The State of the Art in Geothermal Power Plant

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ABSTRACT

This paper provides a technology assessment of current and future technologies for power generation from geothermal resources. A particular attention will be given to power cycles suitable for electricity generation from fractured hot-dry-rock which dominates the Australian geothermal resources.

By and large geothermal energy is an untapped energy resource despite its potential and clear environmental advantages (e.g. minimal CO_2 emissions) over other sources of energy, such as fossil fuels and nuclear energy. Although according to the IEA geothermal power production is expected to steadily increase at a rate of 4.3% per year reaching a share of 0.6% of the global electricity production by the year 2030, the growth clearly falls short of expectations. The contribution of the geothermal energy to the world's electricity production by 2030 can be potentially one order of magnitude higher than the IEA's estimate, should the technical problems associated with the use of geothermal energy be resolved.

Within this context, the study of geothermal power cycles is regarded as one of the key areas for major technological improvements since many of the problems associated with the geothermal power technology are underpinned by inefficient and often unsuitable heat exchange processes within power cycles. That is partly due to the fact that most power cycles currently employed in geothermal applications were originally designed for large-scale power production from fossil fuels where higher temperature sources are available for heat exchange.

Geothermal power cycles can be generally classified into following groups: (1) non-condensing direct steam cycles, (2) condensing direct steam cycles such as single- and double flash, (3) binary cycles, and (4) combined cycles. The choice of one power cycle over another depends on a number of parameters most importantly the reservoir temperature and the type of geothermal fluid (i.e. vapour or liquid). For example, in the case of relatively high temperature ($T > 235$ °C) steam dominated reservoirs, the steam from the geothermal well can be used directly to run a turbine/generator and hence the most suitable power cycle is a non-condensing direct steam cycle.

Steam dominated reservoirs are unfortunately quite rare and most common geothermal sources are of either water dominated or hot-dry rock nature. Depending on the temperature of the reservoir, various hydrothermal power cycles can be used to generate electricity from both water dominated and hot-dry rock geothermal reservoirs. Typically, at temperatures between 150-200 °C, the preferred cycles are the so called "Flash Steam" power cycles in which some of the water from the production well is flashed into steam in a separator and then powers the turbines/ generator unit. Flashing of the geothermal fluid can be carried out in either single- or double-flash configurations where the fluid is flashed into steam in two different separators each operating at different pressures. The cycles associated with flashing systems are often referred to as condensing "direct steam" cycles.

For lower temperature reservoirs (100-150 °C) the preferred options are "Binary" power cycles where the geothermal fluid is passed through a heat exchanger to heat a secondary working fluid that runs the actual power cycle. The secondary working fluid is usually an organic fluid which vaporises at a lower temperature than water. Two examples of more novel and efficient binary power cycles which have been purposely developed for geothermal applications are Kalina and Regenerative Supercritical (RGSC) cycles which are discussed in more details during the presentation.

Flash and binary cycles can be hybridised to improve the conversion of geothermal energy to electrical power. In such systems some of the geothermal fluid from the production well is first used in a flash cycle to run a primary turbine/generator unit. The condensate from the turbine outlet is then mixed with the remaining hot geothermal fluid and passed through a binary cycle for further generation of electricity. The cycles associated with such hybrid power plants are referred to as "combined cycles".

With the exception of Kalina and RGSC cycles, the major limitation of other geothermal power cycles is the fact that similar to Rankine cycle they have been designed to operate under or near the saturation dome of the working fluid's phase diagram. As a result, the evaporation and condensation of the working fluid both happen at constant temperatures. This, however, implies that there are great temperature mismatches between the working fluid and heat source / sink during the heat addition or rejection processes. For a binary cycle, for example, the temperature difference between the working and geothermal fluids in the primary heat exchanger unit could be as high as 80-100 °C. From a thermodynamics point of view, greater temperature differences associated with a particular power cycle increase the generation of entropy and, thereby, reduce the efficiency of the heat exchange processes. This thermal inefficiency which is underpinned by the thermodynamics of a given power cycle may lead to significant revenue loss.

The major advantage of the Kalina cycle over other conventional geothermal power cycles is the fact that the multi-component working fluid employed in the cycle has a variable phase change temperature. As a result, unlike other conventional cycles the evaporation of the working fluid occurs over a range of temperatures and, hence, the mixture temperature can track that of the geothermal fluid from the production well. The amount of thermal energy recovered from the geothermal sink is, therefore, greatly enhanced helping to minimise the entropy generation and improve the efficiency of the heat exchange unit. Similarly, the condensation of the working fluid takes place over a temperature range permitting additional heat recovery to be made in the condenser. Although the Kalina cycle with its multi-component working fluid has indeed shown improved thermal efficiency, it is at the expense of absorption and distillation equipment added to the cycle. It is this complexity which significantly increases the cost of a Kalina plant as opposed to other types of power plants. The added complexity and, in particular the high sensitivity of the cycle towards pressure and composition of the ammonia-water mixture, also limits the application of the cycle over a wider range of reservoir temperatures. The RGSC cycle avoids this complexity by using a single-component working fluid. The necessary variable phase change temperature is achieved by operating under supercritical conditions.