Proceedings Australian Geothermal Energy Conferences 2013
Brisbane, Australia, 14-15 November 2013

First Australian Geothermal Plant-Mulka Case Study

John Popovsky

The University of Queensland (UQ)

John.Popovsky@uqconnect.edu.au

Keywords: geothermal energy,mulka,organic rankine cycle

ABSTRACT

Geothermal energy with in Australia can be harnessed through organic rankine cycles (ORC's). Hot sedimentary aquifers can be used as geothermal energy resources. In particular, an ORC that became operational in 1986 in Mulka, South Australia demonstrated electricity generation by utilizing a geothermal resource (The Great Artesian Basin). The Mulka plant has its place in geothermal history and in Australia as being the first of its kind; possibly even a world's first operating at such a low temperature. Its operating temperature was 86 °C and was designed to produce 20KW of electricity. The average power consumption during the first 7months of operation was 3.5KW (Collins et.al, 1987). The expander, unlike traditional ORC's was a refrigeration screw compressor reversed to act as screw expander. Preliminary plant testing showed that plant was capable of producing electrical power of up to 16.4kW and a maximum expander efficiency of 59%.The ORC is of particular interest for outback communities where electricity is primarily supplied by diesel electric generators. With the high cost of fuel and the growing concern over the effects on C02 emissions on the environment, geothermal energy can provide a zero emission electricity generation alternative in areas and circumstances where it is appropriate.

1. INTRODUCTION

The increasing concern on greenhouse gas emissions and its effects on global warming, climate change and environmental pollution have shifted attention from the traditional use of fossil fuels towards alternative sources for energy production. Geothermal energy is an alternative energy resource that can produce clean green energy. Much attention has been focused on large scale geothermal plants (>1Mw) utilizing hot geo-fluid typically greater than 200℃. Until recently, little focus has been placed on low scale geothermal plants, typically in the <20kW scale utilizing low geothermal temperatures of less than 100 ℃. One example is the Mulka Organic Rankine Cycle (ORC) that utilized geothermal energy through hot geo-fluids in the Great Artesian Basin (GAB). The history of the Mulka ORC, operation and performance is presented in the paper.

2. MULKA HISTORY

2.1 Mulka Site

Mulka is a rural town located over 900km North from Adelaide. The site selection process was a joint effort between Enerco Pty.Ltd and the Department of Mines and Energy. The Mulka homestead was selected as it had a pre-existing bore, ideal operation parameters and very enthusiastic landowners (Collins et al, 1987). The pre-existing bore has been refurbished in 1985 as part of the South Australian Department of Mines and Energy bore refurbishment program. The bore was provided with new bore headworks and a gate valve to minimize water wastage. Operation parameters such as temperature and pressure were considered ideal at the homestead, with a bore temperature of 86℃ and pressure of 130kPa. These were considered ideal, as the artesian pressure provided a steady flow rate requiring no additional pumping. While the flow rate and bore temperature were sufficient to supply enough heat energy to the R-114 refrigerant working fluid allowing the organic rankine cycle (ORC) to function and generate electricity.

2.2 The Mulka ORC

The Mulka ORC is a prominent example of power generation by an Organic Rankine Cycle using a low geothermal heat source. It was the first geothermal ORC designed and built in Australia that was successful in providing continuous electrical power to a rural homestead.

2.2.1 Motivation

The Mulka ORC had a multi-purpose function; it provided drinking water for the livestock to the outer areas of the property, solving the previous water distribution problem and provided base load electricity for the homestead. Booster pumps were installed and powered by the ORC to pump water to livestock borough troughs up to 20km from the homestead in all directions, North, South, East and West.

2.2.2 Background

The plant was designed by WHITE Refrigeration Inc in 1983. It was manufactured by Enreco Pty Ltd, a local company found in Crafers, South Australia. The plant was installed at the Mulka site in April 1986 and took five weeks to install (Collins et.al, 1987).

The installation process consisted of the fitting of electrical power points, lights and piping system for the cooling dam and bore access. The design and manufacturing of the plant was funded by the South Australian State Energy Research Advisory Council (SENRAC) in conjunction with the Commonwealth of Australia National Energy research, development and demonstration program (NERDDC). The total expenditure of the NERDDC grant was $65,489 (Collins et.al, 1987). No data can be found for the amount SENRAC funded, however a quote by WHITE Refrigeration Inc on a similar plant, cost $80,000. Therefore a total of $145,489 was spent on the, design, manufacturing and installation of the plant.

The Mulka plant was transported to the site by freight, as it weighed approximately 5000kgs and was quite large and bulky. The majority of the plant was installed at the Enreco Pty Ltd workshop leaving smaller, less bulky components to be installed onsite. The plant was unloaded by unconventional means, limited by resources due to the remoteness of the site and large plant weight. A ramp was dug for the semi-trailer to reverse into then the plant was then skidded onto a concrete slab. (Collins et.al, 1987).

The plant began operation in May 1986 and operated continuously providing 24 hours reliable electricity for three years without any breakdowns or maintenance issues recorded, demonstrating a high degree of frequency stability and response to load changes. The plant ceased operation in 1989 due to the landowners selling the land to the mining company Santos who had no use for it. Factors that may have contributed to the lack of enthusiasm by Santos include the working fluid R-114 refrigerant, effectively a banned substance due to its high global warming potential (Montreal Protocol, 1987), the low electric power output and the potentially high maintenance costs associated with a breakdown. If a breakdown occurs, specialist personal will be required to visit the site, at the expense of the owner. If a part is broken or requires replacing, parts would have to be ordered and transported, increasing the total down time of the plant. The screw expander, due to the designed gears was a specialist part and required manufacturing. Therefore, the total cost of a fixing a breakdown or maintenance has the potential to be quite high and time consuming.

2.2.3 Bore Water

Artesian bore water typically has many minerals that can cause corrosion or scaling in components and piping systems. The water quality of the bore water contained 800mg/litre of sodium bi carbonate, 0.4 mg/litre of calcium and 2.8 g/litre of magnesium (Collins et.al, 1987). Sodium bi carbonate is soluble in water even at low temperatures, therefore did not create a scaling problem. The calcium and magnesium are usually the hard scale forming salts though no signs of scaling were observed in the heat exchanger after 7 months of operation.

2.2.4 Problems

Even though there was no issues or breakdowns recorded there was still some problems. There was evidence of corrosion in the copper tubes that lay under the cooling dam and in tube heat exchanger. Tests results provided by AMDEL found the soil to have a high electrolytic nature, which provided conditions for corrosion (Collins et al 1987). The limestone soil near the bore provided an environment unsuitable for a cooling dam, which was recommended to be close to the ORC to avoid parasitic pumping (Collins et al, 1987). Therefore, the ORC plant was placed 350m away from bore which caused was a slight drop in temperature of the bore water ~3°C. Fortunately, this drop in temperature did not appear to affect the performance of the ORC.

3.0 MULKA OPERATION

The Mulka ORC operated under the principal of a traditional rankine cycle. Though with some differences, the working fluid was an R-114 refrigerant, traditionally a steam. Another difference was the heat source and energy exchange process, which was provided by the hot artesian bore water through a heat exchanger (evaporator). The heat sink was provided by a sprinkler system and cooling dam. As the Mulka plant utilized a hot artesian geo-fluid as the heat source it was categorised as an organic rankine cycle (ORC).

The Mulka ORC used a screw compressor reversed to operate as a screw expander; equipped with a forced lubrication system and a set of gears manufactured by the Hecus Manufacturing Co. The gears allowed the expander to operate at higher speeds and produced a larger torque (Collins et al, 1987). Screw expanders have not typically been applied in rankine cycles. Even though they are flexible with their operation, (can allow droplets of liquid at the expander exit) they are not very efficient with an efficiency range between 40-65% (Lemort et al).

3.1 Mulka Operation Description

The first stage of the Mulka ORC operation is the energy transfer process in the heat exchanger. The heat exchanger transfers energy in the form of heat from the hot bore water to the working fluid R-114. The heat exchanger process in the Mulka cycle consists of two components, the pre-heater and the evaporator. Ideally, the pre-heater heats the working fluid to a saturation mixture containing both liquid and vapour, while the evaporator is used to separate the vapour from the liquid, as vapour has a much higher enthalpy (energy). The vapour becomes a superheated steam, due to the constant pressure in the expander which increases temperature and energy of the working fluid. The superheated steam then flows through a screw expander. The mass flow of the superheated steam turns the screws inside the expander, which creates a positive displacement and drives a shaft. The shaft is connected to a generator, which converts the mechanical turning of the shaft into electricity.

A pressure drop is created between the inlet of the expander and the outlet as mechanical work is being done. The drop in pressure reduces the temperature and therefore the fluid has a lower enthalpy (energy). Water from a cooling dam is pumped by an additional pump through the condenser to cool the working fluid. The same heat exchanging process occurs in the condenser as the in the evaporator. Except, instead of the hot bore water, cold dam water is used to cool to the saturation mixture working fluid to a liquid. After the working fluid is condensed and returned to its liquid state it is pumped to the pre-heater and the cycle is repeated.

A distribution dam was constructed with the addition 15 copper pipes that lay on the bottom of the dam to cool the hot artesian water to 55°C. As the temperature of hot artesian water at the evaporator outlet was 81°C, unsuitable for water consumption and distribution. Another makeup dam was built, which insured that there was sufficient water in the cooling and distribution dams.

4.0 MULKA PERFORMANCE

The Mulka ORC was designed to produce 20kW of power at the condition of the bore temperature being 86°C. Due to the harsh environment conditions present in Mulka, the use of data collection to monitor the performance of the cycle was not installed. This limited the available data to preliminary test results before installation and personal visits to the site. The actual power consumption during the first 7 months of operation was 3.5kW, much higher than expected (Collins et al, 1987) .

Testing of the Mulka ORC before installation demonstrated that the expander could produce power ranging from 5.4 to 16.4 kW, depending on the temperature of the hot and cold water. Therefore, the temperatures of the hot and cold water have a direct effect on the performance of the plant. Investigation into the how much effect the temperature has on the expander efficiency was explored and is displayed in Figure 1. As demonstrated in Figure 1, a slight change in temperature ratio (0.05) can result in a significant change in expander efficiency. The efficiency of the expander had a maximum of 59.8% when ratio of the cold water to hot water was 0.83. It is noted at this efficiency the power output was 12.4 kW slightly less than 16.4 kW, with an expander efficiency of 56.09%.

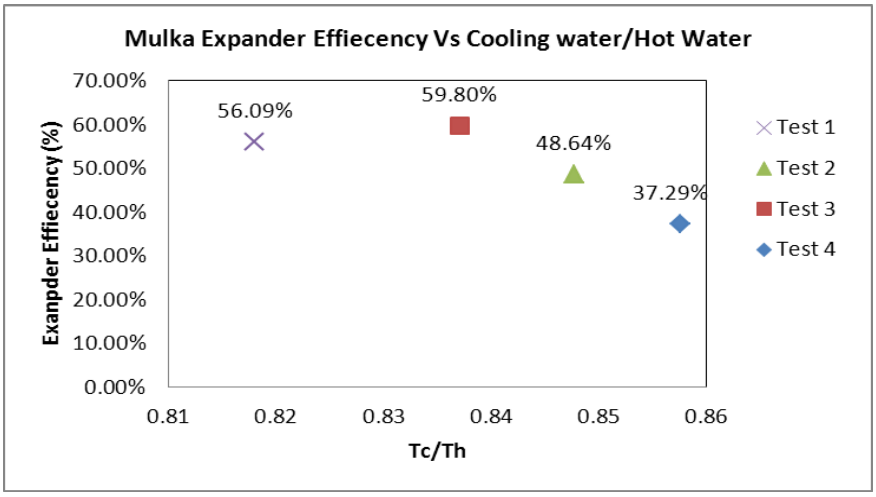

Figure 1 Mulka Expander Efficiency Vs. Cooling Water/Hot Water

The Mulka cycle is estimated to save 13,230 litres of diesel fuel based on an average 20kW electric fuel generator operating at full load 6 hours a day 7 days a week (43680 kWh) (Diesel Service and Supply, 2013). This translates to a saving of 36,508kg of emissions per year (EPA,2005). At a diesel price of $1.5, the fuel cost is ~$20,000. Considering the Mulka plant cost of $80,000, the payback period for the plant is ~4 years. The $80,000 excludes other costs such as transportation and installation costs. Unfortunately, constraints on utilizing the artesian bore water has been put place by the Australian Government as there is growing concern on the effects of bore water usage on the artesian pressure and flow rates (GAB,2000) (W.D.U,2011). Therefore if the Mulka cycle was to be replicated, it would have to comply with strict conditions, permits and water harvesting fees. Unless an additional re-injection well was drilled to ensure all water is circulated back into the basin. Permits are required by the Australian Government Water Act 2000 for the use of artesian water. In most cases on the basin the cost for water harvesting is $4 per mega litre (Water Act,2000) .

5.0 CONCLUSION

The Mulka cycle demonstrated geothermal thermal electrical power generation provided by the geo-fluid in the Great Artesian Basin. The cycle, during the first 7months consumed an average of 3.5kW of power which clearly indicates that the 20kW cycle is oversized for the homestead. The Mulka ORC supplied continuous stable electricity and water for the homestead and outer laying areas. It produced zero emissions, saving 36,508kg of emissions when compared to an average 20kW diesel electric generator and was free of any additional maintenance or operating costs for three years. The high degree of load stability was credited to the screw expander, which was a screw compressor reversed to act to as an expander. The maximum efficiency of the screw expander was calculated to be 59.09%. The preliminary test demonstrated that the cycle could produce a maximum of 16.4kW when the hot water was 88.1ºC and cold water was 22.4ºC. Due to the Australian Government Act there are strict conditions on utilizing artesian water. Therefore replicating the Mulka ORC can only be achieved in areas and circumstances where it is appropriate. Factors contributing to the suitability of cycle integration include a pre-existing bore, re-injection bore, appropriate bore temperatures, water permits and water harvesting fees.

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