ADVANCES IN ABOVE GROUND GEOTHERMAL AND ALLIED TECHNOLOGIES (AGGAT)

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ABSTRACT

Above Ground Geothermal and Allied Technologies (AGGAT) represents the technological research and development base for above ground technologies in power generation. Much progress has been made in the development of these technologies over the past decade and even more so since its formal inception in 2012 through dedicated financial support from NZ government. The New Zealand Heavy Engineering Research Association has been actively promoting and supporting the advancement of this research at a national scale through its AGGAT research roadmap and programme which encompasses research and development in the areas of technology concepts, turbines, heat exchangers, control systems and binary fluids. This paper presents an update on the activities undertaken in each area of its research and implications of their outcomes for New Zealand Industry.

1. INTRODUCTION

1.1 Low Enthalpy Geothermal

With an increasing shift in global perceptions towards renewable energy, the need is growing faster than ever before for renewable energy alternatives to current carbon producing energy generation as well as greater accessibility to them (REN21, 2014). Geothermal energy is recognized as an excellent renewable energy candidate for generating power. New Zealand has one of the most abundant geothermal energy resources in the world utilizing its high temperature geothermal steam fields to host some of the world's largest power generation plants. At least 13% of the total electricity production in NZ is provided by geothermal resources (NZGA, 2013) and this is understood to have increased after the completion of recent plant installations.

The opportunity of geothermal power generation demonstrated in NZ is offered internationally as NZ expertise is applied to develop geothermal power generation facilities worldwide (NZTE, 2013). Parallel to conventional steam based geothermal technologies; lower temperature geothermal resources have also gained significant attention for their energy harvesting potential. This is based on power generation technologies capable of extracting energy at low temperatures typically between 80-150°C. International research and development is active in the area of low enthalpy geothermal technologies and research efforts have intensified in NZ as well to ensure the next generation of geothermal technology is aligned with the sector's needs.

1.2 Organic Rankine Cycle

Heat extraction and subsequent power generation from a low temperature geothermal resource is achievable through commercially available technology in the form of binary cycle power generation plants. Electrical power generation units using binary cycles have become the fastest-growing group of geothermal plants due to the high prevalence of low to medium temperature resources (IEA, 2011). Of these the most commercially predominant is the Organic Rankine Cycle (ORC) which is a modified version of the steam based Clausius-Rankine cycle. Steam is replaced with an organic fluid to take advantage of its low boiling point allowing heat extraction to take place at a lower operating temperature. The Organic Rankine Cycle (ORC) configuration is shown below in Fig. 1.

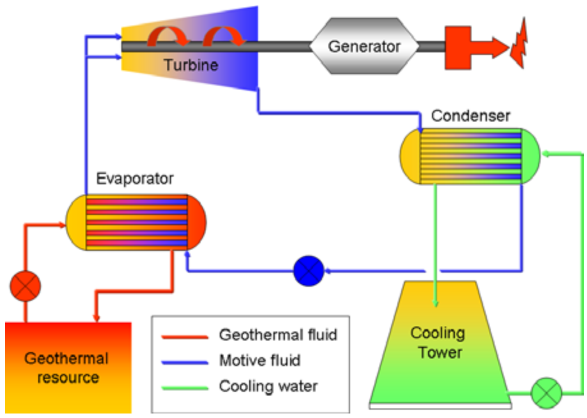

Figure 1: Organic Rankine Cycle Configuration.

In the simplified schematic above (Fig. 1), the energy conversion process starts with the uptake of heat from a geothermal resource into an evaporator (at times preceded with a preheater) to heat the binary fluid up to its boiling point. The heated binary fluid undergoes isentropic expansion in a turbine rotating a shaft connected to a generator to produce power before discharging as spent fluid into the condenser. Here the fluid condenses back into liquid (with the aid of a cooling tower in the absence of cooling water) before returning to a pump for recirculation and repeating the cycle.

Whilst ORC technology is commercially available, challenges exist in the form of low cycle efficiencies (<10-12%), high investment costs ($2500-5000/kW) and limited flexibility in the design of commercially available modules (Nusiaputra, 2014). New Zealand despite its geothermal expertise has not yet entered this market to provide a NZ solution to these challenges. This technology significantly draws on heavy engineering expertise.

1.3 The AGGAT Programme

Research efforts in NZ have predominantly focused on below ground activities such as reservoir engineering, drilling, geothermal chemistry etc. However there has been a parallel need for a concentrated agenda to advance above-ground geothermal technologies in NZ. This agenda has a technological basis and is complimentary to the international marketing efforts undertaken by Geothermal NZ. A paper was presented at the NZ Geothermal Workshop in 2012 (Habib, 2012) introducing the research agenda for Above Ground Geothermal and Allied Technologies (AGGAT). The current paper provides an update on the activities undertaken since and progress achieved till now.

The Heavy Engineering Research Association of NZ (HERA) undertook the challenge of facilitating R&D activities more than five years ago in above ground geothermal technologies at the behest of its 600 strong heavy engineering member companies who affirmed clean energy to be a priority area going forward. Since then the efforts have turned into a nationally driven programme which was boosted significantly by an R&D grant from the Ministry of Business, Innovation and Employment (MBIE) in 2012. The programme now involves two major NZ universities as research partners with several member companies seriously engaged in supporting the programme with their heavy engineering expertise. The programme is also supported by two international partnerships in the development of turbines.

The major AGGAT research themes focus on the areas of:

- Technology Concepts
- Turbines
- Heat Exchangers
- Materials & Fluids
- Control Systems

A research roadmap detailing the research questions under each theme is available from the HERA library (Habib et al., R5-47 2012). A presentation providing the geothermal context to the AGGAT research roadmap was presented at the Above-Ground Technologies Workshop in Auckland earlier this year (Habib, July 2014). AGGAT is a registered trademark logo and can be used by programme partners to indicate their association with the programme. The ultimate objective of this programme is to construct and deliver at least one pilot scale ORC demonstration facility in the next two years.

1.4 Heavy Engineering Industry of NZ

HERA represents the Heavy Engineering Industry of NZ through its membership of more than 600 engineering companies. The majority of members involved in metals fabrication operate as contractors to deliver product installations in the engineering sector with very few that can claim to be manufacturers of their own products based on their own intellectual property. However the companies possess significant and refined skills in engineering fabrication and machining that are not generally well-known which sometimes leads to the misperception of a lack in fabrication and machining capabilities within NZ.

Page & Macrae Engineering (Mt. Maunganui) is one of the leading regional providers of heavy engineering expertise specializing in geothermal installations. Page & Macrae was recently involved in major installation projects for the Mighty River Power Ngatamariki 88MW and Contact Energy Te Mihi 166MW developments (Fig. 2).

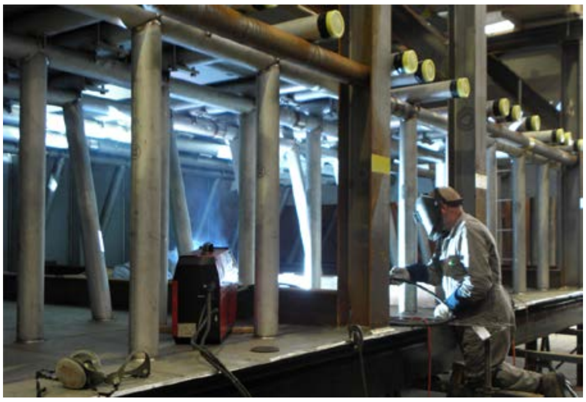

Figure 2: A condenser module for Te Mihi Geothermal Power Station in Page & Macrae's Stainless Steel fabrication workshop at Mt. Maunganui (Page & Macrae Engineering, 2014)

Another example of a geothermal specialty company is Allied Industrial Engineering (AIE) located in Kawerau. AIE have a history in dealing with large scale (MW) turbines and generators having worked on several of them for the nearby Kawerau and Norske Skog geothermal power plants (Fig. 3).

Figure 3: Turbine refurbishment underway at AIE workshop, Kawerau, NZ (NZTE Geothermal companies' profiles, 2014)

Metrology Group in Hamilton house specialist equipment and capability for precision measurement and machining of specialty engineering components supplying parts to the airline industry. At the recent Above Ground Technologies workshop, Metrology Group showcased a number of capabilities which also included manufacture of a turbine rotor as pictures in Fig.4 below.

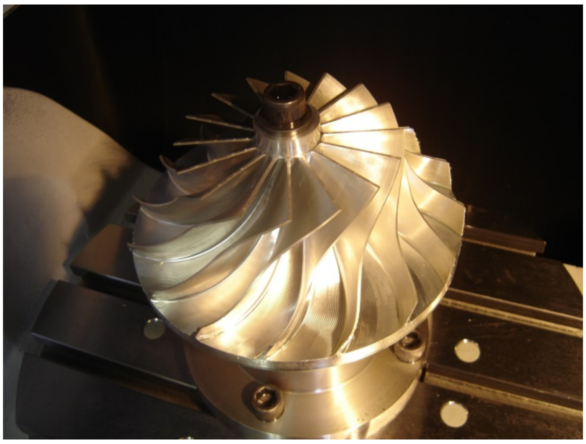

Figure 4: Turbine impeller prepared with Metrology Group capabilities, Hamilton, NZ (Metrology Group workshop presentation, 2014)

2. GEOTHERMAL BINARY ORC DEMONSTRATION FACILITY

As mentioned previously, the objective is setting up a binary plant ORC demonstration facility. The facility is expected to possess as much local manufactured content as possible. Efforts have been underway on multiple fronts to facilitate the delivery of a pilot plant. The breadth of activities being undertaken is depicted through the breakdown diagram shown in Fig. 5 below which is by no means exhaustive. It does show the current activities in progress as highlighted green with the next steps of activities that are planned for this coming year, highlighted in yellow. The activities planned for the second year are highlighted in blue.

The objective is reliant on the support and expertise of a number of project partners. A resource partner is required who can make available a geothermal resource on which to carry out the demonstration. A research partner is required to carry out the design and modelling activities associate with the ORC plant. A heavy engineering member company supports the project by manufacturing the binary ORC plant. For areas with minimal design expertise such as turbine design and construction, international collaborations are being forged with companies possessing expertise in those areas. From Fig. 5, it can be noted that this team structure is in place (highlighted green) with programme management coming from HERA. The AGGAT Science programme is providing the R&D expertise in the five research themes mentioned earlier which will feed innovations into the next generation of binary plant technologies. An overview of the sequence of activities leading towards a market ready ORC product is given below in Fig. 6.

As can be seen from Fig.5 the design stage is mostly complete (highlighted green) and the next steps are to build and monitor. It is expected that this will be achieved in the next two years.

Market studies have been carried out by HERA for the US and European markets with marketing strategies outlined for product entry and establishment (Ludewig,

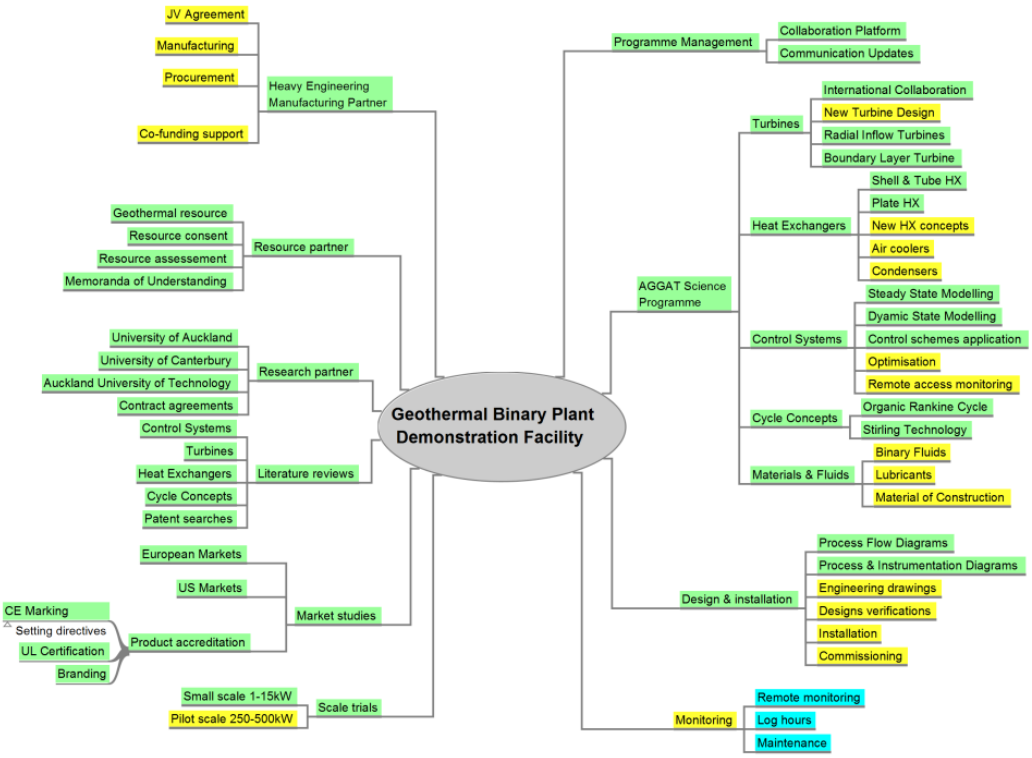

Figure 5: Breakdown of activities for the set-up of a binary ORC demonstration facility

2013). Brand development and promotions guidelines have also been prepared (Kotouc, 2013) for member companies to consider as part of their market preparation process. Regular technology review updates have been carried out to keep abreast of market developments (Jung, 2012) and patents (Pauko, 2012) in binary technologies.

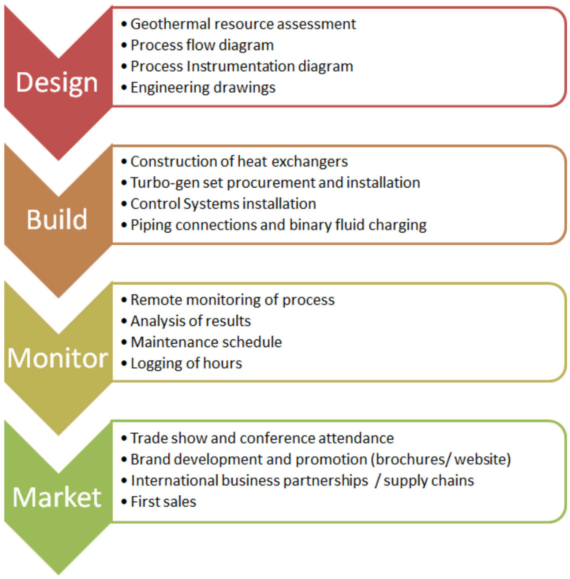

Figure 6: Major stages in preparing a geothermal binary ORC product

2.1 Geothermal resources

The first step in the overview presented in Fig. 6 is to find a suitable geothermal resource as pilot plant ORC demonstration site. Three potential resources were investigated for this purpose however on assessment, one of the resources was found to possess insufficient heat for a pilot scale demonstration. Another excellent resource was parked due to major construction works being undertaken on the site. The third resource has undergone preliminary assessment confirming high geothermal heat potential. Details will be confirmed once sufficient progress has been made in resource assessment and plant installation.

2.2 500kW ORC plant

Based on preliminary resource assessment results, it has been proposed that a 500kW geothermal resource facility be constructed as an ORC demonstration unit. This suggestion came from a Heavy Engineering Member Company which manufactures equipment at this scale and is interested in expanding its portfolio within the energy market by including ORC technology in its offerings as well.

Through the AGGAT programme, a 1kW ORC test rig has been developed as well (introduced later in the paper) which can provide preliminary test results at small scale. Instead of proceeding towards a direct installation, it was proposed to carry out small scale trials with the turbine design in question to verify results expected from prior calculations. This will be a necessary pre-requisite step that will provide confidence in moving forward to a larger scale. A schematic flow chart of the testing process is shown below in Fig. 7. It must be noted that in this example, the member company is capable of designing and manufacturing their own turbine and currently uses it in other medium scale applications. The 1kW tests will primarily serve to validate the turbine performance at small scale before proceeding towards a larger scale investment.

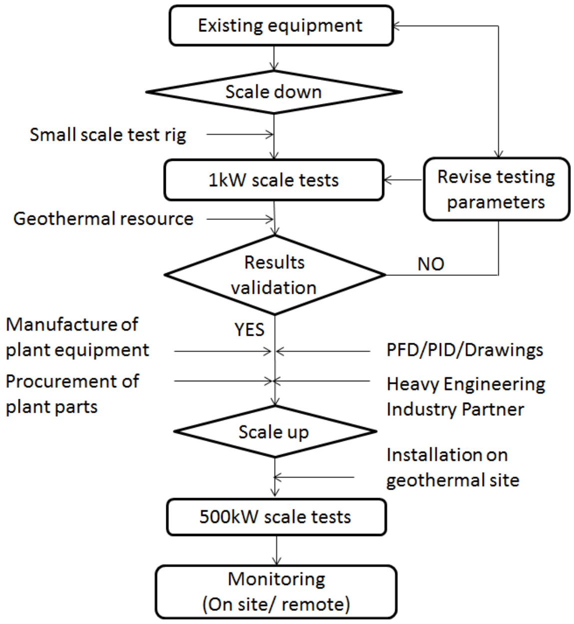

Figure 7: Schematic flow chart of steps towards building a 500kW geothermal ORC unit.

3. DEVELOPMENT OF TEST RIGS

In addition to the 500kW demonstration unit and 1kW ORC test rig, simultaneous efforts have been made to prepare rigs for materials testing and for geothermal scaling. These are objectives as part of the AGGAT Science Programme described earlier.

3.1 1kW ORC test rig

A small scale test rig capable of producing up to 1kW of power has been developed at the University of Canterbury as part of the AGGAT Science Programme. The heat source for this rig is the exhaust gas from a Capstone Turbine however this could also be provided by an equivalent geothermal resource. A schematic of the ORC test rig is provided below in Fig. 8.

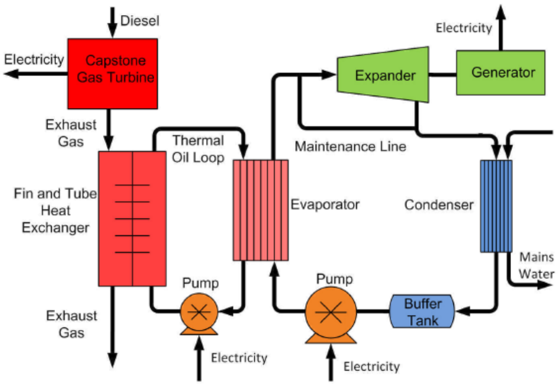

Figure 8: Schematic of the 1kW ORC test rig at University of Canterbury. (Mill et al., University of Canterbury, 2013)

Heat extraction is achieved through a fin and tube heat exchanger (contributed to the program by a HERA member company, Advance Boiler Services Ltd). The heat extracted into a thermal oil loop is transferred to a binary fluid. Plate Heat Exchangers (PHEs) have been used here for evaporation and condensation. This may not be a preferable selection in a geothermal environment due to scaling concerns from silica blocking the flow pathways. However for the purpose of turbine testing, this is considered to be acceptable. The purpose of using PHEs is to reduce the footprint and enhance heat transfer coefficients. The ORC test rig is pictured in Figs. 9 and 10.

Figure 9: Picture of the 1kW ORC test rig (Mill et al., University of Canterbury, 2013)

A buffer tank is also in place to keep the fluid pump primed and prevent pump dry operation. Variations of turbo-gen sets have been installed in the test rig including scroll expanders and modified turbo-chargers.

A load for the electricity generated is provided by a bank of high powered connected light bulbs (Fig. 10).

Figure 10: Picture of the ORC test rig in operation as demonstrated by powered flood lights. (Mill et al., University of Canterbury, 2013)

A paper was published on health and safety regulations and concerns for the geothermal industry in NZ (White, 2013) which suggested the industry to better map the risk landscape associated with geothermal development. This concern is noted in the AGGAT Science Programme and is a priority in all AGGAT developments taking place.

The test rig works under reasonably high pressure and temperature. Due considerations have been given to health and safety practices of the rig. For example the refrigerant cannot be charged into the rig without a qualified technician. An operating manual has been prepared as a guide for user operation. No one is allowed to operate the rig unless trained or in the presence of a trained rig operator.

The test rig has demonstrated capability to produce up to 1kW of power. Further modifications to the rig are underway to add instrumentation and monitoring capability for more accurate control and response during operation. It is anticipated that the test rig could be used to carry out small scale validation tests for various process equipment before building larger scale versions of the same for field-based applications. The test rig can also provide comparison results for geothermal applications which will be added to the AGGAT experimental results database for future reference.

3.2 Material-testing rig

A field-based material-testing rig has been designed to investigate the performance of various materials as part of the Materials Knowledge Base Development Project within the AGGAT Science Programme (Heinzel, 2013). A schematic of the test rig is provided in Fig. 11.

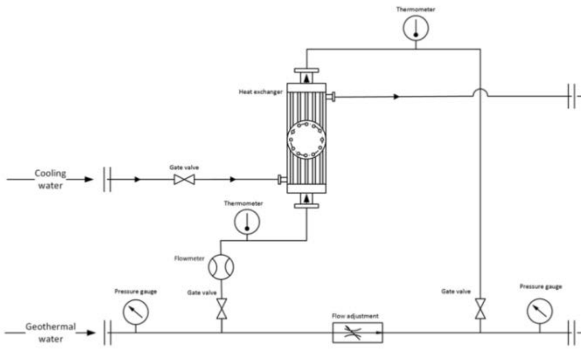

Figure 11: Schematic layout of the materials-testing rig (Heinzel, 2013)

Geothermal brine scaling and its control has been the subject of a number of investigations in literature (Dunstall *et al*., 1998; Gray, 2010; Addison *et al*., 2012; Erstich *et al*., 2012., Zarrouk *et al*., 2014) illustrating the importance of this issue to the geothermal industry. The AGGAT Science Programme is aligned to address this challenge through using the materials testing rig to develop information that will be helpful in understanding scaling mechanisms and determining appropriate scale control / mitigation techniques.

A shell and tube heat exchanger has been designed which consists of tubes made with different materials. The tubes will be subjected to brine flow under controlled hydrodynamic conditions for scale deposition observations using destructive tests afterwards. The test rig is being developed in collaboration with a number of heavy engineering member companies who will be contributing various parts towards its construction and installation. Construction is currently underway and will be completed and commissioned within this year.

3.3 Future activities

The programme is currently undergoing its two-year progress review by the Ministry of Business, Innovation and Employment. Subject to a successful outcome, the programme will continue for a further two years during which time it is planned to achieve the objective of setting up a geothermal pilot scale ORC demonstration facility. During this time, concurrent research activities will take place to deliver a suite of design tools for the partner companies, databases in materials, fluids, heat exchangers and turbines supported with process and experimental data, standardised module options for ORC units and an optimised control systems package available to AGGAT member companies. It is envisaged that with the collaboration of international turbine development partners, a new turbine design could also be achieved.

This outlook is not without its set of challenges that will need to be overcome in terms of co-funded projects, timely delivery of outputs through astute project management and most importantly a change in NZ industrial mind-set from contractor to IP owner that will embrace the upcoming future of the geothermal industry.

Next year, HERA and partners plan to host a global AGGAT conference in NZ in conjunction with the World Geothermal Congress being held in Australia (with field trips and a short course in New Zealand). This conference will be the opportunity to show-case NZ above ground geothermal research.

4. CONCLUSIONS

Low enthalpy geothermal energy is an attractive source of energy that can be effectively harvested with commercially available binary cycle technology. New Zealand has every advantage based on its geothermal history to develop this expertise as an offering to the international market. The AGGAT Programme is leading the development of this expertise and supports initiatives aligned with this agenda.

Progress made over the last two years has seen the development of test rigs that will be instrumental in supporting the development of a pilot scale geothermal ORC demonstration unit.

Over the next two years, pending a successful MBIE review, the AGGAT challenge will be to transform the current progress into a geothermal ORC demonstration unit.

A global AGGAT Conference is planned in 2015 to be held shortly after the World Geothermal Congress. This platform will provide the NZ geothermal industry with an opportunity to showcase its AGGAT research and development achievements.

ACKNOWLEDGEMENTS

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