINKING, AND GLOBAL TRENDS** Keynote Speaker | Andrea "Andy" Blair		
9.45	**Morning Tea**		
	Session 1.1. Environmental **Treaty Room 1**	**Session 1.2. Reservoir Engineering 1** **Treaty Room 2**	**Session 1.3. -Geoscience 1** **Rangitira Room**
10.15	51 | ENVIRONMENTAL BASELINE SURVEY FOR GEOTHERMAL DEVELOPMENT AT KIBIRO GEOTHERMAL PROSPECT IN UGANDA – Ouma ***(INTERNATIONAL PRESENTATION)***	28 | SWANHILD. NUMERICAL PRESSURE TRANSIENT ANALYSIS USING THE VOLSUNG GEOTHERMAL RESERVOIR SIMULATION PACKAGE – Mclean	105 | INVESTING IN EXPLORATION GEOSCIENCE AND INNOVATION. A GIS-BASED GEOTHERMAL RESOURCE PRIORITISATION TOOL FOR TOHOKU REGION, JAPAN – Bignall
10.30	80 | ECOLOGICAL INFORMATION FOR GEOTHERMAL SITES IN WAIKATO REGION – Beadel	116 | REPRESENTATION OF UNKNOWN PARAMETERS IN GEOTHERMAL MODEL CALIBRATION – Nicholson	42 | A REVIEW OF THE HYDROGEOLOGY OF THE TAUHARA DOMESTIC BORES, TAUPŌ, NEW ZEALAND – Lebe
10.45	37 | CHANGING RESOURCE MANAGEMENT OF SURFACE WATER ALLOCATION TO MEET GEOTHERMAL DRILLING DEMANDS – Collins	123 | THE ROLE OF THERMAL STRESS IN ENHANCING THE RESERVOIR PROPERTIES OF ENHANCED GEOTHERMAL SYSTEMS – Aliyu	9 | THREE NEW HOT SPRING VENTS EXPOSED AT ORAKEI KORAKO GEOTHERMAL FIELD, NEW ZEALAND – Lynne
11.00	47 | SINTER-FORMING SPRINGS AND GEYSERS OF THE WAIKATO REGION – Luketina	12 | AN UPDATED COMPUTER MODEL OF ROTORUA GEOTHERMAL FIELD – Dekkers	25 | IMAGING FEEDZONE DIVERSITY. CASE STUDIES FROM SUMATRA, INDONESIA AND THE TAUPŌ VOLCANIC ZONE, NEW ZEALAND – Wallis
11.15	44 | GREENHOUSE GAS EMISSIONS FROM NEW ZEALAND GEOTHERMAL. POWER GENERATION AND INDUSTRIAL DIRECT USE – Mclean	140 | ESTIMATING WAIRAKEI'S 50 YEARS AND 100 YEARS MWE POTENTIAL CAPACITY FROM A CALIBRATED NATURAL STATE MODEL USING EXPERIMENTAL DESIGN (ED) AND RESPONSE SURFACE METHODOLOGY (RSM) – Ciriaco	50 | BLACK TERRACE, ROTOMAHANA – White
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11.45	EASTLANDS | INDUSTRY UPDATE	43 | PATCHING HELE-SHAW CELLS TO SIMULATE SILICA SCALE DEPOSITION IN DISCRETE FRACTURE NETWORKS – Aghajannezhad	138 | GEOLOGICAL MODEL & PERMEABILITY FRAMEWORK OF BUKIT DAUN GEOTHERMAL FIELD, INDONESIA – Ikhwan ***(INTERNATIONAL PRESENTATION)***

Tuesday 24 November (continued)

12.00-1.30	**Lunch and Poster Session.**		
	18 | NEW ZEALAND'S REGULATORY AND PLANNING FRAMEWORK FOR CONVENTIONAL GEOTHERMAL RESOURCE USE – Kissick		
	20 | GEOCHEMISTRY OF EXTENSIONAL–TYPE GEOTHERMAL SYSTEMS IN UGANDA – Twesigye		
	23 | A REVIEW OF SMALL–SCALE GEOTHERMAL POWER PLANTS IN JAPAN AND ITS OPPORTUNITIES FOR NEW ZEALAND'S GEOTHERMAL BUSINESS – Imamura		
	31 | A NEW NUMERICAL MODEL OF AMATITLAN GEOTHERMAL SYSTEM, GUATEMALA – Xicara		
	40 | A COMPARATIVE WATER GEOCHEMISTRY STUDY OF FIVE GEOTHERMAL FIELDS IN THE TAUPO VOLCANIC ZONE. ATIAMURI, MOKAI, NGATAMARIKI, WAIKITE, AND WAIOTAPU – Lebe		
	75 | USE OF ICE PLUGS IN GEOTHERMAL ANTI–SCALANT TUBING SYSTEMS – Duque		
	121 | CHARACTERIZATION OF HULULAIS SUBSURFACE ROCK FORMATION AND ITS IMPLICATION TO STRATOVOLCANO FACIES MODEL. HULULAIS GEOTHERMAL FIELD, INDONESIA – Nusantara		
	126 | GEOLOGY FAULT NETWORK OF HULULAIS GEOTHERMAL SYSTEM, BENGKULU, INDONESIA – Nurseto		
	127 | VOLCANOSTRATIGRAPHY OF HULULAIS GEOTHERMAL FIELD, BENGKULU, INDONESIA – Pratama		
1.00	**NZGA AGM**		
1.30	**NZGA | INDUSTRY UPDATE**		
1.45	**MB CENTURY | INDUSTRY UPDATE**		
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2.30	MERCURY ENERGY | INDUSTY UPDATE	130 | HE PUNA I RAWEKE, HE PUNA WHAKATŌTŌ – Severne	139 | A CONCEPTUAL APPROACH TO "3-D PLAY FAIRWAY" ANALYSIS FOR GEOTHERMAL EXPLORATION AND DEVELOPMENT – O'Brien
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3.00	GOETHERMAL NEW ZEALAND | INDUSTRY UPDATE	128 | TE AHI TIPUA KI TĀHORAKURI A130. ESTABLISHING AN ECONOMIC DEVELOPMENT PLAN FOR WHANAU & HAPŪ IN DEGRADED GEOTHERMAL ENVIRONMENTS – Kora	
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4.00	26 | NGATI TUWHARETOA GEOTHERMAL ASSETS LTD REBOILER PLANT WATER/STEAM CHEMISTRY IMPROVEMENTS TO RESOLVE ONGOING CORROSION ISSUES – Addison	6 | AN UPDATED COMPUTER MODEL OF MONTSERRAT GEOTHERMAL FIELD – O'Sullivan	JACOBS | INDUSTRY UPDATE
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4.30	97 | DEI, DOUBLE ENERGY INPUT. A NOVEL MODEL FOR ELECTRICITY GENERATION – Ramirez	10 | ON THE CHOICE OF PRIMARY VARIABLES IN TRANSIENT GEOTHERMAL WELLBORE MODELLING – Tonkin	DOBBIE | INDUSTRY UPDATE

Wednesday 25 November

8.45	**Housekeeping**		
9.00	**GEOTHERMAL RESEARCH IN COLOMBIA. LESSONS LEARNED AND FUTURE PERSPECTIVES** **Keynote Speaker | Daniela Blessent *(INTERNATIONAL PRESENTATION)***		
9.45	**GNS | INDUSTRY UPDATE**		
10.00	**Morning Tea**		
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12.00	71 | MANAGING DEBRIS IN GEOTHERMAL PRODUCTION FLUID – Rivera Diaz		THORNDON COOK | INDUSTRY UPDATE
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2.15	**CONTACT ENERGY | INDUSTRY UPDATE**		
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5.00	NZTE | INDUSTRY UPDATE ***(INTERNATIONAL PRESENTATION)***	89 | GEOTHERMAL DEVELOPMENT. A GAME OF CHANCE AND WIT – Potter	52 | CO2 DISCHARGE FROM LAKE ROTOITI, NEW ZEALAND – Yang
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7.00	**NZGW Conference Dinner**		
10.30	**The Duke of Marlborough Hotel | Russell**		

Thursday 26 November

8.45	**Housekeeping**		
9.00	**THE FUTURE FOR HYDROGEN IN NZ** **Keynote Speaker | Linda Wright**		
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11.00	**WHAKAREWAREWA | INDUSTRYUPDATE**	84 | WELL INTERVENTION AND ENHANCEMENT IN DIENG GEOTHERMAL FIELDS, INDONESIA – Elfajrie ***(INTERNATIONAL PRESENTATION)***	104 | COVID-19 AND OIL PRICE DROP'S IMPACTS TO THE GEOTHERMAL DRILLING PROJECT IN INDONESIA – Fininda ***(INTERNATIONAL PRESENTATION)***

Thursday 26 November (continued)

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Abstracts

3 | USING AIR-CAP TESTING TO MONITOR AND MEASURE GEOTHERMAL WELL CASING INTEGRITY

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Keywords: *Well Integrity, Casing Integrity, Well Inspection, Well Control, Process Safety, Geothermal Well Casing*

Monitoring and managing well casing integrity is an important part of safely managing geothermal wells over their lifetime. A failure of casing integrity can lead to contamination of shallow aquifers and ultimately could even lead to an uncontrolled blowout.

Historical methods for monitoring well casing integrity involve go-devils, casing corrosion caliper logging, camera surveys and pressure-temperature-spinner (PTS) surveys. Go-devils, casing corrosion caliper logging and camera surveys can give indications of physical damage with no information on whether integrity is compromised, whilst pressure-temperature-spinner surveys can give results on well casing leaking but only if the conditions are suitable to indicate the loss of containment.

Session 5.1

4 | FUTURE SUCCESS LOW TEMPERATURE MICRO GEOTHERMAL POWER GENERATION

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Keywords: *Geothermal, Organic Rankine Cycle, Power Generation, Energy Efficiency*

Low temperature, micro geothermal generation offers significant renewable energy opportunities worldwide. In the past low temperature geothermal and co-produced fluids were considered a nuisance and uneconomical for power generation. Today advances in technology are available to tap this prevalent resource to generate fuel-free, emission-free power, but unfortunately due to a lack of knowledge on technologies available for sustainability, the industries opportunity to utilize low temperature resources is often overlooked.

We are working diligently to overcome this knowledge gap, communicating with the Industry that a solution exists for the development of these resources and coupled with the growth in electricity usage and environmental concerns of the use of fossil fuels for power generation, they should no longer be overlooked.

Currently, the majority of geothermal power production that occurs is on the multi megawatt scale that require investment in resource development and infrastructure. There are however thousands of existing bore holes available from exploration for oil and gas, exhausted production wells, exploration for large geothermal resources and natural hot water springs that can be tapped for sub MW scale powerplants with minimal infrastructure and impact on local environments.

This presentation will discuss the advances in technology enabling the economic use of low temperature geothermal resources for power generation and application as bottoming plants to improve efficiency of existing geothermal infrastructure. It will cover the development and application of Organic Rankine Cycle technology incorporated in compact heat to power generation equipment, the lessons learnt, case studies of installed systems and future developments including the optimization of equipment for use of low global warming potential refrigerants.

This presentation will also include incorporation of power generation as part of direct use systems, containerized systems and potential for efficiency gains in existing high capacity geothermal plants.

Session 8.2

5 | FUTURE GEOTHERMAL GENERATION STACK – FACTORS INFLUENCING NEW GEOTHERMAL PROJECTS IN NZ TO 2060

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Keywords: *Geothermal, generation, New Zealand, 2060, GHG*

This paper is based on a review that was commissioned by the Ministry for Business, Innovation and Employment (MBIE) in consultation with Transpower, with the objective of estimating the possible timing and cost of future geothermal projects in New Zealand over a 40-year horizon.

Access to resources is likely to constrain the pace of development as well as project cost and electricity price. Regulatory and consenting difficulties may lead to delays for future projects.

It is not expected that new technology will greatly reduce the cost of future geothermal generation nor significantly extend the geographical spread of its coverage to many lower-temperature resources. Thus, future large-scale development is likely to continue to be within the Taupō Volcanic Zone and at Ngāwhā in Northland.

Geothermal generation can run in a load-following manner, but the most economic use of geothermal generation will remain as base load because of the high fixed cost associated with the resource development. Previous studies in New Zealand have over-stated the greenhouse gas (GHG) emissions of existing and future geothermal plants. More specific figures are given based on actual recent data for developed fields, as well as revised estimates for greenfields. The present MW-weighted average emissions intensity for existing geothermal projects is 76 gCO_2eq/kWh (2018), which has been steadily declining (from 91g CO_2eq/kWh in 2015).

Greater future direct use of geothermal energy is generally expected to be complementary with rather than competitive to electricity generation or to be based on lower-temperature resources. Scaling factors based on enthalpy and project size have been applied to the power plant portion of the project cost. On this basis capital costs range from 4,734 to 9,767 NZD/kW with a weighted average of 5,782 NZD/kW.

The total estimated available future geothermal generation by 2060 is 1,035 MW. This total is slightly higher than previously presented (MBIE 2016), but it is likely that many projects will be commissioned later than previously assumed.

Session 6.2

6 | AN UPDATED COMPUTER MODEL OF MONTSERRAT GEOTHERMAL FIELD

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Keywords: *Montserrat, geothermal model, natural state, inverse modelling*

The model of the geothermal field on Montserrat Island, developed at the University of Auckland in 2018, has been updated in the following three ways. First, the model grid was extended to the south-east to include more of the area around the Soufrière Hills Volcano, and the grid was refined. Secondly, temperatures inferred from a seismic velocity anomaly model (Ryan & Shalev, 2014) were included in the suite of data to be used for model calibration. Thirdly, three software packages were used for parameter estimation with the natural state model, namely: iTOUGH2, PEST and iWaiwera. iWaiwera uses the adjoint method to evaluate derivatives efficiently and therefore it was able to very quickly estimate a large number of model parameters.

A good match to the downhole temperatures in wells Mon-1 and Mon-2 was obtained as well as a good match to the inferred temperatures at three elevations.

Session 3.2

8 | A PRACTICAL APPLICATION OF CHLORIDE MASS BALANCE METHOD TO THE EVALUATION OF A GEOTHERMAL STEAM GATHERING SYSTEM IN INDONESIA

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Keywords: *Geothermal, power station, tracer testing, separator performance.*

A new geothermal power plant with an 85 MW generation capacity was built last year in Muara Laboh, West Sumatra, Indonesia. The double-flash geothermal steam generation system consists of two high pressure separators and one low pressure separator. As the performance of the separators is critical to the safe and efficient operation of the turbines, a testing program was developed and conducted to verify the performance of the separators.

A key indicator of separator performance is the steam dryness measured on the pipeline downstream of the separator. A natural tracer mass balance method is used to measure the steam dryness, with chloride selected as the natural tracer due to its abundance in geothermal fluids and being preferentially dissolved in brine rather than in steam.

Representative steam and brine samples were collected from steamline and brineline test points downstream of the separators and analysed for chloride and sodium in the laboratory. These chloride and sodium concentrations are used to calculate the steam dryness using a mass balance method. Special traversing isokinetic probes were developed and successfully used to collect representative steam samples in the tests.

Session 6.3

9 | THREE NEW HOT SPRING VENTS EXPOSED AT ORAKEI KORAKO GEOTHERMAL FIELD, NEW ZEALAND

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Keywords: *Reactivation of buried hot spring vents, changes to surface activity, Orakei Korako, Ground Penetrating Radar.*

At Orakei Korako geothermal field, Taupo Volcanic Zone, New Zealand, three new hot spring vents appeared in 2019, underneath and adjacent to the boardwalk. These vents were buried and have now been reactivated following a small hydrothermal eruption. Two of these vents currently have 98°C clear, blue water at their base while the third vent is steaming. Prior to exposure of these three vents, this site had elevated near-surface temperatures for many years which we recorded at 100 °C at 0.5 m depth during our repeated site visits. A survey undertaken in 2012 to assess heat migration pathways at Orakei Korako documented hydrothermal alteration in the shallow subsurface at the site where the three new vents are now visible.

Session 1.3

10 | ON THE CHOICE OF PRIMARY VARIABLES IN TRANSIENT GEOTHERMAL WELLBORE MODELLING

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Keywords: *wellbore, multi-feed, transient, two-phase, simulation, finite volume method, primary variables*

Transient flow in a geothermal wellbore is modelled using equations for conservation of mass, momentum and energy. Additional constitutive equations that describe phase slip, heat transfer and frictional effects are also required for model closure. The transient wellbore simulator described in this paper solves discrete two-phase conservation equations numerically using the Newton-Raphson procedure. Additionally, the constitutive equation describing phase slip is included in the set of equations to be solved implicitly. This method requires four primary variables, however, the best choice of the primary variables is not clear. This paper discusses the use of different combinations of primary variables in our transient geothermal wellbore simulator. The numerical performance of each model is assessed using a set of problems that have been developed to test the transient simulator. This suite of test problems covers a range of operating conditions and serves as a benchmark for future simulator development. It was found that using pressure, temperature (swapped with saturation for two-phase conditions), vapour velocity and liquid volume flux resulted in the best numerical performance for all cases tested.

Session 3.2

11 | DEVELOPMENT OF A TRANSIENT, MULTI-FEED GEOTHERMAL WELLBORE SIMULATOR

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Keywords: *wellbore, multi-feed, transient, two-phase, simulation, validation*

Simulation of the flow in a geothermal wellbore is an important reservoir engineering task, but most existing geothermal wellbore simulators can only deal with steady-state conditions. This paper discusses the theoretical background of a transient geothermal wellbore model that is currently under development. The simulator is capable of modelling transient single and two-phase flow in wells with multiple feed-zones. A geothermal wellbore simulator solves the conservation of mass, momentum and energy equations governing the flow in a geothermal wellbore. These, along with the additional equations required for model closure, are presented. These governing equations are discretised and solved numerically using the Newton-Raphson procedure. The simulator is tested using analytical solutions for simplified single-phase flow situations. Steady-state validation cases are presented for both single-feed and multi-feed wellbores and a simulation of the transient behaviour of a geothermal production well is presented as a test case. Finally, further applications of the simulator are discussed.

Session 3.2

12 | AN UPDATED COMPUTER MODEL OF THE ROTORUA GEOTHERMAL FIELD

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Keywords: *Computer modelling, Rotorua*

Two improvements have recently been made to the model of the Rotorua Geothermal Field, developed at the University of Auckland. First, a finer, regular rectangular model grid is used. Secondly, a Leapfrog-based geological model and an alteration model are used to better define the permeability structure of the computer model.

With a new regular rectangular grid, we can run the model with AUTOUGH2 or Waiwera, and with the Waiwera version we are able to use iWaiwera for rapid parameter estimation (inverse modelling).

With this computer model, based on a better geoscientific conceptual model, we have obtained a good match to the large suite of downhole temperatures and to the pressure histories measured in a small number of wells.

Session 1.2

13 | ACCURATE LOCATION OF FEED ZONES: ASSESSING OBSCURATION BY THE LINER IN GEOTHERMAL WELLS

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Keywords: *Completion testing, stage testing, well testing, geothermal wells, cold water injection, perforated liner.*

Feed zones in geothermal wells are typically identified primarily from pressure, temperature and spinner (PTS) data captured with a downhole tool during completion testing, when water is being injected into the well. Completion testing usually occurs after the slotted liner has been installed in the well, and it is frequently assumed that feed zone locations are at least partially obscured by the presence of the liner. In some wells there is also stage testing during drilling, to aid the decision on whether to continue drilling or not. Critically, stage testing occurs prior to the installation of the liner, and also captures PTS data. Some stage testing only captures data within the well casing down to the casing shoe. However, there are a number of examples with sufficient PTS data captured in the open-hole section to allow comparison to the results from completion testing. These examples show that the location and nature of the feed zones can be seen in much finer detail when the liner is not present.

The aim of this research is to quantify the degree to which the liner obscures the feed zone locations by comparing temperature logs acquired during open-hole testing (stage testing) with those acquired after liner installation (completion testing). Several field examples are presented, from liquid-dominated wells in the Taupō Volcanic Zone.

Session 5.1

14 | CAN THE REYKJAVÍK DISTRICT HEATING SYSTEM (DHS) BE USED AS A MODEL FOR A ROTORUA DHS? A COMPARATIVE STUDY

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Keywords: *Rotorua, Reykjavík, geothermal, district heating system, DHS, surface features, reservoir, infrastructure, funding.*

The Rotorua geothermal field is managed by the Bay of Plenty Regional Council under the Resource Management Act and provisions of the Bay of Plenty Regional Policy Statement and the Rotorua Geothermal Regional Plan. The latter is currently being reviewed as is required every ten years by the Resource Management Act 1991. Feedback during initial community engagement stages of the review included questions around the potential for a district heating system (DHS) in Rotorua based on the experience of the Reykjavík DHS. This paper presents a high-level desktop study comparing the Rotorua and Reykjavík geothermal fields. Aspects such as historic background, current development model for the fields, statistics of use, funding, costs, government input and administration of the field are discussed. The Reykjavík DHS was a pioneer engineering work which changed the way Icelanders lived. It evolved over decades of trial and error and significant governmental support. The Icelandic DHS suited perfectly a country with heat demand year-round and abundant geothermal resources, but a limited variety of other indigenous heating and energy options. Incommensurable differences between Reykjavík and Rotorua cities and access to the geothermal resource make the Icelandic DHS unsuitable for Rotorua. Some obstacles are technical, and while these could be overcome, solutions would be complex and costly, possibly making the system economically infeasible. Several other issues for a Rotorua DHS were greatly simplified with the Reykjavík municipality offering the utility service. The geothermal resource in Rotorua could be more efficiently and equitably utilised for residential space heating. However it is expected that better results would be achieved by fine-tuning the Rotorua Geothermal Regional Plan according to the local settings than replicating the Reykjavík DHS in Rotorua.

Session 4.2

15 | PENTANT EVACUATION FOR BINARY PLANTS

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Keywords: *pentane, evacuation, binary plant, Ngatamariki, geothermal power plant, vacuum pump*

Mercury owns and operates several Ormat binary plants located in the North Island of New Zealand. For each site n-Pentane is the motive fluid and its flammable nature presents challenges with respect to maintenance activities on pentane plants. Until recently Mercury has relied on specialized contractors or flooding vessels with water to enable hot work such as welding to take place on pentane equipment. With large binary units this approach is not always practical and for the past two years Mercury have undertaken significant research and planning to enable the safe evacuation of pentane plant.

A key focus for the project has been to assess and reduce risks associated with the evacuation procedure. With guidance from Ormat and collaboration with other New Zealand pentane site operators Mercury have established a guideline for evacuation of pentane plants.

The approach taken uses a combination of nitrogen purging and evacuation techniques to remove pentane from a unit. A key piece of equipment designed and fabricated by Mercury is a portable pentane evacuation skid for use at any of their pentane sites. This paper discusses the effectiveness of the pentane evacuation, lessons learned along with Mercury's plans to improve pentane safety in their plants.

Session 4.1

16 | GEOHEAT STRATEGY FOR AOTEAROA NEW ZEALAND – 2020 PROGRESS UPDATE

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Keywords: *Geoheat strategy, economic development, New Zealand, Action Plan, strategy implementation, low carbon energy, industrial symbiosis.*

The Geoheat Strategy for Aotearoa New Zealand 2017-2030 is a cross sector initiative working to increase the direct use of geothermal energy.

The Geoheat Strategy was formulated based on a consultative process undertaken in 2015 2017, and the first Action Plan was delivered in 2018-2019. This paper provides an update on strategy implementation, and in particular, introduces the second Action Plan, released in January 2020 for the period 2020-2021.

Discussed in this paper are:

- outcomes achieved through the 2018 and 2019 period,
- progress achieved overall towards the 2030 Strategy objectives,
- mechanisms currently being used to deliver the strategy outcomes,
- review of Strategy direction, and
- insight into current and future activities.

Session 4.2

17 | OPTIMAL SETTINGS FOR DIRECT GEOTHERMAL USE INVESTIGATED WITH NUMERICAL MODELLING

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Keywords: *Direct use, low-temperature geothermal, numerical modelling, TOUGH2, Monte Carlo simulation*

Geothermal energy has been used in the central part of the North Island of New Zealand since people first settled there. Traditionally it was used for bathing and cooking. During the 20th century, uses expanded to include heating and cooling of buildings, green houses and aquaculture farming. Direct geothermal use tends to be located in areas where there is a known heat source with easily accessible heated water; many of New Zealand's direct use applications are focussed within the Taupo Volcanic Zone, or in areas with hot springs such as Hanmer Springs in the South Island. With the New Zealand government's ambitious targets to reduce fossil fuel dependencies, clean and efficient sources of energy will become increasingly important. Determining the potential, and potential limitations, of low-temperature geothermal energy will be important to help in establishing the contribution that it can make to the nation's energy ambitions.

This project aims to identify the ideal settings for low-temperature heat extraction. We will use numerical modelling to determine what rock properties and thermal characteristics result in usable low-temperature geothermal systems. We will distinguish key settings that are suitable for different direct use technologies such as ground-source heat pumps, residential warm water extraction or direct heating for small-scale commercial industry. We can then start to build up a map of the most promising types of geothermal use for different regions in New Zealand.

Session 4.2

18 | NEW ZEALAND'S REGULATORY AND PLANNING FRAMEWORK FOR CONVENTIONAL GEOTHERMAL RESOURCE USE

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Keywords: *regulatory framework, planning framework, review, permitting, consenting, resource consent, geothermal electricity, governance, New Zealand, Geothermal: Next Generation (GNG), regional plan, statutory framework, resource management.*

In New Zealand, geothermal resources are treated as water resources, and their use is predominantly governed by broad environmental resource management legislation. Geothermal use and development projects are authorised by resource consents under the Resource Management Act by regional and district councils. Projects of this nature must also navigate a complex framework of interconnected legislation with implications at national, regional and district levels through policy documents and plans.

This paper summarises the current regulatory and planning frameworks that apply to the development and use of conventional geothermal resources in New Zealand. This review was undertaken to inform studies on the suitability of the existing planning framework for managing the potential future use of supercritical geothermal resources.

Poster

19 | NEW ZEALAND'S SUPERCRITICAL OPPORTUNITY: MOVING FROM POTENTIAL RESOURCE TO DEPLOYED TECHNOLOGY

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Keywords: *supercritical resources, strategy development, permitting frameworks, technology deployment, de-risk investment, Geothermal: Next Generation, earth energy*

Tapping into deeper supercritical resources to access significant reserves of higher temperature (400˚C-600˚C), sustainable, renewable geothermal energy is not a new idea. Yet, present levels of understanding are insufficient to offer industry-ready solutions for New Zealand.

We are working to develop a New Zealand supercritical heat strategy (2020-2050), looking to accelerate from today's understanding through to early deployment of applicable technologies by 2040. Sector-wide roll-out aims to align with New Zealand's aspirations to be "carbon zero" by 2050. The strategy will build on the scientific understanding of New Zealand's supercritical resources, account for international experiences, and propose work streams to address the technological, legal, regulatory, economic and other challenges to utilisation of supercritical resources.

This paper presents the current state of knowledge on New Zealand's supercritical opportunity and outlines the intended strategic review of barriers and opportunities, working with stakeholders across the New Zealand industry, researchers, business, Māori, and Government. The critical challenge is to go beyond conventional geothermal systems, in search of the scientific, technological, regulatory, market and societal solutions that together, will de-risk and accelerate New Zealand's supercritical exploration and development.

Session 5.3

20 | GEOCHEMISTRY OF EXTENSIONAL-TYPE GEOTHERMAL SYSTEMS IN UGANDA

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Keywords: *geochemistry, deep circulation, amagmatic, extensional*

The purpose of this paper is to explain the geochemistry of Uganda's amagmatic extensional-type geothermal systems, particularly the origin of the chemical properties and corresponding reservoir properties. This type of system is a fault bound deep circulation system unlike magmatic systems which rely on shallow magma chambers. The fault zones are tectonically active which ensures deep circulation and high permeability. These amagmatic systems have low to medium temperature sources with subsurface temperatures ranging between 100oC and 200oC. Deep circulation geothermal fluids are less chemically charged compared to those from magmatic systems due to low temperature sources. Geothermal fluids from most of Uganda's geothermal areas are of neutral to slightly basic pH (6.0-9.0) and can be classified as fresh water to moderately saline based on their recorded TDS and conductivity values. Their TDS varies depending on the surrounding rocks through which the fluids flow from the reservoirs to the surface where they manifest as hot springs. Fluids from South-Western Uganda geothermal prospects have a relatively low Cl concentration and are mainly classified as HCO3 type or SO4 type. Fluids from Western Uganda geothermal prospects have a relatively high Cl concentration and are mainly classified as Cl-HCO3 type or intermediate type with moderately high salinity in excess of 10,000 TDS. Possible subsurface temperatures for Uganda's hot springs range between 100oC and 250oC based on geothermometry and mixing models proving they are low to medium temperature sources. Soil-gas and gas-flux measurements along Kibiro, Buranga, Panyimur, Katwe and Ihimbo hot springs revealed concealed deep penetrating structures which control geothermal activity. The 3He/4He ratios of geothermal fluids from Kibiro fault-bounded geothermal system suggest no deep mantle signature. Stable isotopic studies of deuterium and oxygen-18 indicated high altitude fluid sources. Normally geothermal fluids contain <1ppm Mg content but most of Uganda's hot spring waters contain 1-10ppm Mg suggesting mixing with surface cold waters.

Poster

21 | EXPERIMENTAL DETERMINATION OF RATE CONSTANTS FOR THE BREAKDOWN OF THE ORGANIC TRACERS 2-NSA, 2,6-NDS, 2,7-NDS, 1,5-NDS AND 1,6-NDS UNDER GEOTHERMAL CONDITIONS

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Keywords: *tracer studies, naphthalene disulfonic acid, naphthalene sulfonic acid, NDS, NSA, experimental geochemistry.*

Naphthalene sulfonates are widely used in the geothermal industry as tracers. Experimental results show, however, that these compounds do have their temperature limits. Knowledge of the rate of thermal breakdown is essential to ensure successful tracer tests. In addition, information on the breakdown products could be useful in interpreting fluid temperature history. The main goal of this project is to broaden the understanding of the processes taking place when these tracers are exposed to conditions found in geothermal environments.

The experiments were conducted to measure the rate of the thermal breakdown reactions. Five polyaromatic (di)sulfonates: 1,5-naphthalene disulfonate (1,5-NDS), 1,6-naphthalene disulfonate (1,6-NDS), 2,6-naphthalene disulfonate (2,6-NDS), 2,7-naphthalene disulfonate (2,7-NDS) and 2-naphthalene sulfonate (2-NSA) were studied. Aqueous solutions containing NDS/NSA were sealed inside glass ampoules using an oxy-acetylene torch and placed in cold-seal pressure vessels. These were exposed to between 200°C and 330°C for different times from 20 hours to 3 months. The experimental solution consisted 0.05M NaCl at neutral pH. The various naphthalene sulfonates were analysed by high performance liquid chromatography (HPLC) using fluorescence detection.

The rate constants were estimated by least squares fitting of the results. These show that NDS breakdown rates are temperature dependent. Stability increased as follow: 1,5-NDS<1,6-NDS<2,6-NDS/2,7NDS <2-NSA. Additionally, 2-NSA and 1-NSA were detected as breakdown products of naphthalene disulfonates. 2-NSA and 1-NSA were not stable at 300˚C.

Session 6.3

22 | CONCEPTUAL MODEL OF OUTFLOW ZONE IN MOUNT UNGARAN GEOTHERMAL SYSTEM, SEMARANG, CENTRAL JAVA USING GEOLOGY AND GEOCHEMISTRY OF MANIFESTATION ANALYSIS

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Keywords: *caldera, geochemistry, Kendalisodo, outflow, Ungaran.*

This research is conducted in the outflow zone of Mount Ungaran geothermal system, Semarang, Central Java, Indonesia, i.e. Kendalisodo and surrounding which is located in the eastern and southeastern part of Mount Ungaran. The purpose of the study is to build the conceptual model of the Kendalisodo geothermal system. Methods used comprise of literature study, geological traverse mapping, water sampling, and geochemical study for anions, cations, gas, and stable isotopes δ18O, δ2H, and δ13C analysis. Geothermal surface manifestation in the study area includes Kendalisodo, Diwak, Derekan, and Kaliulo warm springs; with travertine and salt deposits in some areas. Fumarole and hot springs appear in the upflow zone of Gedongsongo. In the study area, there are two geothermal systems, i.e. Kendalisodo and Diwak system. These two systems are separated by the Old Ungaran Caldera. Both systems are non-volcanic and medium enthalpy systems. The Kendalisodo reservoir has a temperature of 170 ± 10˚C. The hydrothermal fluid of the Kendalisodo system originates from meteoric water catchment on the southeast slope of Mount Ungaran; the meteoric water is heated up by the remaining heat of Mount Kendalisodo intrusion. The fluid has experienced mixing with cold water before discharge in the upflow zone at the Kendalisodo area. The Kendalisodo geothermal system, geologically and geochemically, is different from the main geothermal system of Mount Ungaran (Gedongsongo). The Diwak geothermal system has a reservoir with a temperature of 160 ± 10˚C. The hydrothermal fluid of the Diwak system is also from meteoric water, which is heated up by high heat-flow and/or overpressure system. The fluid then flows upward through the Derekan Fault and discharges in the upflow zone as the Diwak and Derekan warm springs. The fluid also flows laterally through the Derekan Fault and mixed with formation water to form Kaliulo warm spring in the outflow zone.

Session 8.2

23 | A REVIEW OF SMALL-SCALE GEOTHERMAL POWER PLANTS IN JAPAN AND ITS OPPORTUNITIES FOR NEW ZEALAND'S GEOTHERMAL BUSINESS

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***Keywords:** Japan, Onsen, small-scale geothermal power plant, direct use*

The word 'Onsen' can be found in the oldest Japanese historical documents called 'Kojiki' written in the early 700s. As of the end of March 2019, there are 27,421 Onsen hot spring wells all over Japan. Historically, Japanese people have used these hot springs for bathing, and this is associated with tourism and in many cases, they are used for medical purposes. These historical Onsen are specifically defined by Japanese law in the Hot Spring Act 1948 and these hot springs are subject to protection. Today, 87% of direct use cases of geothermal energy are for those Onsen while its use has also diversified to a variety of purposes such as greenhouses for horticulture, aquaculture to grow not only prawns but also eels, tilapia, softshell turtles, tiger puffer and sturgeon at different locations. In recent years, hot spring water has also been used to generate electricity and there are 60 such power plants in Japan. All of them are less than 2 MW installed capacity and most of them were built after 2011 when the Japanese government introduced the Feed-In Tariff system.

What does this mean for New Zealand's geothermal businesses? There may be hints for the direct use of geothermal energy in New Zealand since in the Japanese case use is unique, very diversified and the number of those direct uses is greater. The author is very confident that Japan and New Zealand can fruitfully collaborate in this area in terms of direct investment. Indeed, The author is very positive for this and it is a chance for New Zealand business to expect some return and trade benefits. We can also sell our advanced New Zealand technologies and services in Japan such as subsurface analysis and any other hot-spring-related services.

In this paper, we want to share some hints for New Zealand businesses wishing to work in Japan and identify any possible opportunities for New Zealand businesses to work in Japan.

Poster

24 | GENDER MAINSTREAMING IN THE DEVELOPMENT OF DIENG AND PATUHA GEOTHERMAL FIELD, INDONESIA

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***Keywords:** Gender, Gender Mainstreaming, Social, Geothermal Development*

Indonesia ranks 116th out of 189 countries on the 2018 Gender Development Index (GDI). Nationally, female development still lags behind compared to men. From 2010, the development of men has a "high" status with a Human Development Index (HDI) above 70 while the development of women is still in the range of the 60s and has a "moderate" status. This is what causes Indonesia's GDI to still be below 100 over the period 2010-2017.

In Indonesia, the female position in many categories (representation, employment, etc.) is lower compared to that of men. The development of a geothermal project provides hope and opportunity for the communities in the project area, including female groups/ villagers. In developing geothermal projects in Patuha (West Java) and Dieng (Central Java),

Indonesia, PT Geo Dipa Energi conducted a gender assessment. Low participation of women in public consultations was found, as well as poor access to various job opportunities in geothermal projects.

In addition, based on available data, there are still gaps in employment opportunities between men and women in geothermal projects in both regions. One of the main causes is the local norms that lead women to carry multiple responsibilities in domestic and public spheres, thereby reducing the capacity of women to access various opportunities from the project.

This paper presents challenges and opportunities in mainstreaming gender at a geothermal project in Indonesia, in particular during the preparation period in which the gender assessment was being conducted. The series of public consultations and women's group discussions indicated that geothermal project development should consider the impact on women and other vulnerable groups. The project developer should clearly state the opportunities for female participation in project implementation, as part of the company's commitment towards improving the local socioeconomic standards.

Session 4.2

25 | APPROACHES TO IMAGING FEEDZONE DIVERSITY WITH CASE STUDIES FROM SUMATRA, INDONESIA AND THE TAUPŌ VOLCANIC ZONE, NEW ZEALAND

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Keywords: *Rantau Dedap, Muara Laboh, Ngatamariki, Wairakei, borehole image log, fracture, geomechanics*

There is a fast-growing inventory of studies on borehole image logs acquired in geothermal reservoirs as more operators elect to deploy this technology. Our contribution to this inventory is to illustrate how judicious use of these data may reveal the geologic controls on permeability. We also provide an open source Python library that enables others to replicate the methods described herein. Our study includes a discussion of geometric sample bias, as well as those data integrity and geological factors that influence fracture frequency. We also demonstrate slip tendency modelling as an approach to identifying fractures that may be relevant beyond the borehole wall, which is key for geothermal wells where thermal stresses have enhanced both the number and apparent aperture of fractures at the borehole wall. We illustrate these methods using seven well case studies from a wide range of lithologies, four reservoirs, and two tectonic settings—one dominated by a volcano-tectonic rift and the other a mega-shear zone. The reservoirs are Muara Laboh and Rantau Dedap in Indonesia and Ngatamariki and Wairakei in New Zealand.

Session 1.3

26 | NGATI TUWHARETOA GEOTHERMAL ASSETS LTD REBOILER PLANT WATER/ STEAM CHEMISTRY IMPROVEMENTS TO RESOLVE ONGOING CORROSION ISSUES AND PREVENT FUTURE TUBE FAILURES

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Keywords: *Corrosion, reboiler. Hydrogen sulfide, sodium hydroxide, film forming substances*

The Ngati Tuwharetoa Geothermal Assets Ltd (NTGA) Kawerau reboiler plant has suffered from major corrosion and plant failure issues since commissioning, including the premature complete replacement of the tube bundles. These corrosion related failures have occurred due to water/steam chemistry issues and interactions with plant materials not being fully considered and understood in the design process of the plant.

In 2018 a major root cause analysis was undertaken into the failures that included a detailed chemical and metallurgical investigation and successfully identified the failure mechanisms. A number of simple chemical treatment changes, including hydrogen sulfide neutralization, pH correction and the application of corrosion inhibiting film forming substances (FFS), were carried out to successfully mitigate ongoing corrosion of the plant and to significantly extend asset life.

Session 3.1

27 | GEOTHERMAL STEAM TURBINE DEPOSITION FUNDAMENTALS AND PROPOSED IAPWS GEOTHERMAL STEAM PURITY LIMITS

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Keywords: *steam turbine, steam purity, deposition, scaling, corrosion.*

Geothermal steam turbines are prone to forming significant turbine mineral deposits under suboptimal steam purity and quality conditions. These deposits can then lead to operational and maintenance issues that are detrimental to turbine performance, reliability and availability

The mechanisms related to how deposits form within geothermal steam turbines are discussed in relation to both vaporous and mechanical transport of impurities in steam. Saturated and Superheated steam conditions and their impact on deposition within a geothermal turbine are reviewed. The formation and behavior of the liquid films that form within geothermal steam turbines are outlined and the impact on these liquid films by reheating due to heat transfer across a turbine disk or shaft is discussed.

Session 3.1

28 | SWANHILD: NUMERICAL PRESSURE TRANSIENT ANALYSIS USING THE VOLSUNG GEOTHERMAL RESERVOIR SIMULATION PACKAGE

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Keywords: *Swanhild, Volsung, well testing, pressure transient analysis, numerical*

The need for numerical models for geothermal pressure transient analysis (PTA) has been long recognised. Until recently the only tools/software available for PTA in the geothermal industry have been based on analytical models, which are too simplistic to represent geothermal wells. The lack of numerical tools for PTA led to the creation of the numerical PTA framework (McLean and Zarrouk, 2017), which is a set of guidelines on how to set up and run numerical PTA models using TOUGH2 and Python. Analysis of the model results and comparison to field data required skills in writing auxiliary computer scripts by the individual reservoir engineer. Despite assistance from the many functions built into Python, numerical PTA was still relatively time-consuming and cumbersome to perform. Specialized software was necessary to bridge this gap, and hence Swanhild was developed, based on the numerical PTA framework guidelines.

This study presents testing of the new Swanhild software application. Swanhild forms part of the Volsung geothermal reservoir simulation package and is specifically designed to run numerical PTA simulations using the standardised approach as specified by the numerical PTA framework. The application makes numerical PTA straightforward, including model setup and inversion with field data. The model matching can be performed manually or automated using non-linear regression. A comparison between Swanhild and the TOUGH2/Python implementation of the numerical PTA framework across a range of model parameters reveals no practical difference in the model results, thus validating Swanhild for use in numerical PTA. Software licenses for Swanhild are available for free as part of an ongoing effort to enable and promote quality PTA in geothermal wells.

Session 1.2

29 | HYDROGEOCHEMICAL CHARACTERISTICS OF GEOTHERMAL WATER IN MOUNT LAWU, INDONESIA

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Keywords: *Mount Lawu, Indonesia, hydrogeochemical.*

Mount Lawu is a stratovolcano located in the border of Central and East Java province, Indonesia. Mount Lawu holds a vast potential of geothermal energy indicated by widely distributed thermal manifestations. This study aims to evaluate the hydrogeochemical characteristics on the western side of Mount Lawu and also to create a simple preliminary hydrogeochemical model based on geological and geochemical data. Surface manifestations showed all types of chloride, sulphate and carbonate water are present among both hot and cold fluid chemistry with pH ranging from 1-2 and 6-7 on the central and proximal facies of Mount Lawu respectively. Isotopic analysis of thermal water indicates both magmatic water and meteoric water that circulates within Mount Lawu geothermal system. Fe and As concentrations appear to be higher in some manifestations indicating intense rock-fluid interaction from the reservoir to the surface. Moreover, Na/K geothermometer indicates an intermediate-high enthalpy system. Based on these findings, a hydrogeochemical model was synthesized and also proved that Mount Lawu is a volcanic geothermal system with intermediate-high enthalpy energy.

Session 7.3

30 | SIGNIFICANCE OF PRESSURE LET DOWN STATION IN MITIGATING EFFECTS OF SILICA PRECIPITATION IN STEAM PIPELINES: A CASE STUDY OF OLKARIA 280MW PROJECT

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Keywords: *PLDS, De-superheating, Silica*

In 2012, KenGen began construction of two geothermal power plants: 140MWe Olkaria IV and 2 additional units, units 4 & 5 (Olkaria IAU) adding140MWe to Olkaria I and thereby increasing power generation in Kenya by 280MWe. The two power plants have turbine inlet pressures of 6.0 bara and 5.0 bara for Olkaria IV and Olkaria IAU respectively. This meant the steam gathering systems would also operate at that pressure.

While the project was in progress, a new optimization study reported that the deeper wells in Domes, East and North East fields which serve the power plants with steam tap fluids from reservoirs that are rich in silica. The issue was compounded by high enthalpies of the wells averaging 1790kj/kg to 2300kj/kg thereby increasing silica solubility and chances of precipitation in steam pipelines.

The concern raised resulted in KenGen incorporating Pressure Let down Stations (PLDS) in the two power plants that would maintain the steamfield pressure at the maximum but within the constraints of the already selected equipment, and then expand the steam adiabatically to drop its pressure to required values.

This paper will use the case study of these power plants to highlight the significance of the Pressure Let down Stations in controlling the effects of silica deposition in steam gathering systems.

Session 7.2

31 | A NEW NUMERICAL MODEL OF AMATITLAN GEOTHERMAL SYSTEM, GUATEMALA

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Keywords: *Reservoir modeling, Dual-porosity, New generator type DELT, AUTOUGH2, TIM, Py-TOUGH, Calcite scale.*

The Amatitlán geothermal field has a high-temperature reservoir with feed zone temperatures and pressures in most of the production wells reflecting boiling conditions. The existence of a shallow vapor-mobile two-phase region (i.e., a "steam cap") and a deeper extensive two-phase reservoir were confirmed by two wells (AMF7 and AMF8). Gas concentrations are variable but modest calcite scaling exists in AMF1RD. Temperature distribution suggests that the upflow of the Amatitlán geothermal system takes place beneath a significant area of the active Pacaya volcano. The revised conceptual model suggests that the outflow of the system flows laterally toward Lake Amatitlán.

A three-dimensional numerical model consisting of 11,240 grid blocks was developed for reservoir simulations. Natural-state and production/injection simulations for near 12 years of exploitation were conducted using this model and AUTOUGH2 simulator, TIM pre-and post-processor and Py-TOUGH scripts. TIM and Py-TOUGH were essential for optimizing the model block structure, adding meteoric recharge and background heat into the model, assigning the topography to the top surface of the model and to represent Lake Amatitlán, all required for dealing with the complexity of the real geothermal system. Simulated temperatures and pressures distribution in natural state match field data measured prior exploitation. For production history matching a dual porosity model was developed and it reproduces current

flow rates and enthalpy of produced fluid by the production wells. The model also reproduces pressure transient data of one monitoring well (AMF7). The effects of calcite scaling on production parameters of well AMF1RD is addressed in the model mainly by using the new generator type DELT, Yeh, A., et. al (2012).

The model is capable now for predictions. As an example, a base case scenario was run; this base case scenario was divided into two different cases: Scenario one considers continue production as it is now for the next fifteen years without taking into account scale in the best production well AMF1RD. The second scenario is the same case as scenario one but it takes into account scale in well bore and formation of AMF1RD. Results of simulated prediction scenarios are that by considering the scale issue during the simulation study, the simulated MW thermal are more realistic that the case that doesn't consider scale. The difference in terms of MW thermal for both scenarios is about 2% lower for the most realistic case. Simulations also show a decline on MW thermal for both cases of about 0.90 MW thermal per year.

Poster

32 | COMMUNITY ENGAGEMENT IN GEOTHERMAL DEVELOPMENT IN UGANDA. CASE STUDY OF KIBIRO GEOTHERMAL PROSPECT

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Keywords: *Community engagement, barriers, awareness, culture*

Geothermal development in Uganda like any other development projects in other parts of the world has been met with a number of non-technical barriers which when not properly handled can have devastating effects on projects. These non-technical barriers include lack of awareness and information by stakeholders on the concept of geothermal energy, very high economic expectations and various environmental misconceptions about such developments. The Kibiro Geothermal prospect has hot springs that have been held in high regard culturally by the Bunyoro Kitara Kingdom and its subjects for centuries. Therefore, the proponent has to convince the Kingdom and its subjects that these developments will have no effect on their cultural sites. However, these barriers can easily be mitigated by carrying out continuous and extensive geothermal sensitization, workshops targeting the relevant stakeholders. The Government of Uganda applied a number of strategies that include tours to Olkaria Geothermal project in Kenya, site meetings, social media outreach and information sharing, one on one interaction with opinion leaders, workshops with the cultural leaders of Bunyoro Kitara Kingdom. These strategies whose aim is to obtain a social license, gain trust and approval for the project have yielded good results. This notwithstanding, there are a number of barriers that are encountered by the project proponents which include mobilization of funds to implement the different engagement strategies.

Session 4.2

34 | COMMON PRACTICE OF FORMATION EVALUATION PROGRAM IN GEOTHERMAL DRILLING

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Keywords: *formation evaluation, cutting, coring, borehole image, drilling, geothermal*

Formation evaluation program in drilling operation, particularly geothermal drilling, is very much determined by the purpose and objective of drilling itself. During early exploration phase, the formation evaluation program is carried out by collecting as much subsurface information as possible. This was applied because of available subsurface data to support the development geothermal project are very limited. On the other hand, the program is very influenced and directly involve to the drilling operation that might risks the drilling operation, in term of well stability and well cost perspective. Thus, the effective and efficient techniques are highly required in the making of proper formation evaluation program.

The main purpose of formation evaluation is to get a better understanding of subsurface geology and developed geothermal system so the best future strategy of field development can be determined. By doing this evaluation while drilling, it will give an advantage to the drilling operation itself. Knowledge of the real-time drilled formation, in term of its behaviour, characteristic, and composition, will help the improvement of drilling performance and increase the well success ratio.

This paper will present the available technical guidelines that can be applied to evaluate the formation during drilling operation, completed by the pros and cons. Those techniques including drill cutting examination and analysis, drilling data interpretation, rock coring analysis, both conventional and sidewall coring, and well-logging, including PTS logging, acoustic and electric borehole imaging, and also other logging activity. All those techniques expected to enhance the better understanding of subsurface geology and improve the drilling operation.

Session 7.3

35 | CUSTOM PDC BITS SIGNIFICANTLY INCREASE DRILLING PERFORMANCE IN TAUHARA GEOTHERMAL DRILLING PROJECT

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Keywords: *PDC technology, drill bits, drilling performance, fixed cutter bits*

The use of polycrystalline diamond compact (PDC) bits in geothermal applications has always presented challenges in terms of bit durability, directional response, and economic viability of such bits in these applications.

This paper focuses on two sets of challenges associated with designing PDC bits in 20¾ in. and 12¼ in. sizes to drill through hard volcanic and sedimentary formations in the Tauhara geothermal field of New Zealand.

This paper discusses PDC drill bit design, cutter selection, root cause analysis of drilling dysfunctions, and other limitations affecting overall drilling efficiency. It will also demonstrate drilling parameter sensitivity analysis, drilling practices used to reduce bit damage while

improving overall drilling performance, and the economics for both sections.

For the above project, two bespoke bits were designed, built, and tested. This paper presents the results of these bit runs, the learnings made, and future iterations. It will show that the tailored bits outperformed all previous bit runs in the Tauhara field and saved the Operator significant drilling time.

Session 5.1

37 | CHANGING RESOURCE MANAGEMENT OF SURFACE WATER ALLOCATION TO MEET DRILLING RIG DEMANDS

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Keywords: *Resource Management Act 1991 (RMA), Water Supply, Surface Water, Drilling, Loss Control, River, Allocation.*

Access to water, as managed under the Resource Management Act 1991 (RMA) is becoming increasingly constrained in New Zealand. Geothermal drilling operations require relatively large amounts of surface water albeit on a variable and infrequent basis to provide for drilling mud and circulation fluids. As fluids are "lost" during drilling to the deep underground formations, more fluids and water are required to provide for safe and successful drilling operations. This paper identifies key policy issues involved with surface water allocation and use, through the lens of geothermal drilling and identifying several methods to effectively manage the resource during a well programme. Investigations into current water provision within two Council regions are discussed, as well as observations of how water is to be managed in New Zealand.

Session 1.1

40 | A COMPARATIVE WATER GEOCHEMISTRY STUDY OF FIVE GEOTHERMAL FIELDS IN THE TAUPO VOLCANIC ZONE: ATIAMURI, MOKAI, NGATAMARIKI, WAIKITE, AND WAIOTAPU

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Keywords: *Water chemistry, chloride, silica, sodium, potassium, magnesium, boron*

Our study involved a comparison of hot spring geochemistry data collected between 1905 and 2009 from five geothermal fields in the Taupo Volcanic Zone (TVZ), New Zealand. Atiamuri, Mokai, Ngatamariki, Waikite, and Waiotapu were chosen as the geothermal systems for this study for their east-west and north-south coverage of the central TVZ, their comparative data availability, and for representing development and protected systems. One neutral-chloride hot spring that best represented the deep reservoir fluid was chosen for each geothermal system. Water-type and geoindicator ternary diagrams were utilised for observing changes in each hot spring overtime. Chloride (Cl-), silica (SiO2), sodium (Na), potassium (K), magnesium (Mg), and boron (B) were the main parameters used for interpreting reservoir conditions and associated near-surface influences. Semi-qualitative concentration trend maps were constructed for comparing geochemistry trends between the five fields. The geothermal systems of Mokai and Ngatamariki as well as Atiamuri and Waikite which represented our East-West distribution of systems showed minimal similarities in geochemistry trends. Ngatamariki and Waiotapu were compared as the spatial relationship between these two fields is consistent with the major structural trend of central TVZ. They show definite trend similarities, especially for sodium concentrations between 1978 – 1984. Specific reasons or events causing similarities to occur between Ngatamariki and Waiotapu are not known. It has long been unclear if Waikite and Waiotapu are hydrologically connected. Geochemistry trends identified in our study for these two systems suggest they have dissimilar water chemistry, which may indicate separate geochemical controls. Caldera boundaries and lithological conditions surrounding the caldera-bounded Mokai and Atiamuri systems are identified as important factors for isolating fluids from these systems and minimising external influences on observed geochemical parameters. Our water chemistry study offers insights into comparing geochemistry trend changes at a regional scale by observing different geothermal systems with distinctive conditions.

Poster

42 | A REVIEW OF THE HYDROGEOLOGY OF THE TAUHARA DOMESTIC BORES, TAUPŌ, NEW ZEALAND.

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Keywords: *Domestic bore, direct use, Taupo, Tauhara, hydrogeology, aquifer*

Five hundred and twenty-four domestic bores have been installed for water and space heating in Taupō township, mainly within the resistivity boundary of the Tauhara geothermal field. Geochemistry data indicate that the dominant water type extracted from the allocated aquifer is steam-heated waters. Due to minimal data existing on the lithological conditions of the bores, lithostratigraphic data from well THM-18 is used for interpreting the subsurface stratigraphy of the allocated aquifer area. No significant variations in temperature-elevation relationship are observed at different geographical areas

across Taupō township. Elevation and bore depth measurements suggest that the Oruanui Formation is the most common lithological unit from which hot fluids are extracted. The Upper Huka Falls Formation is intersected by fewer bores and records lower temperatures than the overlying Oruanui Formation. Fluids exceeding 160 °C were encountered in the Middle Huka Falls Formation, however the formation is a less practical drilling target than the Oruanui Formation aquifer for future domestic bore drilling due to its situation at significantly greater depths. The Oruanui Formation is the most productive and most ideal target zone for future fluid extractions due having a reliable high temperature resource at a relatively shallow depth. Future monitoring of the bores could create a better understanding of the relationship between the domestic bores and surface geothermal features and streams, which have seen a general decline in discharge in recent years.

Session 1.3

43 | PATCHING HELE-SHAW CELLS TO SIMULATE SILICA SCALE DEPOSITION IN DISCRETE FRACTURE NETWORKS

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Keywords: *Silica Deposition, Computational Fluid Dynamics, Hele-Shaw Cell, Discrete Fracture Network*

Due to mineral deposition in geothermal reservoirs, the electrical production of geothermal power plants decreases over time. Specifically, silica can form extremely hard and dense scales not only in power-plant equipment and pipelines but also within and around wells, restricting flow and reducing power-plant efficiency. Understanding the effect of silica scaling on flow rates can inform the required maintenance during different stages of the geothermal plant lifetime. Accordingly, a detailed analysis of silica scale growth offers powerful insight to predict the productive lifetime of the reservoir and mechanical infrastructures. Fluid within many geothermal reservoirs is largely transported along a network of fractures. However, available simulation methods to study mineral deposition within large-scale fracture networks are computationally expensive. We have developed a new modeling framework based on representing individual fractures using the Hele-Shaw cell analogy and simulating fracture networks by connecting these Hele-Shaw cells together using pressure constraints at intersecting nodes of the computational mesh. This methodology allows the rapid computation of flows in realistically large fracture networks. This paper will discuss how this modeling framework can be used to study the transport of diluted specious in rock fractures, which provides a backbone for the simulation of silica scale deposition in a discrete fracture network.

Session 1.2

44 | GREENHOUSE GAS EMISSIONS FROM NEW ZEALAND GEOTHERMAL: POWER GENERATION AND INDUSTRIAL DIRECT USE

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***Keywords:** Carbon dioxide, methane, greenhouse gas, geothermal, emissions, direct use.*

Greenhouse gas emissions for geothermal power stations in New Zealand are reported annually under current regulations. The CO_2 and CH_4 emissions data are combined and reported as one CO_2-equivalent (CO_2e) emissions factor. In combination with the amount of steam used each year, and the MWh (net) of electricity generated that year, the overall geothermal emissions intensity for each power station can be calculated as gCO_2e/kWh(net). A recent study presented the emissions intensity for the 12 major geothermal power stations in New Zealand focusing on the calendar year 2018, with data back to 2010 for some stations. In this paper the emissions intensity is presented for the calendar year 2019, and compared with trends from previous years. In New Zealand the emissions intensity for geothermal power generation is on average an order of magnitude lower than for fossil fuels.

In most cases the geothermal emissions intensity numbers are calculated assuming that all of the CO_2 and CH_4 present in the steam entering the power station are released to the atmosphere during the power generation process. However in some geothermal plant designs a fraction of the gases are retained in the condensates, which are reinjected back into the reservoir. Accounting for the gases in the condensates results in a more accurate calculation of the actual emissions intensity. Another nuance of the emissions intensity for geothermal is that the numbers do not account for the benefits of geothermal fluids for direct use applications such as industrial process heat. Direct use projects utilise energy directly, as thermal energy, which is not accounted for in the emissions intensity data which only deals with electrical energy. Nevertheless the benefits of geothermal direct use are a very real, if invisible, part of the geothermal emissions intensity story, and examples are given.

Session 1.1

47 | SINTER-FORMING SPRINGS OF THE WAIKATO REGION, NZ

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***Keywords:** Waikato region, sinter, hot springs, geysers.*

Sinter-forming springs and geysers are among the rarest, the most vulnerable, the most spectacular and the most prized among the Waikato Region's geothermal surface features. This paper summarises a Waikato Regional Council (WRC) Technical Report titled Sinter-forming Springs and Geysers of the Waikato Region (Cody et al, 2020, in prep) herein after referred to as "Sinter Springs", that provides an inventory of sinter-forming springs and geysers in the Waikato Region (the Region), notes on their location, activity, characteristics, and any threats that they face. It is hoped that this report

will assist in the preservation of these features by providing a guide to assist further monitoring.

There are 169 sinter-forming springs in the Waikato Region, down from 668, and 51 geysers, down from 161, in the 1950s. The greatest loss of features was caused by the inundation of many features at Orakei Korako when the Ohakuri Dam was constructed for hydroelectric electricity generation, and by the extinction of features on the Wairakei-Tauhara Geothermal System due to the large-scale extraction of deep geothermal fluid for the Wairakei Power Station.

Ohaaki, Mangakino, Atiamuri, Ngatamariki, Mokai, and Rotokawa have also lost sinter-forming springs due to inundation of springs when hydro-electric lakes were created. Tokaanu-Waihi and Rotokawa have non-sinter-forming springs that are affected by lake and river level management.

WRC's policy framework under the Resource Management Act 1991 (RMA) protects these features. Consequently, there has been little change in numbers since the 1990s when the policy was formed.

Session 1.1

48 | TWENTY-FIVE YEARS OF GEOTHERMAL MONITORING BY WAIKATO REGIONAL COUNCIL: EMBRACING CHANGE, COLLABORATION, AND INNOVATION

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Keywords: *geothermal, monitoring, RMA, PSInSar*

Waikato Regional Council (WRC) has a statutory obligation under the Resource Management Act 1991 to monitor the state of the regional geothermal environment, keep records, and make those records available to the public.

Therefore, WRC undertakes geophysical, geochemical, and ecological monitoring of the region's geothermal environment, stores the data in a variety of databases depending on the data type, interprets the data and publishes reports in several media for different audiences. The WRC website provides environmental articles for a lay audience, Technical Reports, environmental indicators, and downloadable data. Papers are publicly available through the International Geothermal Association (IGA) papers database and through other open-access journals.

Monitoring is undertaken to determine the natural state of the regional geothermal resource, its variability, any trends and to identify any anthropogenic changes. This informs the policy development, resource allocation and organisation decision making processes to ensure that the resource is managed sustainably.

Monitoring is funded through resource consent holder annual charges and the general rate levied on regional landowners. This small income stream is augmented by collaboration with and support of other research bodies such as Crown Research Institutes (CRIs) and universities who have central government research grants.

WRC researchers have had significant success in developing or supporting the development of new monitoring techniques including remote sensing technology to provide system-wide and multi-system monitoring as well as interaction with groundwater and surface water, geothermal ecologies and the gradation from geothermal to non-geothermal environment.

Change is constant in our monitoring programmes as we embrace new information-gathering technologies, data collection, storage, retrieval, analysis and interpretation applications, and communication media. Collaboration with tangata whenua on Matauranga Maori physical and meta-physical monitoring is becoming more and more a part of what we do.

Session 2.2

50 | BLACK TERRACE, ROTOMAHANA

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***Keywords:** Black Terrace, Rotomahana, sinter, GPR, passive seismic tomography.*

Prior to 1886 there was widespread thermal activity around Lake Rotomahana. In addition to the Pink and White terraces, there were smaller sinter terraces, including one known as Black Terrace, or Te Ngawha a Te Tuhi. All of those features were either ruined or buried during the 1886 Tarawera eruption. The former locations of the Pink and White terraces are now beneath the enlarged Lake Rotomahana, but the Black Terrace site to the northwest is outside the former and current lake.

About two months after the Tarawera eruption, a hydrothermal eruption at the location of Black Terrace threw out rocks and mud, and the crater grew to ~180 m in diameter over two days before activity gradually waned over the next few weeks. Being surrounded by hills covered in unconsolidated eruption debris, this crater was rapidly infilled over subsequent years. It is no longer obvious on maps, aerial photos, or in the field.

Through a combination of geological and geophysical techniques, we believe that we have relocated the buried Black Terrace Crater, although it remains to be seen whether any sinter is preserved at depth.

Proximity to the crater is indicated by boulders (up to 1.5m diameter) that overlie Rotomahana Mud near the site. Those boulders are mostly rhyolite, but include several fragments of silica sinter.

There are indications from LIDAR of a partially preserved crater rim deposit around the inferred southern edge of the crater.

Ground Penetrating Radar (GPR) revealed possible normal fault features close to where the western crater rim was inferred to lie, and features that might represent a buried, partial ejecta apron to the west of the buried crater rim.

Passive seismic tomography data revealed a lateral east-west change, with hard reflectors located 35-50m below the ground surface within the bounds of where the crater floor is inferred to lie.

Session 1.3

51 | ENVIRONMENTAL BASELINE SURVEY FOR GEOTHERMAL DEVELOPMENT: CASE STUDY KIBIRO GEOTHERMAL PROSPECT, UGANDA

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***Keywords:** Geothermal, environment conditions, baseline data, mitigation measures.*

The shift to environmentally friendly energy sources is one of the main items on the agenda of global environmental debates. Geothermal energy is one of the resources that often are located in remote, forested and wildlife areas, whose environment is a source of social and economic necessities for Ugandans. Therefore, in order for government and stakeholders to assess the impact of geothermal projects on the environment, the developer must prepare a detailed Environmental and Social Impact Assessment (ESIA) for the project. The current state of physical, social and economic environments is defined in baseline surveys before a project begins and are necessary for the design and assessment of any project.

The potential impacts of a project cannot be determined without knowing the existing state of the environment. Baseline surveys will also be used to monitor the effects of projects during operation, such as physical, biological and socioeconomics aspects. The baseline data is built through collection and analysis of existing data, community consultation programs and specific field surveys. An Environmental and Social Impact Assessment (ESIA) is then carried out to discover early enough, if there would be any adverse effects on the environment and local ecosystems. An ESIA would ensure that any developments undertaken are environmentally benign and socially acceptable to stakeholders including geothermal energy development partners. In this article the Kibiro geothermal project serves as example. This project is anticipated to have both positive and negative environmental impacts based on baseline studies. However, the negative impacts can be contained through recommended mitigation measures.

Session 1.1

52 | CO_2 DISCHARGE FROM LAKE ROTOITI, NEW ZEALAND

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Keywords: *Lake Rotoiti; CO_2 flux; dissolved gases.*

Twenty percent of the surface area of Okataina Caldera is covered with lakes. Lake Rotoiti located at the northwest edge of Okataina Caldera, hosts numerous underwater hydrothermal vents. Western Lake Rotoiti has relatively shallow waters (10-40m) and is closely associated with Tikitere and Taheke geothermal fields. Plumes of gas and bubbling warm water can be observed in the lake resulting in a 10-20 MW geothermal heat flux of Central Basin located at the centre part of Lake Rotoiti. In this study, we present the results of a lake survey that focuses on surface CO_2 emission using the floating accumulation chamber method and sequential Gaussian simulation for processing the data. In addition, dissolved gas composition and surface CO_2 flux measurement give us a better understanding of the degassing pathways and mechanism of the geothermal fluids in Lake Rotoiti. The result of this lake survey benefits from the comparison of natural greenhouse gas output of Rotoiti to other volcanic lakes in Okataina Caldera and in New Zealand.

Session 6.3

55 | GEOLOGY OF EXTENSIONAL –TYPE GEOTHERMAL SYSTEMS IN UGANDA

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Keywords: *deep circulation, magmatic, amagmatic, extension-type geothermal systems*

Geothermal systems in East Africa are either magmatic or amagmatic/extensional-type systems. Magmatic driven systems rely on shallow magma chambers as their heat source for example in Ethiopia and Kenya while the extensional-type systems are associated with deep seated magma chambers. This clear distinction is highlighted in the subsurface temperature differences seen in the western and eastern branches of the East African Rift System. Most of Uganda's geothermal systems are non-magmatic deep-circulation/extensional-type systems similar to the Great Basin in the USA and Western Turkey. In many respects, they typify other fault-controlled geothermal systems that are driven by deep circulation of ground waters. At these rift fault-bounded geothermal systems, fluid movement is controlled by the permeable rift fault zone that bounds the rift valley. During the rift formation in Uganda; there was extension, fracturing and thinning of the crust causing the mantle to become elevated which results in areas of elevated heat fluxes that are exploration targets for geothermal resources.

The heat that drives these amagmatic systems is believed to result from active/extensional tectonics that permit the deep circulation of meteoric fluids through high angle faults and elevated heat flow that raises the temperature of fluids to 150˚C and above. The 3He/4He ratios of geothermal fluids from fault-bounded Kibiro Geothermal systems were measured to determine if a mantle signature was present, a value of 0.2 RA was obtained (Kato ,2018) therefore no signature was indicated. The fact that the Kibiro prospect area is not proximal to young volcanic/magmatic rocks and the absence of the mantle signature, supports the presence of extensional-type system. Soil gas and gas flux measurements have indicated high permeability concealed fault-bounded geothermal systems at Kibiro, Buranga and Panyimur areas. During exploration studies in Uganda, the exploration targets are at the points where the escarpment and the basin intersect, this is believed to be the location of the rift bounding faults controlling the up flow of geothermal fluids.

Session 7.2

56 | GENERATOR EXCITATION SYSTEM REPLACEMENT IN GEOTHERMAL POWER STATIONS – MERITS AND PITFALLS

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Keywords: *Excitation, generator control, system upgrade*

Some geothermal power stations exceed their projected operating life by adopting life-extension techniques. While some mechanical equipment in power station can readily exceed their design life, most of the control equipment need replacement due to obsolescence and difficulty getting technical support.

This paper presents the options available for the replacement of ageing excitation system, which is one of the major components that control the operation of turbine-generators. The performance requirements, functions and elements of modern excitation systems are discussed as an overview. The main drivers to proceed with replacement projects are elaborated with consideration of transmission system requirements, as well as long-term plans

and objectives from generation companies. Technical issues and pitfalls in the retrofit design process need to be considered to avoid delays during installation work. The timeframe to complete the installation and wiring works is limited as these are done during scheduled plant outages. Issues that are specific to geothermal plant applications are deliberated with consideration of technologies currently available in the market. The upgrade work has to consider the interfaces between the excitation system and other equipment, such as control system DCS, electrical protection relays, dependable power supplies, measuring devices, and generator. Experiences on excitation replacements projects in geothermal power plants are shared to provide generation companies some guidance in doing similar retrofit projects.

Session 3.1

57 | COMPARISON OF WELLHEAD COMPLETION DESIGNS FOR GEOTHERMAL OPERATIONS IN INDONESIA: EXPANSION SPOOL AND CASING HEAD COMPLETIONS

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Keywords: *Geothermal Wellhead, Wellhead Completions, Casing Head Flange, Expansion Spool, Geothermal, Drilling, Indonesia*

Geothermal wellheads shall be designed to operate during the life of the well. In a hot, acidic, and corrosive geothermal operating conditions, the selection of wellhead completion is critical. The purpose of this study is to compare the conformity of two wellhead completion designs for application in Indonesia: expansion spool completion and casing head completion. Using cross-sectional analysis, this study assessed wellhead designs currently available in the market and comparing the results against technical judgements. This study also discusses the advantages and disadvantages of both designs, and the rationale behind the current design preferences in the geothermal industry in Indonesia.

Session 8.2

59 | PRE-INDEPENDENCE AFRICA: A LOST OPPORTUNITY FOR GEOTHERMSAL RESOURCE DEVELOPMENT

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Keywords: *Africa, colonialization, diet, European, geothermal, hominin fire use; human evolution, independence, manifestations, Paleo-Indians, settlers.*

Paleo-Indians, settlers living around hot springs were the first to explore and utilize geothermal resources in North America over 10,000 years ago. European settlers moving westward probably encountered hot springs in Yellowstone area and large scale use of hot springs energy in la Grande, Oregon was recorded in 1862. Only 16 years later in 1878, explorer Stanley reported on the geothermal manifestations in pre-independence Africa in Burundi.

Geothermal based electric power generation was invented in Italy in 1904 and a feasibility study was carried out in 1911 in the now Democratic Republic of Congo (DRC) but the first use of geothermal energy for power production did not occur in Africa until 1952, when a plant producing 550.000-kWh of electricity per year, was constructed at Manono Province (DRC) in the now Democratic Republic of Congo (DRC). So why have not more African countries developed their geothermal power resources to date? The only exception being Kenya generate 667 MW of geothermal electricity.

Geothermal resources remained undeveloped until the African Geothermal Resource countries (AGRC) attained independence. Some countries have developed strategic geothermal energy policy, institutional, and regulatory frameworks for de-risking geothermal projects and also have considered the development of requisite human resources. the continent's Geothermal projects in the 21 AGRC are largely financed by regional programmes, international agencies and the country governments. The stand out is Kenya with a ranking of 9th rank among geothermal top ten countries in the World. Djibouti's current geothermal development status is attributed to the above ingredients in addition to the creation of geothermal corporate bodies, namely: The Geothermal Development Company Ltd (GDC) and Djibouti Office for Geothermal Energy Development (ODDEG), respectively.

Conversely, the AGRCs who are currently lagging in the development of their geothermal resource the slow progress is related end to the absence of some of the above ingredients thus necessitating their governments and policymakers to create or enhance their policy framework to ensure the rapid development of geothermal energy in Africa.

Session 7.3

62 | DIGITAL TWINS FOR THE GEOTHERMAL INDUSTRY: THEORY AND PRACTICE

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Keywords: *Digital twin, geothermal industry, dynamic geothermal plant modelling, decoupling model*

The term 'digitalisation', currently popular in many industrial sectors, refers to the construction of computer models intended to improve production and efficiency. The 'digital twin' can be considered as one of the core concepts of the digitalisation, and while still at the conceptual stage for many manufacturing operations, there are examples from the power industry - such as the Digital Wind Farm from GE Renewable

Energy used to optimise turbine operations, and improved maintenance planning of the EDP (Energias De Portugal) Alqueva II hydro power plant using a Digital Hydro Plant. In this paper, we will present results from our recent two projects on the concept of linking digital twins within the NZ geothermal industry. The first is dynamic modelling of a geothermal power plant, and the second is an exploration of the economic optimisation when coupling both process and reservoir simulators to provide accurate prediction of both reservoir and plant behaviours over the life time of the plant. The gaps between theory and practice are summarised and the anticipated future trends in digital twins for the benefit of the NZ geothermal industry are also highlighted.

Session 4.1

63 | RATIONALE FOR THE SCIENTIFIC DRILLING PROJECT "INTERACTION": INTERACTIONS BETWEEN LIFE, RIFTING AND CALDERA TECTONICS IN OKATAINA

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Keywords: *scientific drilling, mātauranga Māori, interactions, caldera, rift, biosphere, hydrology, Okataina Volcanic Centre*

The Okataina Volcanic Centre (OVC) in Aotearoa, New Zealand is of high cultural significance to Māori. The OVC is also a nested caldera complex, one of two giant active calderas of the Taupō Volcanic Zone (TVZ), ranked as New Zealand's highest threat volcano. In-situ, sub-surface observations required to better understand interactions between volcanism, rifting, fluid circulation and the deep biosphere are sparse. We propose the INTERACTION (Interactions between life, rifting and caldera tectonics in Okataina) scientific drilling programme to provide rock and fluid samples, downhole measurements and a base for a long-term observatory. Downhole samples and data, and new high-resolution ground-based surveys near the borehole will refine and fill gaps in the extensive geophysical, geological and geochemical datasets collected across the OVC and wider TVZ region since the 1950s, and advance fundamental concepts of caldera systems globally.

Scientific drilling at the OVC, coupled with extensive stakeholder engagement will lead to improved resilience to natural hazards and sustainable management of groundwater and geothermal resources. Close collaboration with Māori will achieve both scientific and cultural outcomes. New geothermal concepts (heat source, permeability and recharge), geophysical data acquisition and new technology deployment, will help future geothermal development in the central TVZ and elsewhere. Altogether, scientific drilling at the OVC will advance our understanding of: (1) drivers to volcanic eruptions, feedbacks between volcanic and seismic events, caldera evolution; (2) large-scale hydrology and magmatic systems; and (3) diversity, function, and geological processes that support deep subsurface microbial activity and response to a highly active geosphere. At these early stages of planning, we invite contributions to the concept of this project in the exceptional OVC settings and strengthen linkages with other ongoing research and geothermal drilling programmes.

Session 2.3

64 | EFFECTIVE TURBINE PLANT OUTAGE EXECUTION

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Keywords: *Turbine, outage, maintenance*

The results of a systematic approach to several extraordinary turbine maintenance outages that were executed over one year by ProGen as the service provider will be discussed. All of these outages were conducted successfully within the time and budget parameters set. There were no commissioning or operational issues encountered upon return to service. All of the outages were planned to a tight schedule based on optimizing historical performances. Although emergent work was discovered during most of the projects, the work was able to be managed within the allowed time frame and within the planned budget.

The paper will discuss the challenges faced and successes achieved with the execution of these outages. It will focus on the principles followed to ensure the outcomes achieved.

The principles discussed will be:

1. Partnership relationship between the supplier and the owner/operator
2. Planning for the outage using historic and forecasted findings
3. Plant life cycle managing and forecast
4. Preparation for execution done to the correct level
5. Decision making during the complete process leading up to the outage
6. Execution of the outage
7. Technical communication and decision making during the outage
8. Reporting on the completed outage
9. Post outage actions and planning for future outages

Session 4.1

66 | CULTURAL VIEWS, PERSPECTIVES AND OBSERVATIONS OF THE HEALTH AND WELLBEING OF THE ROTORUA GEOTHERMAL SYSTEM

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Keywords: *Rotorua, Māori, mātauranga, mauri, cultural.*

Te Ahi Kaa Roa are a collective of representatives from the hapū and iwi who have maintained continuous occupation of Ōhinemutu, Whakarewarewa and Ngapuna villages in Rotorua since pre-European times.

Ahi Kaa refers to the 'burning fires of occupation', and the whānau who reside in these villages have a long and unique relationship with the geothermal resources, features and activity around them. Each geothermal tāonga or feature is named and 'known', in terms of their characteristics, behaviours and perceived personalities. Their mātauranga, which includes intergenerational knowledge, is built upon sensory-based tohu or indicators.

Council has legal requirements and obligations to Māori under the Treaty of Waitangi, Resource Management Act 1991 and Local Government Act 2002. Because of their intergenerational knowledge and experience, Bay of Plenty Regional Council (Council) initiated the establishment of the group as one way to enable and ensure a tangata whenua lens or perspective regarding the management of the Rotorua Geothermal System and that mana whenua are afforded a clear voice in the review of the Rotorua Geothermal Regional Plan (Doorman, Bhana & Camburn, 2020).

While not the sole focus of the group, a key output of this relationship has been the collation of cultural views, perspectives and observations of the current health and wellbeing of the Rotorua Geothermal System. This paper focusses on this aspect of the groups work acknowledging that their involvement in Council's process and aspirations for the management of the Rotorua Geothermal system are broader.

While there are similarities in what is measured in cultural and contemporary terms (e.g. behaviour of geothermal features), the Māori worldview highlights that the environment and all it sustains (including people) is interconnected and cannot be looked at in isolation.

There has been a significant change in geothermal use and management over time by tangata whenua due to the intergenerational impacts of colonisation and resultant loss of control over their natural resources. Subsequent land use and development within the city, and the bore closure programme in the 1980s have occurred without iwi consent or input.

Te Ahi Kaa Roa hope the knowledge and mātauranga shared as part of the current work with Council will help to inform future management and monitoring of the system.

1 taonga are prized and protected as sacred possessions of the tribe. The term carries a deep spiritual meaning and taonga may be things that cannot be seen or touched.

Session 2.2

67 | POIHIPI GEOTHERMAL POWER PLANT WATER COOLING SYSTEM – TAKING A HOLISTIC APPROACH TO INVESTIGATING PROBLEMS AND IMPLEMENTING SOLUTIONS

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***Keywords:** Cooling water, microbiological control, algae, biocides, Sulphur Oxidising Bacteria, geothermal, Wairakei, Poihipi.*

The type of equipment comprising a geothermal power station main cooling water system can have a significant influence on the cooling water chemistry, sulphur deposition and micro- and macro-biological control in addition to the reservoir steam chemistry. A holistic approach is best when investigating problems to better understand the system and how best to implement solutions. Poihipi Road Power Station is the only geothermal steam turbine power station in New Zealand to have a shell-and-tube (surface) condenser, which has a significant influence on the cooling water chemistry compared to a direct-contact condenser. Prolific algae growth on the cooling tower also resulted in fouling throughout the cooling system and required frequent mechanical removal which increased the risk of dispersing into the air any Legionella bacteria that may have been present with the algae.

This paper provides an overview of the investigation approach performed to better understand the issues with the cooling water system and how best to address them.

Session 4.1

70 | INVESTIGATION AND APPLICATION OF FLASHING FLOW NOZZLES TO MITIGATE GEOTHERMAL TURBINE LIFE REDUCTION AT TE MIHI POWER STATION

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***Keywords: s**team impurities, turbine, flashing nozzle, steam separation, steam scrubbing.*

Because flash steam is not completely dry after processing in the separation equipment, pipelines and demisters are used to remove the remaining moisture together with condensation formed during transmission. If they are not fully effective, the result is scaling of turbine inlet nozzles, erosive wear of turbine internals, corrosion of alloy blade paths and rotor forgings. This significantly reduces the economic life of steam turbines. This issue of poor steam quality and purity is common to many geothermal plants worldwide, and prevalent in stations with separators nearby.

Investigation determined that significant moisture travels downstream of the separators as droplets less than 10 micrometers in size. Preventing the formation of these small sized droplets results in a significant reduction of mist borne-impurities that are resistant to conventional methods of gravity, centrifugal or impingement separation.

Using the TRIZ (Theory of Inventive Problem Solving) methodology, a systematic review of 34 engineering options to improve the steam purity at Te Mihi Power Station was conducted. Importantly, this drew on knowledge from outside the geothermal industry. The main solution selected was the application of flashing flow nozzles instead of orifice plates, or control valves, to minimise the creation of droplets < 10 micrometers in diameter when producing flash steam. Plant tests following installation measured a significant reduction in the total mass of

mineral impurities flowing through the Te Mihi Power Station low pressure steam system.

This was a low cost but effective improvement, avoiding invasive modifications to the steam system. Minimising the creation of droplets smaller than 10 micrometers is an important design consideration for future steam field and station developments around the world. Furthermore, the internal design of cyclone separators and transmission systems should avoid sharp edge flow shedding which can increase creation and entrainment of small droplets.

Session 5.2

71 | MANAGING DEBRIS IN GEOTHERMAL PRODUCTION FLUID

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Keywords: *Strainers, filtering, debris, scale, solid removal, solid waste management, cleaning, maintenance, separators.*

Geothermal debris from flowing geothermal wells is a common occurrence in geothermal plants and needs to be managed to avoid damaging critical equipment such as heat exchangers, turbines, pumps, or reinjection systems. Slotted well liners, strainers and liquid/solid separators are examples of equipment used for this purpose. This paper reviews equipment designs developed in New Zealand to manage debris around steam fields between 1988 and 2020. Sources, types of debris and its impact on plant operations and maintenance are also described. A discussion around learnings based on field operations is presented, as well as suggestions for debris management equipment improvements.

Session 4.1

75 | USE OF ICE PLUGS IN GEOTHERMAL ANTI-SCALANT TUBING SYSTEMS

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***Keywords:** anti-scalant tubing, geothermal, chemical injection, scale formation, ice plugs*

Anti-scalant tubing is commonly used in geothermal wells to allow chemical injection of anti-scalant fluids from the surface, delaying scale formation downhole. This tubing is intended to be continuously exposed to severe well conditions creating a need for monitoring and inspecting the injection string periodically. One of the methods used to inspect the tubing is called tubing lift. This consists of retrieving part of the anti-scalant tubing string from the well. This procedure moves the localised stress point on the tubing string and also allows inspection of part of the anti-scalant tubing at the surface.

Over time, this excess tubing collected at the surface becomes problematic, taking up space at the wellhead, and needs to be removed. A common solution to this problem is to cut and re-join the tubing with the slack removed. Unfortunately, this process has the inherent risk that when the tubing is cut, for a short period, the well remains open to the atmosphere. To avoid this exposure, the alternative is to retrieve the entire tubing string followed by unspooling & spooling, cutting and re-running the string in the well. However, this is a timely and costly endeavour for such a small change in the anti-scalant tubing string.

To improve the cut and re-join process, the idea of a temporary well barrier was explored, and ice plugs were found to be a suitable solution to well containment. Ice plugs have been used in process industries in a variety of applications, but there currently exists no documented evidence of their use in geothermal anti-scalant tubing maintenance.

This paper discusses the use of ice plugs in geothermal anti-scalant tubing operations, and how they have provided a simple and inexpensive solution in contrast to a full tubing retrieval while still addressing the well control risk of the cut and re-join method.

Poster

76 | INTEGRATION OF THE CALCIUM SILICATE (CASIL) TECHNOLOGY INTO GEOTHERMAL POWER GENERATION TO PREVENT SILICA DEPOSITION

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***Keywords:** Silica scale prevention, calcium silicate technology, geothermal energy, enhanced electricity generation, reduced maintenance, direct use, mineral extraction, paper, building, environmentally beneficial applications.*

Silica supersaturation in geothermal brine results in the formation of intractable silica scale deposits in pipes, heat exchangers and reinjection wells. This scale prevents the full effective utilisation of geothermal resources for electricity generation and heat recovery applications. It is a major problem worldwide. Also, process equipment and reinjection wells can be blocked, which necessitate costly maintenance and plant downtime. Current approaches attempt to address the problem by using higher steam/water separation temperatures to reduce silica saturation, acid dosing or additives to retard silica polymerisation. However, the use of these is not wholly satisfactory; silica still precipitates and

electricity generation and heat recovery remain compromised.

We have developed our proprietary new nanostructured calcium silicate, CaSil, technology to address the problem and are demonstrating it in an automated pilot scale operation at Wairakei. We remove the problematic dissolved silica as a novel CaSil material. This lowers the silica saturation index (SSI) substantially below 1. The technology is applicable to a range of brine compositions, temperature and pressure conditions. The technology opens up opportunities for further mineral extraction (e.g. lithium, base metals). Additionally, more heat energy can be safely extracted from the brine without causing silica scaling during electricity generation or industrial direct use applications. Because of its unique surface chemistry the CaSil material does not stick to metal pipes, significantly reducing maintenance costs for process equipment and reinjection wells, and plant downtime.

The CaSil material is a useful product that has a range of industrial and environmental remediation applications. These applications utilise the unique 3D framework structure of CaSil, which provide it with high liquid absorbent and surface area properties. By careful control of the calcium silicate chemistry and some post-separation treatment, new CaSil materials are generated with properties suitable for high volume applications in the building, paper, paint, absorbent, mining and environmental remediation industries.

Session 5.2

80 | ECOLOGICAL INFORMATION FOR GEOTHERMAL SITES IN WAIKATO REGION

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Keywords: *Indicators, geothermal vegetation, rare species, monitoring, pest animals, pest plants.*

Geothermal ecosystems are some of the most threatened ecosystems in the Waikato Region, having undergone significant reductions in extent and condition. Five geothermal ecosystem types have been recognised in New Zealand. These are all considered to have been naturally rare prior to human colonisation of New Zealand (Williams et al. 2007) and have all been identified as Critically Endangered (Holdaway et al. 2012). Waikato Regional Council (WRC) has an inventory of geothermal sites in the Waikato Region, which contains a summary of ecological information prepared by Wildland Consultants (2014).

A framework of ecological indicators assessing geothermal extent, condition, and protection status was developed recently (Wildland Consultants 2015), but information gaps meant that this framework could not be applied across all Waikato geothermal sites. Key gaps identified were lack of information on non-vascular plant species, herpetofauna, fish, invertebrates, and fungi. In addition, relatively few sites had any quantitative monitoring or detailed ecological restoration plans. A framework was therefore developed to prioritise the filling of these information gaps by surveying priority geothermal sites.

Session 1.1

81 | WELL PERFORMANCE DIAGNOSTICS AND FORECASTING USING THE GUDRUN WELLBORE SIMULATOR - CASE STUDIES FROM KAWERAU, NEW ZEALAND

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Keywords: *Kawerau, wellbore simulator, wellbore modeling, Gudrun, Volsung*

Ngati Tūwharetoa Geothermal Assets Ltd. (NTGA) relies on real-time wellhead data trends and periodic downhole wellbore surveys to understand and forecast geothermal fluid supply availability and reinjection capacity. This paper illustrates the use of Gudrun, the standalone wellbore simulator application of the Volsung geothermal reservoir simulation software package. Here we have applied Gudrun for well performance diagnostics and are using it for forecasting future well performance based on future reservoir conditions.

Wellbore models were developed for a production and an injection well from the Kawerau Geothermal Field, calibrated with wellbore data and history-matched with continuous wellhead data to determine model performance. The calibrated wellbore models were used to forecast well performance using expected reservoir and wellhead conditions. The wellbore model forecasts provide insight into well performance and reservoir changes and are useful proxies for field performance forecasting while developing a full-field numerical reservoir model. Ongoing investigation is also carried out to determine whether mismatches between the wellbore model forecast and actual wellhead performance could be used as basis for optimising the wellbore downhole monitoring program.

Session 4.1

83 | B-VALUE MAPPING FOR VOLCANIC-RELATED GEOTHERMAL SYSTEM: A CASE STUDY OF NEVADO DEL RUIZ VOLCANO, COLOMBIA

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Keywords: *Microseismicity, Magnitude of completeness, b-values, Nevado del Ruiz volcano.*

The Nevado del Ruiz Volcano (NRV) (Colombia) has two areas with geothermal potential located to the north and north-west of its crater which are highly seismically active. In the period of 2000 - 2018 thousands of volcano-tectonic events have been recorded beneath the volcano and within the two geothermal areas, with most earthquakes occuring at depths of 2-9 km and Md magnitudes up to 4.4.

Physical interpretations of subsurface processes related to volcano-geothermal activity can be performed by analyzing microseismicity information (hypocenters and magnitudes). The frequency-magnitude distribution of earthquakes in any region on Earth can be described by the Gutenberg-Ritcher relationship. This relationship is linear and from the slope, a common seismological parameter is estimated: the b-value. In the literature, high b-values have been associated with the presence of magmatic bodies, fluids migration, changes in fluid pressure, and high fracture density. Hence, the quantification of b-value and its uncertainty can be associated with the physics of subsurface mechanisms for earthquakes triggering. The aim of our study is to map b-values (2D and 3D) and delimit its anomalies with implications on the

prospective geothermal areas of Nevado del Ruiz volcano. Potential mechanisms in the area are associated with fluid recharge from rainfall, variable stresses and changes in fluid pressures due to magma injection and fluid-phase transition (liquid water-to-vapor transitions).

Session 2.3

84 | WELL INTERVENTION AND ENHANCEMENT IN DIENG GEOTHERMAL FIELD, INDONESIA

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Keywords: *Dieng, well enhancement, acid stimulation*

PT Geo Dipa Energi, (Persero) started developing Dieng Geothermal Field in 2002 and has since implemented operational strategies to sustain steam supply to the installed plant capacity of 60 MWe. Periodically, the company conducted a candidate selection and prioritization of the wells for well workover and enhancement to address steam supply and injection capacity shortfall. The results of evaluation formed the basis in implementing a well intervention and acid stimulation campaign for the prioritized candidate production and injection wells in Dieng Geothermal Field. Improvements were initiated in terms of well testing and analyses and acid treatment design to increase the effectiveness of the well stimulation. The use of electronic pressure-temperature-spinner logs and improved well test interpretation became essential for better candidate selection, acid treatment design, quantification of pre-acidizing well parameters and evaluation of acidizing results. To date, acid stimulation program has been successfully implemented in three production wells and two injection wells. Considerable improvement in production and injection capacities of these wells were attained that improved the operational level of the power plant in Dieng Geothermal Field.

Session 7.2

85 | HYDROTHERMAL ALTERATION AND FLUID CHARACTERISTICS STUDY OF PANTI GEOTHERMAL FIELD, PASAMAN REGENCY, WEST SUMATRA, INDONESIA

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Keywords: Fluid characteristic, geochemistry, geothermal, hydrothermal alteration, Panti.

Panti Geothermal Field is being associated with pull-apart basin at Sumatran Fault System and Tertiary volcanic activities. This field has seven hot and warm springs with temperatures up to 99°C. A more detailed analysis is needed to get a better understanding of subsurface alteration and fluid characteristics in Panti geothermal field. This research's goal is to understand the alteration process and fluid characteristic by determining lithologies, subsurface alteration, and manifestation fluid characteristics.

Primary data of a geothermal gradient well core (PNT-1) with 534 meters depth and manifestation fluid geochemistry data were used in this research. Secondary data of geological and geophysical reports of the observation field were used to support the research. Megascopic and microscopic observation, X-Ray Diffraction, fluid inclusion, and water geochemistry analysis were conducted in this research.

The lithologies of PNT-1 were grouped into Granodiorite, Old Talu Volcanic Product, Young Talu Volcanic Product, and Alluvial Unit of Eocene-Holocene age. The intensities of alteration from samples are weak to intense. Alteration zones consist of [1] Smectite-Chlorite-Quartz Zone at 0-85 meters depth, [2] Smectite-Chlorite-Quartz-Calcite Zone at 85-481 meters depth, and [3] Illite-Chlorite-Calcite-Quartz-Epidote Zone at 481-534 meters depth. Dissolution and open-space filling also occurred. Hydrothermal alteration paragenesis of open-space filling minerals shows that ancient fluid was neutral with 140-160°C then cooled down to 120-130°C. Currently, Panti Hot Springs are neutral, partially equilibrated, sulphate water type, while Ujung Padang and Lundar hot and warm spring are neutral bicarbonate water. Lundar Warm Spring is partially equilibrated while Ujung Padang Hot Springs are immature. There are 3 hydrothermal systems named Panti, Ujung Padang, and Lundar. The systems sourced from meteoric water that charged through tectonic fractures, heated up by unrevealed intrusion rock, and discharged as thermal springs towards faults. Panti, Ujung Padang, and Lundar system have permeable zones with temperatures less than 150°C on Granodiorite, Granite-Granodiorite, and Slate unit respectively.

Session 7.2

86 | APPLYING EGS (ARTIFICIAL WATER RECHARGE) TO A GEOTHERMAL RESERVOIR IN JAPAN

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Keywords: *EGS, R&D, Water Injection, Artificial reservoir, Artificial water recharge, Recharging, Simulation, Reservoir Management, AE*

The power generation output of many Japanese geothermal power plants has been declining over time. One of the reasons is the imbalance between their production and the natural recharge of meteoric water. To mitigate or improve the decline, JOGMEC, an independent administrative agency in Japan, has focused on artificial recharge technology, which is classified as a type of enhanced/engineered geothermal system (EGS).

In 2013, JOGMEC set out a project to apply the technology to Japan's geothermal power plants. The purpose of this project is to establish appropriate recharge methods for their long term stable production, including techniques for predicting and evaluating the effects of the EGS (artificial water recharge). To establish methods and verify the effectiveness of the project, recharge tests were carried out in 2017 and 2019 through to early 2020 at the Yanaizu-Nishiyama geothermal power plant in Fukushima prefecture, of which production has been gradually declining. Although some positive effects of the EGS have been confirmed, continued recharge and further verification are required to establish the appropriate methods and prove their effectiveness.

Session 7.3

87 | OPPORTUNITIES FOR ELECTRICITY GENERATION WITH BINARY CYCLE POWER PLANTS IN LUMUT BALAI GEOTHERMAL AREA

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Keywords: *Lumut Balai, Brine, Binary Cycle.*

Lumut Balai Geothermal Field is a working area managed by Pertamina Geothermal Energy (PGE) in South Sumatra Province, Indonesia. This field has generated 55 MWe of electricity to the grid on the Sumatra Island after Lumut Balai Geothermal Power Plant (GPP) Unit-1 achieve the commercial operation date in the first quarter of 2020. Lumut Balai GPP Unit-2 EPCC project will follow with 55 MWe capacity in the future. The two GPP units are turbine condensing power plants.

Lumut Balai Geothermal Field is a two phase field with water predominance (dryness of around 20%) where this two phase fluid flow into the separator to separate dry steam and hot brine. Dry steam is used to turn turbines and generators to produce electricity and hot brine is injected into the reservoir through a reinjection well. The injected hot brine still has high heat potential and can be used to generate electricity using a binary cycle power plant.

This paper tries to find out how much electricity is generated from the binary cycle power plant by utilizing hot brine, which may be a binary cycle that can be used as a way to increase the generation capacity in Lumut Balai Field in the future.

Session 7.3

88 | SIGNIFICANCE AND METHODOLOGY OF GEOTHERMAL RESOURCE POTENTIAL SURVEY IN JAPAN

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Keywords: *Geothermal, JOGMEC, Resource Potential Survey, Airborne Geophysical Survey, AGG, HTEM, Heat-flow Drilling, Corling.*

While Japan is blessed with high geothermal energy potential, many areas remain unsurveyed due to the mountainous landscape of Japan and the environmental regulation regarding national parks. In these areas, Japan Oil, Gas and Metals National Corporation (JOGMEC) conducts airborne geophysical surveys (gravity, electromagnetic, magnetic) and heat-flow drilling surveys in order to understand the geological structure. The data obtained through these surveys is provided to geothermal resource developers as well as local governments in order to reduce exploration risks and promote their further survey for geothermal resource development.

In addition to these surveys, from this year, JOGMEC starts implementing surface geophysical surveys (gravity, magnetotelluric) and deeper drilling survey for identifying geothermal fluids in order to acquire more detailed subsurface information. By conducting these surveys, JOGMEC hope to reduce the exploration risk and contribute to the further geothermal resource development.

Session 7.2

89 | GEOTHERMAL DEVELOPMENT: A GAME OF CHANCE AND WIT

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Keywords: *Geothermal development, educational game, diversity, STEM, community engagement, WING*

In order to inspire diverse young people into STEM careers, colleagues from Mercury NZ Ltd partnered with The University of Auckland (UoA) Women in Engineering Network (WEN) and presented an introduction to geothermal development to high school aged youth during Enginuity Day 2019. Beyond typical methods of industry presentation to students, the Mercury team decided to create an interactive game to foster engagement and learning.

The sequence of the game leads players through the entire process from exploration to commercial development of an unexplored geothermal resource. In the first stage, participants are provided maps and geoscience data, which they analyse to select well locations. In the second stage, they discover the productivity and enthalpy of their new wells. Penultimately, using well data and information about the efficiency of various power plant types, they place a fictional power plant and design pipelines to connect their wells. Finally, the game is scored by translating the production of their powerplant and wells drilled into an economic output.

To simulate the unpredictable reality of geothermal development, chance cards are allocated at multiple stages with varying degrees of financial setback.

The reception to the game was overwhelmingly positive. While it was designed specifically to introduce high school aged women to the

geothermal industry, a similar style of game could be adapted to engage other ages or to focus on other topics.

Session 6.2

90 | INJECTIVITY CHANGES AT NGATAMARIKI

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Keywords: *Ngatamariki, Taupo Volcanic Zone, injection, injectivity index, temperature, microseismicity*

Ngatamariki geothermal system in the Taupo Volcanic Zone of New Zealand generates power from an 82 MWe binary power station. All the produced geothermal fluid is reinjected into four injection wells minus minor losses of around 2%. Wellhead pressures, flow rates, and injectivity of Ngatamariki reinjection wells have varied over the 7 years of operation. The injectivity index of a well is determined from the amount of fluid injected over the pressure required to inject it. Injectivity is known to vary with temperature of injection fluid and rock formation.

Two of the injection wells at Ngatamariki are presented in this work: NM08 and NM09. The injectivity indexes for these wells are determined downhole and incorporates fluid density changes, friction losses along the wellbore, and changes in reservoir pressure. In the first few years of operation after drilling, a large increase in injectivity index has been observed in both wells. In recent years the injectivity has declined overall. Additionally, and investigated here, a varying rate of decline in injectivity index has been observed recently. The temperature of the reinjection brine varies up to 10°C. The correlation between the difference in injectivity index in NM08 and NM09 and change in injection temperature is examined. The correlation between the difference in injectivity index and microseismicity is also investigated. Uncertainties in determining injectivity index are explored. The reasons for injection variation are not fully understood and warrant further investigation.

Session 4.1

91 | A NON-PRODUCTIVE TIME ANALYSIS FROM GEOTHERMAL DRILLING CAMPAIGN IN WEST JAVA TO IMPROVE FUTURE DRILLING PLANNING

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Keywords: *Geothermal, Indonesia, drilling, non-productive time, offset well analysis.*

Drilling is one of the most cost-intensive activities in a geothermal project. The longer it takes to drill a well, the more expensive the well becomes. It is therefore important to optimize the time spent in drilling to optimize the cost of a well. The occurrence of an unplanned event that might prolong the drilling operation can be classified as Non-Productive Time (NPT), and this period will contribute to the cost overrun of the well. Understanding the major NPT happened in a drilling campaign and extracting lessons learned out of it, is hence crucial for improvement in the future drilling campaign.

A drilling campaign for a vapor-dominated geothermal field in West Java, Indonesia, was carried out around 25 years ago. However, the drilling activity report and data were not documented and processed properly. Therefore, when a drilling campaign expansion is about to commence, the scattered and unprocessed drilling records make it difficult to create offset well analysis. This will cause the drilling engineering and planning are not as straight-forward, because the engineer has to sort, cleanse, and processed the data first before being able to generate analysis.

This paper aims to demonstrate the offset well analysis from the drilling operation perspective. An overview of daily drilling report processing into a usable information for drilling planning is discussed. The NPT contributors incurred during first drilling campaign 25 years ago are identified and analyzed. The NPT analysis then can be used to assist the drilling planning with the final goal to improve future drilling planning process and to potentially save cost by mitigating the most possible problems to occur in the field.

Session 8.2

92 | DRILLING ACTIVITIES AND PARAMETERS ANALYSIS TO OPTIMIZE STUCK PIPE PREVENTION IN A GEOTHERMAL FIELD

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Keywords: *geothermal, drilling, non-productive time, stuck pipe*

Geothermal drilling has been an issue with its high cost taking up to fourty-percent of total field development cost. This high cost can still increase significant amount caused by the long duration of geothermal drilling due to non-productive time. The long duration for non-productive time represents problems

encountered in geothermal well drilling. One of the most frequent problems is the stuck pipe, a condition whereby the drill string cannot be pulled or moved. Generally, the stuck pipe is classified into differential sticking and mechanical sticking.

This study is analyzing the occurrence of stuck pipe empirically with qualitative and quantitative analysis. The analysis is done through offset-well data consists of drilling activities and drilling parameters. The drilling activities cover the duration of productive time and non-productive time, including activities before and during the stuck pipe. Meanwhile, the drilling parameters consist of torque, standpipe pressure, rate of penetrations, revolution per minute, pumping rate, well inclination not to mention lithological data from formation evaluation log. The objectives of this study are to determine the wells with stuck pipe occurrence, most troublesome depth intervals, possible type and cause of sticking, parameters cut-off and patterns, and also lithology type with most frequent stuck pipe occurrence. This study also includes the challenges in analyzing the available drilling data of this field. In results, all possible stuck pipe were mechanical sticking and occurring in Andesites-dominated rocks located in high-temperature reservoir zone with no exact drilling parameters cut-off and patterns are found.

Session 8.3

94 | UTILISATION AND SEQUESTRATION OF SUPERCRITICAL CARBON DIOXIDE IN THE GEOTHERMAL FIELD

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Keywords: *Hot Dry Rock, Global warming, CO_2, Sequestration, Utilisation*

Geothermal energy is expected as one of the renewable energies against the global warning, which we have to overcome in this century. However, the conventional geothermal development that pumps up and uses the subsurface hot water has not been much promoted because of the objection of the local residents. The Hot Dry Rock (HDR) method, which does not pump up underground hot water, was studied but suspended by economical and other reasons.

The HDR technology creates an artificial reservoir by hydraulic fracturing at the area where natural geothermal system is not or poorly developed, and pressurises water into the reservoir to extract subsurface heat. Several demerits have been pointed out such as the outflow of water from the reservoir, and the low temperature due to the bypass of injected water (Short Circuit). The induced earthquake during the hydraulic fracturing and the water circulation is another matter of concern.

Carbon dioxide (CO_2) in the supercritical condition ($ScCO_2$) has better thermal properties as the heat transport fluid than water. $ScCO_2$ inhibits the dissolution from host rocks and the sedimentation of minerals in the fractures. Large buoyancy can be expected to reduce the pumping energy. Also, $ScCO_2$ can penetrate into narrow micro-cracks due to its small viscosity. An output of about 1.5 times that of water can be expected with use of $ScCO_2$ as a working fluid.

$ScCO_2$ that migrates from the flow path would be expected to be sequestered and fixed as carbonate minerals in HDR. In addition, the formation of the Short Circuit and the scale production might be overcome by controlling CO_2. The induced earthquakes at the reservoir creation can be also suppressed by using CO_2 as a fracturing fluid. There are many advantages in use of CO_2 but are also many subjects to be solved. We will progress a new geothermal research program using CO_2. In this paper, subjects on the use of CO_2 in the geothermal field and the processes to the implementation will be discussed.

Session 7.3

96 | SIMULATING EFFECT OF INSULATED DRILLPIPE ON DOWNHOLE TEMPERATURE IN SUPERCRITICAL GEOTHERMAL WELL DRILLING

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Keywords: *supercritical geothermal well drilling, down-hole cooling, mud circulation, insulated drill pipe, numerical simulation*

A research and development project on supercritical geothermal power generation technology, in which the exploratory drilling project is known as the Japan Beyond-Brittle Project (JBBP), is in progress in Japan. To design the first exploration well, which is planned to be drilled in a few years, we are studying a down-hole cooling strategy by mud circulation during drilling, casing running, cementing and completion operations. Because the drilling site is not yet determined, numerical simulations were conducted for subsurface conditions based on the Kakkonda WD-1a well, the world first super-hot geothermal well over 500°C previously drilled in Japan.

In this study, we focused on the effect of insulated drill pipe on down-hole temperature during drilling with drilling fluid circulation. It was found that the combination or configuration of insulated and normal drill pipes had considerable influences on the down-hole temperature profiles as well as the thermal performance of insulated drill pipe itself. The optimum insulated drill pipe configuration and drilling operation condition are discussed based on the results of the numerical simulation studies.

Session 7.2

97 | DOUBLE ENERGY INPUT, A PROPOSAL FOR A NOVEL SOURCE OF ELECTRICAL ENERGY

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Keywords: *DEI, Double Energy Input, Hydroelectrical, Seawater, Open Pit Mine, Geothermal, Supercharging, novel source of electrical energy, Sonora, Guaymas, Mexico renewables production.*

In order to slow down adverse global anthropogenic effects such as global climate change and the destruction of ecosystems, alternative energy sources that are clean, renewable, and efficient are needed to replace the existing energy sources.

Double Energy Input is a novel invention that gathers two renewable energy resources: hydro-electrical power and geothermal power. This invention utilises the sea as its reservoir, the dam is a wall of a big pit hole, and in the base of such pit, we will use the geothermal power for ridding off the water.

This model is designed to generate between 1,200 – 1,500 MW of power in the hydro-electrical phase and will generate about 4.86 tons of salt per second. An additional 800 MW of energy will be produced by supercharging the hot water at the bottom with heat and pressure and running a vapour power plant.

This model provides an alternative means for producing clean and renewable energy with two abundant resources, sea-water and geothermal heat.

Session 3.1

98 | DRILL BITS SELECTION ANALYSIS IN NON-CONSIGNMENT PROCUREMENT ARRANGEMENT IN GEOTHERMAL DRILLING PROJECT

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Keywords: *drill bits, drilling procurement, geothermal drilling.*

The drill bit is one of the most important tools in geothermal drilling operations. The main role of this tool is to crush or cut the rock. Unfortunately, the selection of the best available bit for a job can be determined only by trial and error. This is because bit selection refers to several factors, such as the formations and drilling parameters. In non-consignment procurement arrangements, drill bit selection shall be completed prior to the execution.

This paper explores the selection workflow and assumptions used in selecting drill bits for geothermal operation based on offset well and recent market reviews. Discussion covers drilling bit specifications and quantity determination for 3 wells in a drilling campaign. The results are recommendations for preferred drill bit selection in non- consignment procurement arrangement. Important data that must be recorded during drilling is also mentioned in the discussion. This is critical for drill bit selection optimization in future campaigns.

Session 7.2

99 | WELLTEC COMPLETION SOLUTIONS METAL EXPANDABLE PACKER AND 2ND STAGE CEMENTING FOR GEOTHERMAL WELL RE-LINING

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EDC (Energy Development Corporation) in the Philippines faced integrity issues in 3 wells due to casing corrosion and collapse with the 9-5/8" and 13-3/8" casing on a geothermal well and was required to re-line with 7" and 9-5/8" casing with a metal expandable packer WAB (Welltec Annular Barrier) to reinstate integrity of the 9-5/8" and 13-3/8" casing. This paper will discuss an operation in which the new 7" and 9-5/8" casing was deployed and set inside 9-5/8" and 13-3/8" casing using an 812WAB and 1214WAB in conjunction with 2nd Stage Cementing Collar.

Results, Observations, Conclusions

The WAB and 2nd Stage Cementing Port Collar was deployed to setting depth and cementing tool consisting of two cups style packers and an injection port positioned in-between was used for both setting/expanding the WAB. Then, opening the cement collar and performing the cementing operation and subsequently closing the cement collar, all in the same run. The fluid level was below the setting depth, so the equipment was installed in a "dry" well and throughout the operation continuous cooling was performed by pumping water down into the well.

By establishing returns to surface after opening the stage collar we were able to get a positive confirmation of the WAB being set, the cementing operation of the annulus was completed in the fully controllable annular volume ensuring 100% cement coverage. As a redundancy in case trapped water should occur, multiple burst discs have been integrated in the WAB to avoid potential casing collapse or deformation.

As a result, the client could put the well back on production with full integrity, albeit with a slightly reduced wellbore diameter.

Novel/Additive Information

Welltec's WAB metal expandable packer minimizes completion and workover risks through quick and simple isolation of the integrity issues, capable of offering high temperature metal to metal sealing whilst ensuring a life of well product.

Session 7.2

101 | SIMULATING INTERFERENCE EFFECT BETWEEN REINJECTION WELLS

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Keywords: *Interference, Transient, Injection Well, Injection Capacity.*

Ensuring the performance of reinjection wells is important for the sustainability of geothermal field management. One of the problems that is rarely noticed in the reinjection performance is the interference-effect. The interference-effect could cause a significant drop in injection well capacity.

Two reinjection wells were suspected of having interconnected fracture permeability and bounded reservoir. Although the distance between the feed zone is more than 300 meters, Well D-2 experienced a temperature drop and pressure increase during the Injectivity Test of

Well D-3. A method to estimate optimum total reinjection capacity is delivered.

The approach is using the nodal analysis to obtain each wells' reinjection capacity. Then, analytical and semi-numerical transient models are used to obtain reservoir properties also to simulate the optimum reinjection capacity due to the interference-effect.

Session 7.3

103 | GEOTHERMAL STEAM PURITY MODELLING – THEORY AND PRACTICE

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Keywords: *Geothermal steam purity, modelling, chloride ion, silica, silica distribution.*

Geothermal steam purity modelling is considered by some to be an esoteric exercise. Two experienced practitioners in geothermal process engineering and geothermal chemistry seek to demystify steam purity modelling for the next generation of practitioners. This is done by explaining the basic principles used (along with key assumptions) and how modelling can assist steam separation and scrubbing pipeline design. Verified by drain-pot sampling, it provides an accurate measure of the overall efficiency of steam line scrubbing and gives confidence in the level of steam purity at the turbine – a key parameter operators are interested in.

Steam purity modelling considers initial steam separation performance and quantifies heat and mass transfer within steam lines in discrete stages, corresponding to each successive condensate removal point as well as final demisting prior to admission to the power plant. Chloride ion is a representative dissolved impurity that is non-volatile and remains entirely with the liquid phase in each stage; it is present in steam lines due to minor amounts of brine carryover.

The removal of slightly volatile silica can also be accounted for. Heat loss from pipelines can produce significant amounts of steam condensate which is involved in solution/mixing within each stage. If the condensation can be reasonably estimated in any section, then it can be used as a dilution-tracer to calculate the purity of the total steam flow in that section.

Assumptions about turbulent mixing of steam and brine/condensate and attainment of chemical equilibrium in each stage are explained, along with guidance on acceptable scrubbing velocity criteria, and the effectiveness of condensate removal at drop pots.

Insights that may be gained from steam purity modelling are discussed, and "proof" of the validity of modelling is provided by comparing modelling predictions with generalised (i.e. non-specific) geothermal steam system data.

Session 5.2

104 | COVID-19'S IMPACTS ON GEOTHERMAL DRILLING PROJECTS IN INDONESIA

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Keywords: *COVID-19, geothermal, drilling, Indonesia.*

The Corona Virus (COVID-19) pandemic has spread rapidly to more than 200 countries around the world. This does not only raise challenges towards public health but also agitates other sectors, including the energy industry. The economic slowdown and quarantine practices contribute to large impacts on the energy sector, including geothermal.

The continued impact of the COVID-19 pandemic is clearly seen in the movement restrictions by most governments around the world, including in Indonesia. Thus, this will inevitably cause the geothermal sector to experience more postponed projects.

Drilling is one of the biggest cost contributors to build a geothermal power station with up to 34% of the total project cost. Identifying the market price for drilling material and services is very important. It will allow us to get information about the market status to calculate the total well cost. However, the market survey that has been conducted in 2019 might differ from the current actual price due to COVID-19's impact. Therefore, it will affect the geothermal project cost in total.

This paper aims at discussing how the COVID-19 pandemic will impact the current geothermal drilling cost and the latest market survey in Indonesia. There has been very limited research of COVID-19's impact on the Indonesia geothermal drilling projects. Thus, the presence of this paper intends to fill the gap in the field.

Session 7.3

105 | INVESTING IN EXPLORATION GEOSCIENCE AND INNOVATION: A GIS-BASED GEOTHERMAL RESOURCE PRIORITISATION TOOL FOR TOHOKU REGION, JAPAN

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Keywords: *GIS, Automation, Geospatial Data, Geothermal Resource Prioritization, Tohoku, Japan.*

We have designed, built and are now utilising a GIS-based geothermal resource prioritisation tool for the Tohoku region, Northern Japan. For the first time, we have a toolbox for automating the integration of large, scientifically diverse, multi-sourced public and institutional geospatial datasets, that support Baseload Power's geothermal resource prospectivity assessment process. We assign weighted numerical values to resource, infrastructure and development variables aiding identification of geothermal systems, many overlooked for more than onsen bathing, with attributes for scaled, modular plant electric power and community-driven direct use applications.

The Tohoku region of northern Honshu boasts several hundred hot spring areas, but geothermal development has been hindered by community concerns, limited grid availability

and uncertainties regarding development potential and resource viability, despite a large volume of historical and recent surface surveys and subsurface geoscience (including well data). Our approach facilitates integration of the various datasets, which can be visually presented in an unbiased assessment or as generated resource favourability scenarios. This provides Baseload Power with a unique advantage to identify geothermal areas of interest, initiate an appropriate exploration strategy, and engage with individuals, communities, industry collaborators and regulators early in the project management process, in order to meld appropriate (ORC, binary or other) technologies, our commercial goals, and the aspirations of local and development partners.

Session 1.3

106 | STUCK PIPE FREEING PROBABILITY OF SUCCESS IN GEOTHERMAL DRILLING OPERATION: A CASE STUDY IN JAVA

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Keywords: *stuck pipe, stuck pipe freeing, geothermal, geothermal drilling, probability of success, Indonesia.*

Stuck pipe is a common problem in geothermal drilling operations. Stuck pipe can lead to extra cost due to lost-in-hole tools, sidetrack, fishing operation, and cost due to prolonged total drilling operation/campaign. The commonly faced dilemma in mitigating stuck pipe is to decide whether to continue with the attempts to free the pipe or cut the pipe or sidetrack the well. One of the consideration factors for the issue is to calculate the probability of freeing the pipe.

The purpose of this study is to investigate the connection between the probabilities of success with stuck pipe freeing attempts. Using statistical analysis, the study analysed the events of stuck pipe from a drilling campaign in Java in the 1990s. This study finds out that the answer to previously unknown effective time of work pipe operations. Further studies are needed to establish the relationships of drilling parameters to the probability of success and develop a cost-effective preventive/corrective measure to stuck pipe problem.

Session 5.1

107 | DISCRETE VS INTEGRATED PROJECT MANAGEMENT (IPM) AND INTEGRATED DRILLING SERVICE (IDS) CONTRACT FOR GEOTHERMAL DRILLING IN INDONESIA

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Keywords: *Geothermal, Drilling, Contract, Indonesia*

Drilling for geothermal activity in Indonesia has been growing in recent years. Many energy companies have entered the geothermal industry in Indonesia. These newly established companies usually have limited geothermal knowledge on their team. Most of them use Integrated Project Management (IPM) and Integrated Drilling Service (IDS) contract types to develop their geothermal area starting from the drilling campaign to their power plant purchasing and installation. Unlike geothermal practices, the oil and gas industry in Indonesia is more mature and settled, where most of operators are using a discrete type of contract for drilling.

The purpose of this study is to compare between the discrete contract type and IPM/IDS contract type. Various aspects like company strategy, resources quantity and quality, logistic and location of the project and many other things will give us insight into what is the most suitable drilling contract type between IPM/IDS or discrete for geothermal companies in Indonesia. This application of contracts is analyzed based on the technical and economic aspects to give a summary of what factors need to be considered before applying one type of contract.

This paper is expected to give a thorough summary of the advantages and disadvantages of discrete and IPM/IDS contract types for geothermal drilling campaigns. What type of contract is most suitable for geothermal operators based on the resources they have and the kind of project that they want to develop? Further studies with more sources are still required to fully prove the feasibility of the concept.

Session 8.2

111 | CHALLENGES IN PROVIDING A RELIABLE WATER DISTRIBUTION SYSTEM FOR GEOTHERMAL DRILLING OPERATION IN INDONESIA

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Keywords: *geothermal, drilling, Indonesia, exploration, water supply, water transfer, infrastructure, local community.*

Geothermal drilling activities, both in the exploration and development stage, require a significant amount of fresh water supply. The water consumption generally increases during drilling into the reservoir zone, which consists of fractures and faults allowing higher chance of lost circulation event. Continuous water supply with sufficient flow rate, to be circulated into the hole, is very critical during drilling because it serves many purposes. When the water distribution into the well is interrupted or stopped completely, drilling activity must be ceased to avoid any potential downhole problem due to lack of water or mud circulation. Unfortunately, in Indonesia, providing fresh water for drilling operation is often not an easy

task. Most geothermal prospects in Indonesia are located in fertile mountainous areas that have low rainfall and are inhabited by people, thus the available sources of fresh water are often used for irrigating rice fields. This condition forces geothermal developers to use other water sources with low (acidic) pH that often located far from the existing road. Additionally, the surface contour from the water source to the drilling pad is often extremely uneven.

This paper discusses various potential challenges, both technical and non-technical, in securing fresh water supply for geothermal drilling operations in Indonesia. Several solutions or mitigations based on literature studies and authors experience are also summarized in this study.

Session 5.1

116 | REPRESENTATION OF UNKNOWN PARAMETERS IN GEOTHERMAL MODEL CALIBRATION

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Keywords: *Geothermal model calibration, uncertainty quantification, ensemble-based methods, parameterisation, reservoir modelling.*

Computational reservoir models are commonly used to inform management decisions in the geothermal energy sector. With a well-calibrated model, a range of future scenarios can be simulated and informed decisions can be made. However, the task of calibrating large-scale geothermal models is challenging, both from a conceptual standpoint and in terms of computational cost. Furthermore, decision-makers typically desire the quantification of uncertainty and confidence in any calibration results. These problems have been addressed quite successfully in related fields, such as petroleum engineering, by using so-called ensemble-based uncertainty quantification methods.

Ensemble-based methods use a small collection (ensemble) of models, with each ensemble member having different values for the model parameters (such as deep mass and heat sources or subsurface permeabilities). The associated calibration methods guide this ensemble of different models to regions in parameter space which provide adequate matches to the measured field data, while ensuring an appropriate diversity of models to characterise uncertainty. In the Bayesian framework, ideally, the distribution of the ensemble should converge to the posterior probability distribution representing this uncertainty, i.e., the probability distribution of the unknown parameters given the measured field data.

Session 1.2

117 | AN INTRODUCTION TO OPTIMAL DATA COLLECTION FOR GEOPHYSICAL MODEL CALIBRATION PROBLEMS

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Keywords: *Calibration, estimation, inversion, Bayesian, data collection, optimization, uncertainty quantification, uncertainty reduction.*

Computational modelling and calibration can play a vital role in various geophysical settings, including the management of geothermal reservoirs. The calibration process typically involves perturbing model parameters, such as subsurface permeabilities, so that the resulting simulator outputs match field data, usually consisting of noisy surface or subsurface measurements. In an engineering context, however, model calibration is not a once-off process, but rather an on-going process that often requires careful decision-making about whether to collect new measurements and where these should be collected. Here we present a tutorial-style introduction on how to formulate and solve such decision problems, using two archetypal but straightforward geophysical model problems.

The basic calibration problem can be considered a statistical inference problem. In particular, the Bayesian framework for calibration naturally allows for uncertainties in the data, the parameters, and models to be quantified and incorporated into this process. In this framework, the solution to the calibration (and inference problem) is a so-called posterior probability density, which characterises the remaining uncertainty in the parameters after conditioning on the field data. This uncertainty can then help guide the management of geophysical resources, where, intuitively, reducing (posterior) uncertainty enables higher quality decisions to be made.

Reduction in posterior uncertainty is achievable by a) improving measurement precision at existing locations and hence obtaining similar data with lower noise or b) collecting additional data at new locations. Here we focus on the second option. The cost of collecting data in new areas can be considerable, however, especially when this data requires e.g. drilling a new observation well or constructing and deploying other expensive measurement equipment. Hence, we consider the design problem of how to determine the reward, in terms of uncertainty reduction, of a potential new observation, before collection.

In addition to illustrating the basic principles of optimal data collection and data worth analysis using simple geophysical problems, we also show how the methodology used can be further developed to include, for example, the possibility of spatially heterogeneous costs of acquiring new data.

Session 3.2

121 | CHARACTERIZATION OF HULULAIS SUBSURFACE ROCK FORMATION AND ITS IMPLICATION TO STRATO VOLCANO FACIES MODEL HULULAIS GEOTHERMAL FIELD, INDONESIA

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***Keywords:** Hululais, rock formation, stratovolcano.*

Hululais geothermal field is located in Lebong district, Bengkulu province, Sumatera island, Indonesia. As one of the exploration field operated by Pertamina Geothermal Energy (PGE), Hululais geothermal field targeted to generate 2 x 55 MW electricity by the end of 2020. 24 wells have been drilled since 2010. Retrieved cutting and cores from the drilling wells are the primary data for subsurface modeling. Thus, its identification and characterization is important for the next field development scenario.

An updated new subsurface rock formation is successfully established. They are identified as Upper Suban Agung Volcanic (USAV), Lower Suban Agung Volcanic (LSAV), Hululais Volcanic (HV), Hululais Granodiorite Intrusions (HGI), and Seblat Metasediment (SM). Its unique characters and its huge implications for the field development scenario will be explained in this paper. The knowledge to identify these rock formations will increase success ratio of well drilling, and reduce potential hazard and loss.

Poster

122 | FEED ZONE EVALUATION IN HULULAIS GEOTHERMAL FIELD, BENGKULU, INDONESIA

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***Keywords:** Hululais, feed zone, permeability, feed zone characterization, feed zone evaluation*

Hululais geothermal field is situated within an overlapping area between the Musi and Ketahun Segment. These segments are part of the NW-SE Sumatra Fault Zone. These NW-SE structures and also its local lithological factor is hypothesized to influence the permeability of feed zone in Hululais by certain degree.

Drilling campaign in Hululais has been started in December 2010, this activity provides subsurface data such as rock cuttings and cores, drilling parameters, borehole logging, and completion test data. Spinner data, temperature measurement, loss circulation while drilling, rate of penetration, weight on bit, cuttings, cores, interpreted fracture from borehole logging is integrated and analyzed to evaluate and characterize the feed zone of the wells.

The study depicts that the feed zone distribution and also its permeability is quite unique which is influenced both by structure and lithological factor. The feed zones can be divided into three groups based on their vicinity to the surrounding structure and their lithological factor. This grouping also correlates with its permeability from high to low. Identifying factors that control the distribution and the permeability of the feed zones will reduce the subsurface uncertainty for well targeting in the future field development.

Session 8.3

123 | THE ROLE OF THERMAL STRESS IN ENHANCING THE RESERVOIR PROPERTIES OF ENHANCED GEOTHERMAL

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Keywords: Induced thermal stress, thermal shock, EGS reservoir, multifracture, horizontal wellbores.

The injection of cold fluid into a hot dry rock (HDR) formation causes temperature changes that often induce thermal stress. This will alter the reservoir properties of the rock mass and the fluid, making thermal stress central to understanding the behaviour of HDR geothermal reservoirs. In order to explore the effect of thermal stress on reservoir properties, this paper presents a new numerical model of an enhanced geothermal system (EGS) using a coupled thermo-hydro-mechanical (THM) model. Nine reservoir properties are examined: permeability, aperture, stiffness, pore pressure, effective stress, shear stress, density, viscosity, and temperature. The results show that thermal stress enhances each of these properties substantially when compared with a model without thermal stress. It is clear from the simulation that exclusion of the thermal stress effect in a model could end in an erroneous description of the system output.

Session 1.2

124 | A NEW NUMERICAL MODEL OF THERMAL APERTURE CHANGES IN AN ENHANCED GEOTHERMAL SYSTEM RESERVOIR

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Keywords: *Thermal aperture, hydro-mechanical aperture, combined aperture, EGS reservoir, THM simulation.*

Extraction of energy from deep crystalline formation requires pressurisation of the rock mass to create new or enhance existing natural fractures. The fractures generate a pathway for transport of the fluid and heat back to the surface for optimum energy production. However, the complexity of fracture aperture opening and closure during exploitation has posed a challenge for both engineers and geologists. The most widely used model for fracture aperture changes is frequently limited to the hydro-mechanical effect only. This paper presents a new model that incorporates a complete cycle of thermal, hydraulic and mechanical aperture changes in an enhanced geothermal system (EGS) reservoir using a coupled thermo-hydro-mechanical (THM) simulator. The goal is to understand the extent to which thermal aperture changes might enhance the performance of EGS reservoirs. Three reservoir cases are developed: a model of hydro-mechanical aperture changes with a constant thermal aperture; a model of thermal aperture changes employing a constant hydro-mechanical aperture; and a combined model of both hydro-mechanical and thermal aperture changes. The outcomes show that the changes are greater with the thermal aperture than with the hydro-mechanical aperture due to the impact of thermal contraction.

Session 1.2

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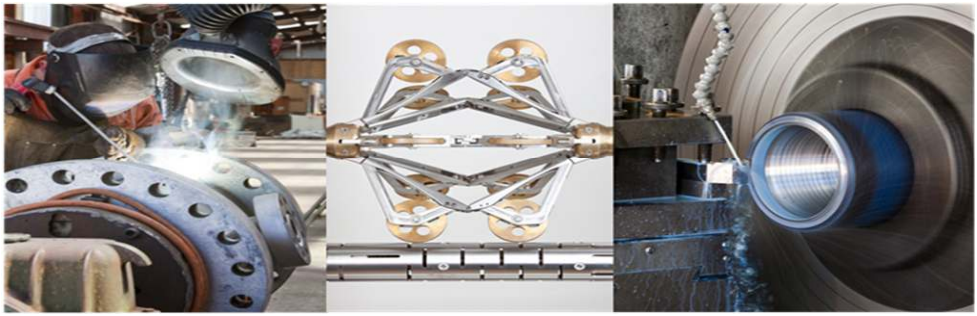

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126 | GEOLOGY FAULT NETWORK OF HULULAIS GEOTHERMAL SYSTEM, BENGKULU, INDONESIA

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Keywords: *Hululais Volcanic Complex (HVC), Suban Agung Fault (SAF), Hululais Geothermal Field (HGF).*

The Hululais geothermal field in Bengkulu, Indonesia is one of the geothermal fields developed by Pertamina Geothermal Energy (PGE), situated on the western side of an overlapping Ketahun and Musi Segment, which is part of Great Sumatera Fault. Morphologically, the Hululais field stand within in Hululais Volcanic Complex (HVC) consisting entirely of Quaternary volcanic rocks. The orientation of structural geology is predominantly northwest-southeast (NW-SE). These structural trends are consistent among surface and subsurface data, fault network, determined from map lineament interpretation, geologic mapping, gravity data and borehole data. The most significant structural features are the Suban Agung Fault (SAF), this master fault strikes northwest through HVC. The northwest trending SAF plays an important role in this system, affect a zone of extension recent volcanism and controls the fluid circulations of Hululais geothermal system.

Ascertain of the fault network in Hululais Geothermal Field (HGF) will assist to define the most productive parts of the zone. Similar fault studies can be applied in other geologic structures to define the most permeable areas in the field.

Poster

127 | VOLCANOSTRATIGRAPHY OF HULULAIS GEOTHERMAL FIELD, BENGKULU, INDONESIA

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Keywords: *Hululais, Sumatra, geothermal, volcanostratigraphy, volcanic facies*

Hululais geothermal field is one of the exploration geothermal fields operated by PT Pertamina Geothermal Energy (PGE). It is located in Rejang Lebong district, Bengkulu province, Sumatra Island, Indonesia. Regionally, this field situated within Bukit Barisan Mountain range on the western side of an overlapping of two major fault segments. They are called Ketahun and Musi Segment. These are two segments of the Great Sumatran Fault complex.

In 2018, geological mapping was carried out to update the data of Hululais volcanostratigraphy by PT PGE. 24 wells were successfully drilled to complete the exploration and development drilling stage on this field. Based on data from surface geological mapping, subsurface (borehole data such as cuttings, cores and borehole image), remote sensing, and some updated modification reports from the previous researchers, Hululais field is part of the quaternary Hululais Volcanic Complex (HVC) from quaternary.

The field comprises six main units (Bukit Resam, Suban Agung, Bukit Beriti, Bukit Gedang, Bukit Lumut and Bukit Pabuar) with associated primary/secondary deposits.

Poster

128 | TE AHI TIPUA KI TĀHORAKURI A130: ESTABLISHING AN ECONOMIC DEVELOPMENT PLAN FOR WHANAU & HAPŪ IN DEGRADED GEOTHERMAL ENVIRONMENTS

Lara Taylor, Tess Kora, Warner Kinita, Anya Seward, Paul White, Diane Bradshaw

Tāhorakuri A130, Ngāti Tahu

Geothermal systems hold strong economic, cultural and scientific significance in the Taupō Volcanic Zone. Since their arrival many iwi have used these systems for cooking, heating and health; thus linking these iwi with their geothermal taonga throughout time. One local iwi, Ngāti Tahu, have been occupying land within the Ohaki Geothermal Field and on the banks of the Waikato River since before the seven-waka arrived from Hawaikii. Their land has experienced significant adverse effects since the commissioning of the Ohaaki Power Station in the 1980's. Extraction of fluids at depth has seen the loss of water flow to geothermal surface features, and the land has suffered from a large amount of subsidence, which has resulted in the migration of the Waikato River and flooding of a large portion of the A130 land block.

Tāhorakuri A130 Ahu Whenua Trust want to reconnect their whanau and economy with their geothermal taonga, with a vision of an eco-papakainga to provide work and housing to their whanau which sustainably utilises the resources that their land provides. In collaboration with GNS Science, the Trust will develop a model for reviving their land which will consider and promote: mātauranga-a-hapū, particularly pertaining to pre-geothermal development in the early-to-mid nineteenth century; western science (geology, geophysics, geochemistry and groundwater); and hapū culture and economic aspirations.

This project develops a deeper understanding of the damage and surface, subsurface and deeper impacts on the land and taonga, and aims at creating an effective plan for developing the Trust's land which will protect, preserve, and possibly restore their wāhi tapu and taonga. Moreover, we expect that the model presents a suitable template for other iwi and geothermal fields.

Session 2.2

129 | MICROBIALLY INDUCED DEGRADATION OF FIBRE REINFORCED PLASTIC (FRP) IN THE COOLING TOWER OF A GEOTHERMAL POWER STATION

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Keywords: *Cooling towers, FRP, sulfuric acid, corrosion, microbial degradation, sulfur oxidizing bacteria, geothermal*

Evaporative cooling water systems in geothermal power plants can pose several challenges for geothermal operators. The challenges of corrosion, deposition and biological control can be magnified in systems utilising direct contact condensers, due to the presence of hydrogen sulfide in the cooling water. Hydrogen sulfide provides an energy source for the growth of sulfur-oxidising bacteria, with the production of sulfuric acid as the main end-product. The sulfur oxidising bacteria can readily colonise such cooling towers, forming a biofilm on the large surface area provided by the tower's structure and fill material.

This paper describes a technical investigation, undertaken following discovery of wide-spread degradation of the Fibre Reinforced Plastic (FRP) structure of a geothermal cooling tower, after only 7 years' of service. The degraded FRP was found only in the top section of the tower, above the Drift Eliminator level. The subsequent investigation identified the cause of degradation as microbially-induced corrosion of the FRP material, due to the presence of sulfuric acid at about 1% concentration (pH 1). Several studies were conducted to understand the nature of the FRP degradation, its effect on the strength of the structural elements, and the extent of degradation over the tower's structure. Subsequent work considered a few possible ways to control bacterial growth and prevent the acid from accumulating. However, no suitable method could be found, with the decision taken to replace the affected FRP with new, acid-resistant FRP material. Because this type of degradation had not been previously reported, selection of new material required the development of an accelerated aging test. This test was extensively applied to FRP samples, covering a range of material formulations, allowing selection of suitable product for use in the tower's repair. This paper concludes with some observations about FRP formulations most suited to this type of cooling tower service.

Session 5.2

130 | HE PUNA I RAWAKE, HE PUNA WHAKATŌTŌ

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Keywords: *Taupō, Ngātoroirangi, Tūwharetoa, Tia, hapū, iwi, manawhenua, exploration, tourism, energy.*

In December 1880, a claim seeking an investigation of the land described as lying between Wairākei Stream in the North and Waikato River in the east, the Waipuwerawera Stream in the south and the boundary of the Oruanui Block in the west, was confirmed as the Wairākei Block. This land has passed through three significant occupation stages. The Manawhenua Landscape was the early settlement of the Taupō environs by Māori voyagers and explorers. Descendants of those early arrivals are reflected in the whakapapa of the hapū who thrived in the area. They were the kaitiaki, living alongside and utilising the natural resources abundant across their whenua. In the 1870's the Tourism Landscape was imposed; Victorian tourists arrived to experience the natural wonders of geysers, hot pools and fumaroles. Kaitiaki no longer had unfettered access to the whenua and its taonga. The third stage, the Energy Landscape, was ushered in with the construction of the geothermal power project. Understanding how these stages have impacted on the whenua and its kaitiaki is important for the restoration and rehabilitation of their mana i te whenua.

Session 2.2

131 | CFD MODELLING OF CORROSION TEST LOOPS FOR GEOTHERMAL FLUID APPLICATIONS

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Keywords: *geothermal, corrosion, scaling, monitoring, test loop, CFD, field testing*

Small bore corrosion test loops in side streams have been commonly used for many years in the oil and gas industry for cooling water corrosion monitoring. This work describes a high temperature flowing brine test loop for on-line Electrical Resistance, Linear Polarisation Resistance and ASTM coupon exposure testing in geothermal applications. CFD modelling of the Electrical Resistance probe access points is presented for small bore piping in "T" and "Y" configurations that achieve mass flow rates similar to pipeline conditions while minimizing the effects of the test element finger intrusion into the flowing brine stream.

Session 5.2

134 | SURFACE HEAT LOSS ASSESSMENT OF ROTORUA GEOTHERMAL FIELD

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Keywords: *Rotorua, Geothermal Surface features, heat loss, heat flux*

Rotorua City is built around the active Rotorua Geothermal Field (RGF) which is valued for its areas of surface activity utilised for cooking, bathing, heating, and tourism. Understanding and monitoring changes in this dynamic geothermal system is crucial in allowing the resource to be used sustainably, while protecting the natural geothermal surface features. Changes in activity of geothermal features over time can indicate changes that may be occurring within the geothermal reservoir due to either natural or anthropogenic causes. Estimating heat loss from a geothermal field provides an indication of thermal activity present in the geothermal system at depth. We present a surface heat loss assessment of the Rotorua geothermal system and compare the results to earlier heat loss surveys, to assess changes in surface heat output. Flow rates, water temperatures and chemistries of major flowing springs and streams were measured, as well as water temperatures and surface areas of large geothermal pools. Calorimetry and ground temperature profiles were also collected from areas of ambient, heated and steaming ground. Evaporative heat loss is a key component of the total heat loss when there is a large surface area of water associated with naturally occurring geothermally heated springs and pools (as occurs in Rotorua). Calculated evaporative surface heat loss from the surveyed geothermal pools is estimated to be 248 MW. Total heat loss (evaporative, discharging flow, convective and conductive heat losses) for the areas surveyed is estimated to be 299 MW. This encompasses approximately 80% of the thermal areas in the RGF.

Session 4.2

136 | TURBULENCE MEDIATED RAPID ALUMUINOSILICATE FORMATION IN HYDROTHERMAL VEIN BRECCIA: NGATAMARIKI GEOTHERMAL POWERSTATION, NEW ZEALAND

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Keywords: *Aluminosilicate, aluminous, silica boehmite, aluminium, scale, precipitation, binary, hydrothermal.*

A recent cleanout of a geothermal brine-pentane heat exchanger at the Ngatamariki geothermal power station provides valuable insight into the in-situ formation processes of both hydrothermal vein breccias and geothermal aluminosilicate scales. Samples of the scale breccia taken during the cleanout primarily consist of broken fragments of a dark-coloured amorphous aluminosilicate pipe scale, which was remobilised and redeposited within the heat exchanger over a period of ~12-hours during the early stages of the breccia forming event. This dark coloured clastic component was subsequently cemented with a white-coloured, massive to very fine-grained amorphous aluminosilicate matrix over the course of weeks. Scanning Electron Microscope (SEM) analyses indicate that the dark component of the breccia formed relatively slowly via colloid impact as a pipe-wall scale before separating from the pipe wall prior to its remobilisation. In contrast, the white fraction of the breccia appears to have

precipitated quasi-instantaneously in place, likely as a result of the turbulence induced flashing caused by the earlier deposited clastic scale obstructing flow into the heat exchanger tubes. The rapidly formed white aluminosilicate fraction served to seal voids within the breccia, forming a strong cementing matrix. The volume and rate of white amorphous aluminosilicate precipitation was significant, with the breccia consisting of up to ~20vol.% white aluminosilicate matrix. A fine white aluminosilicate powder discovered immediately downstream of the breccia appears identical to the white aluminosilicate breccia cement, although unlike the aluminosilicate cement it contains ≥4 w.t.% of the aluminium oxyhydroxide mineral, boehmite. Knowledge gained from the investigation of this event yields invaluable information, both for the prevention of similar scaling events in the future, and the understanding the formation mechanisms of geothermal aluminosilicate scales generally. Furthermore, this event provides unique insight into the interaction between some physical and chemical processes which also occur within active natural hydrothermal systems.

Session 6.3

137 | A ROBUST SUPERCRITICAL GEOTHERMAL SIMULATOR

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Keywords: *Geothermal modelling, supercritical, Menengai, Reykjanes, Krafla, Taupo volcanic zone*

Recent improvements to a supercritical equation-of-state (EOS) for the simulator TOUGH2 are discussed together with its application to simulations of Menengai (Kenya), Reykjanes Peninsula (Iceland), Krafla (Iceland) and the TVZ (New Zealand). The models of Reykjanes Peninsula and the TVZ include multiple geothermal systems.

The new EOS uses smoother and more reliable transitions into and out of the supercritical region than our previous supercritical EOS. This allows natural state simulations to converge robustly, thus enabling models to be calibrated effectively.

An air/water equation-of-state, similar to EOS3 in TOUGH2, but with supercritical capability is also described. This new EOS3sc allows simulation of regions including the shallow unsaturated zone and extending deep to the high-temperature and high-pressure zone.

Session 6.2

138 | GEOLOGICAL MODEL AND PERMEABILITY FRAMEWORK OF BUKIT DAUN GEOTHERMAL FIELD, INDONESIA

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Keywords: *Bukit Daun, Sumatra, exploration, geology and structural modelling, borehole image logs, permeability.*

We present results from a study that investigates the geological setting of Bukit Daun geothermal field, Indonesia and how that geology may influence hydrology. Our analysis addresses geologic controls from the regional to the wellbore scale, and incorporates data provided by Pertamina Geothermal Energy with publicly available terrain images and geologic data. Extensive use of the regional geologic setting (i.e., outside the prospect area) enabled us to improve the confidence and plausibility of the geologic interpretation.

We developed a 3D geologic and structural model and used it as a framework for a hydrologic interpretation that is based on well temperature profiles, feedzone locations, distribution of surface manifestations, and shape of the clay cap. Pertamina Geothermal Energy's drilling success discovered a potentially viable resource and our study proposes a hydrologic model for that resource. Our analysis identifies those elements of the geology that may influence fluid flow at the reservoir and wellbore scale.

Session 1.3

139 | A CONCEPTUAL APPROACH TO 3-D "PLAY FAIRWAY" ANALYSIS FOR GEOTHERMAL EXPLORATION AND DEVELOPMENT

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Keywords: *Play Fairway, Resource exploration, 3-D modelling, Leapfrog*

"Play fairway" analysis has long been utilised in the hydrocarbon industry to assess exploration risk from regional to prospect-level scales. More recently this methodology has seen increased traction in the geothermal industry and resulted in a series of studies in the US. Some of the projects include the states of Hawai'i (Lautze et al., 2015, 2016, 2019), Nevada (Faulds et al., 2018, 2016, McConnville et al, 2017) and Utah (Wannamaker et al, 2016, 2017).

In a play fairway analysis, several parameters potentially indicating the presence of a geothermal resource at depth are categorized, weighted and combined together. This provides spatial distribution of the geothermal resource favourability to limit exploration risk. These analyses are generally limited to the compilation of surface data or results from past surface-based surveys for extended geographical areas, although some parameters such as the geothermal gradient are calculated using dispersed well data.

In this paper, a 3-D conceptual approach to the play fairway methodology is introduced, based on the existence of sub-surface data obtained at the project scale from advanced geological and geophysical surveys, drilling of exploration and/or development wells, laboratory analyses and well testing. A 3-D subsurface modelling tool

was used to integrate the various types of data and then perform calculations and conditional queries using a gridded block model, resulting in a favourability Index model of the geothermal resource

Additionally, this 3-D favourability Index model is always based on the best understanding of the resource as it will dynamically update when new data is integrated. The model can also be refined with additional parameters relevant to specific projects (e.g. local legislative constraints). The methodology and the calculations created can easily be transferred to any other geothermal field dataset to compare results providing a repeatable workflow allowing prospects to be easily benchmarked or compared.

Session 2.3

140 | ESTIMATING WAIRAKEI'S 50 YEARS AND 100 YEARS MWE POTENTIAL CAPACITY FROM A CALIBRATED NATURAL STATE MODEL USING EXPERIMENTAL DESIGN (ED) AND RESPONSE SURFACE METHODOLOGY (RSM)

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Keywords: *Wairakei, probabilistic resource assessment, natural state model, polynomial model, Plackett-Burman.*

Wairakei geothermal field has been operating since 1958, which is years beyond the initial expected production life. There is still significant hot geothermal fluid available for electricity generation that can sustain production for many more years. It is interesting to estimate the theoretical capacity (MWe) of the field assuming it runs for another 40 years, a total production life of 100 years since commissioning.

Two different resource assessment methods were investigated: the volumetric (stored heat) method, and also Experimental Design (ED) and Response Surface Methodology (RSM). In particular, the use of the Plackett-Burman design for building a polynomial model using a calibrated natural state reservoir model with minimum number of required simulation runs was investigated.

Results obtained from Plackett-Burman suggest that Wairakei could sustain a P50 of 294 MWe for 50 years and 219 MWe for 100 years since commissioning. Findings also reveal that permeability and injection parameters are critical to sustain operation for the first 50 years while sufficient permeability and porosity are crucial to support the operation up to 100 years.

Session 1.2

141 | BUOYANCY VORTEX POWER FROM LOW-TEMPERATURE HEAT: PROGRESS

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This paper is a progress report since NZGW 2018, describing laboratory results and a scaling or non-dimensionalisation of atmospheric buoyancy vortices for power generation. It is based on the Oberbeck-Boussinesq assumption and assumes that the vortex flows are pseudo-cyclostrophic and that a radial Richardson number can serve as a predictor of the onset of Kelvin-Helmholtz instability leading to a transition to a turbulent plume. This is used to locate the cold reservoir of the vortex when viewed as a heat engine. It permits the prediction of the behaviour of large vortices in the atmosphere by using data from experiments on small vortices.

Session 6.2

142 | CONCEPTUAL MODEL EVOLUTION OF THE TAUHARA GEOTHERMAL RESERVOIR FROM 1960-2020

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Keywords: *Tauhara, conceptual model, reinjection, pressure response, deep permeability, compartmentalization.*

At the early stages of reservoir exploration the conceptual model for the geothermal resource is of necessity simple. As a reservoir is developed the conceptual model will be refined as new spatial and temporal information becomes available from additional drilling and extended monitoring of the reservoir response to production and reinjection. Pressure response of the early exploration wells at the Tauhara reservoir, drilled in the 1960s some 5-10 km distance from production areas at Wairakei (first power generation 1958), indicated the existence of a relatively shallow and laterally extensive hydraulic connection between the Tauhara and Wairakei reservoirs. The pressure difference between the reservoirs implied that part of the Wairakei hot recharge was derived from Tauhara. Over time, the conceptual model has evolved, incorporating data from new, deeper wells, together with geophysical surveys, and the reservoir response to changing volumes of production and reinjection fluids. The evolution of the conceptual model for the Tauhara reservoir over the last 60 years is presented along with the current understanding of the nature of the interconnections between Wairakei and Tauhara.

Session 1.3

Notes

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