SMALL-SCALE ORGANIC RANKINE CYCLE FOR GEOTHERMAL APPLICATIONS

Kek, B[1], and Raine, R.R.[2]

[1]Fitzroy Project Services, Fitzroy Engineering Group, 139 Cryers Road, East Tamaki, New Zealand

[2]Department of Mechanical Engineering, The University of Auckland, Private Bag 92019, Auckland 1142, New Zealand

bkek@fitzroy.co.nz

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ABSTRACT

In waste heat power generation, heat energy can be recovered using a binary cycle system such as an Organic Rankine Cycle plant. The working fluid will likely be a commercial refrigerant. The turbine generator has a significant bearing on the technical performance and financial viability of the overall system. Turbine generators in commercial power generation use in NZ are sourced from overseas and are of high power ratings, upwards of tens of megawatts. This hinders the utilization of many sources of waste heat such as the waste heat of a geothermal plant as these call for several units in the kilowatt range. We are developing a 50 kilowatt electrical power turbine generator prototype to fill this niche.

Our plan is to develop a modular turbine generator that meets the current and future market demand for waste heat power generation. The waste heat could come from sources such as the petrochemical industry, solar, geothermal, fossil fuel power generation and the waste industry.

This is part of the Fitzroy R&D programme to build a modular Organic Rankine Cycle power generation system with a target power output of 50 kilowatts electrical power supported by Callaghan Institute. The unit generation price will be just slightly higher than large scale geothermal power generation in order to be commercially viable. In order to achieve this, the turbine generator will be designed for high volume manufacturability right from the start of R&D.

1. INTRODUCTION

1.1 Economic landscape for geothermal power generation

Unlike many countries overseas, NZ does not have subsidies for geothermal power generation. Geothermal power generation needs to be financially competitive against conventional power generation technologies such as coal and natural gas. However, geothermal power generation is more environmentally friendly because it does not emit greenhouse gases. In the past, there have been issues of environmental pollution whereby the spent geothermal fluids are directly discharged into waterways with insufficient or no treatment at all. Nowadays, that issue has already been addressing and many jurisdictions require spent geothermal fluids to be either treated to a level where it does not significantly affect the environment as before or injected into an underground reservoir.

1.2 Low power geothermal wells

There is a relatively high minimum geothermal well power output required for imported geothermal power generation technology. This means a significant number of geothermal wells have been drilled but cannot be cost effectively commercialized. This research aims to solve this problem by developing geothermal power generation equipment that can be cost effectively deployed on to low power geothermal wells. This is possible because the cost to transmit electrical power from geothermal power generation is a great deal lower as compared to piping geothermal fluids over an appreciable distance with respect to low power geothermal wells.

1.2.1 Geothermal Resource Parameters

Geothermal resource parameters need to be studied in detail in order to develop a suitable solution. The temperature of the fluid has a strong bearing on the economic viability of power generation. Higher temperatures are preferable as it reduces the cost of some key capital equipment such as heat exchangers.

Higher heat extraction from geothermal fluids is also desirable to a certain extent as some low temperature spent geothermal fluids can cause scaling issues. This is because a significant number of geothermal wells produce fluids with high silica content. When the geothermal fluid is cooled to and below the freezing point of silica, the silica in the fluid will crystalize and cause a great deal of problems, all of which will have financial repercussions. If silica granules form in the geothermal fluid inside of the geothermal power plant, I will act as a potent abrasive and turn the fluid into slurry. This slurry can literally cut through steel and exotic materials thus significant reducing the life of the plant equipment affected. Under certain circumstances, the silica in the geothermal fluid can also cause the fluid to solidify and clog piping and equipment

2. THE ORGANIC RANKINE CYCLE

There are many recent studies on the use of Organic Rankine Cycles (ORCs) in combination with low temperature geothermal sources for the extraction of useful work [e.g. Sauret et al, 2011; Chen et al 2010; Tchanche et al, 2011]. The target output electrical work for the present development is 50 kWe with 15% overall efficiency (between geothermal heat source and electrical output). The objective is to arrange a modular system so that multiple units could be "stacked" when there is appropriate larger heat source available.

The target turbine-generator specifications are for a low cost system with good conversion efficiency.

For the relatively low power application here, radial flow turbines have been suggested for their low cost and reliability [Sauret et al, 2011]. These authors have further suggested R134a and R143a as suitable working fluids for this type of application. We will also assess CO2 and Ammonia as possible working fluids.

In this paper, preliminary estimates are made of the performance characteristics of an ORC system based on these two organic working fluids, R134a and R143a.

2.2 Preliminary modeling and results

Figure 1 shows a simplified sketch of the cycle considered here. The heat source is assumed to have a temperature of 150^{o}C or greater and to be of sufficient capacity (thermal power) to drive the cycle. Electrical power output of 50 kW is designed for, with turbine inlet conditions of 50 bar and 140^{o}C. Turbine outlet pressure is assumed to be 8 bar. These estimates are informed by the work of Sauret et al. (2011).

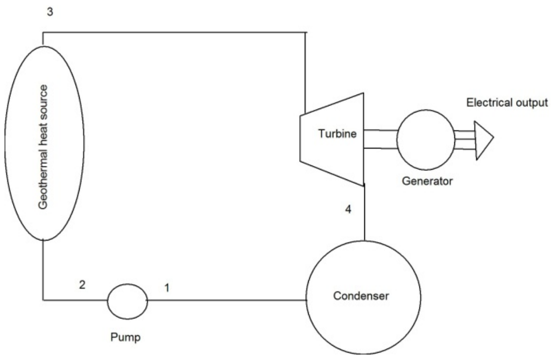

Figure 1: Simplified sketch of the proposed ORC system.

Table 1 presents the assumed conditions which are common to the cycle analysed for both working fluids. The analysis has been carried out in such a way that these assumed conditions can be easily changed in order to determine the sensitivity of the results to such changes.

Table 1: Assumed design conditions for ORC cycles.

Turbine isentropic efficiency (%)	70
Pump isentropic efficiency (%)	70
Pump inlet temperature (^{o}C)	30
Pump inlet state	Saturated liquid
Generator efficiency (%)	90

Thermodynamic analysis has been carried out using the software package EES [EES, 2012] and Figure 2(a) and 2(b) show some of the thermodynamic data presented as diagrams of state for the analysis using R134a.

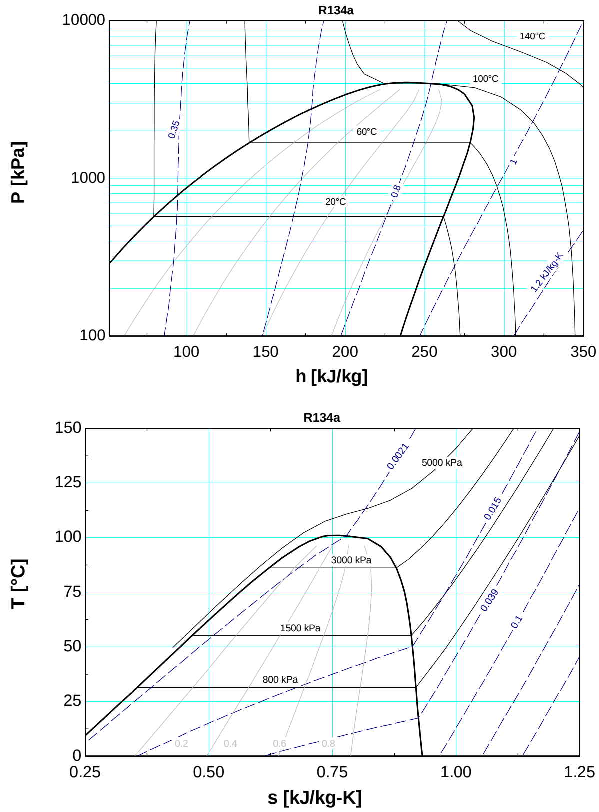

Figure 2: Diagrams of state showing the conditions of the ORC for R134a (a) pressure-enthalpy and (b) temperature-entropy.

Table 2: Illustrative results of the cycle analysis for R134a and R143a

Working Fluid	R134a	R143a
Net cycle efficiency (%)	11.3	14.2
Pump power (kW)	4.2	3.6
Turbine outlet temperature (oC)	67	71
Working fluid flowrate (kg/s)	1.71	1.31
Volume flowrate at turbine inlet (litre/s)	7.22	7.68
Volume flowrate at turbine outlet (litre/s)	53.0	51.1

Table 1 presents some results from the cycle analysis.

Note that both cycles are trans-critical; that is at the high turbine inlet pressure (state 4) they are above the critical pressure and temperature, but expand to a vapour and condense to a liquid in the condenser [Sauret et al, 2011]. Figures 2 (a) and (b) show the P-h and T-s diagrams of state for the R134a cycle analysed here.

3. TESTING

A test rig will be built to test the performance of the prototype turbine generator and condition monitoring. Parameters monitored will be similar to that of conventional utility scale power generation turbines such as vibration, rpm, temperatures and pressures. However, there will need to be significant innovation in designing the test rig since the operating conditions are unconventional and thus would really test the limitations of industrial sensors. The rpm of the prototype turbine generator is higher by a factor of around 7 and the form factor is also much smaller which greatly increase the difficulty of incorporating sensors. Another challenge with a small form factor is that the manufacturing tolerance will need to be very much higher in order to maintain good conversion efficiency.

Apart from generating power from geothermal sources, we are also designing the turbine generator to accept waste heat as a fuel for power generation. There are numerous waste heat sources that can be utilized to generated power. In fact, a number of resources have pointed out that there is more than enough waste heat available than all the other renewable energy combined such as solar and wind energy. For New Zealand, there are large volumes of untapped waste heat power generation potential in industries such as the forestry as well as oil and gas industry. In the oil and gas industry for instance, there is huge amounts of waste heat because many process plants utilize fossil fuels and were designed at a time when fossil fuels were relatively low cost. The sheer size of some plants and distance between heat demand and waste heat source posed a huge impediment towards the financial viability of direct use options. For those cases, the better alternative would be to generate power from the waste heat resource.

4. CONCLUSIONS

So far, response has been very good from current owners of large waste heat streams, such as process plant operators, due to commercial viability of the concept. However, there are several technical hurdles that need to be addressed such as integration into a plant's power network or tying the prototype's output to the local utility's power grid.

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