FIELD-BASED MATERIAL TEST RIG FOR GEOTHERMAL ORC PLANT COMPONENTS

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ABSTRACT

Scaling, also known as fouling, and corrosion are serious problems in geothermal applications. In a binary plant, the components most affected by these phenomena are the primary heat exchangers or evaporators which are in direct contact with the geothermal fluid on the one side and the binary fluid on the other side. The build-up of scale leads to a reduction in heat exchanger efficiency while corrosion results in a reduced equipment lifetime. The extent of scaling and corrosion is a function of the chemical composition of the brine, the process conditions and the selected material.

Test results obtained under idealized conditions in laboratory set-ups are not always a true indicator for the performance of the material under operational conditions and need to be verified by field based testing. The NZ Heavy Engineering Research Association (HERA) is engaged in a research project related to power generation from low enthalpy heat sources (AGGAT). As a part of the research a field-based material test rig (MTR) has been developed in cooperation with partners from academia and industry. As of writing this paper, the test rig was in the last stages of fabrication by one of the industry partners. This paper gives an overview of the features of the MTR and the latest developments regarding the rig.

1. INTRODUCTION

The Organic Rankine Cycle (ORC) is an established thermodynamic process that is well suited for power generation from low enthalpy heat sources. A binary circuit is employed to extract the heat from the primary fluid using an organic medium. The primary fluid in a geothermal context is usually separated geothermal water that has undergone previous flashing and is rich in solids and minerals. The chemical and physical characteristics of the primary fluid are known to be highly site specific.

The build-up of unwanted material on the inside of pipes and other plant equipment, known as scaling or fouling, is a commonly reported problem in geothermal installations. As the scaling layer increases over time, the ability of the equipment to perform its intended task is reduced. The decrease in pipe cross section results in pressure losses and a reduced flow rate. The occurrence and rate of scaling is a complex phenomenon as it is dependent on multiple factors, including brine chemistry, process and environmental conditions and surface properties and material.

Shell and tube type heat exchanger are commonly used in geothermal applications. The geothermal fluid is usually run on the tube side and the clean binary fluid is run on the shell side, as the tube side is easier to clean. The temperature drop of the primary fluid inside the heat exchanger accelerates the scale build-up. The usually low heat transfer coefficient of the scale exacerbates the detrimental effects of scaling for this plant component.

Corrosion is a well-known chemical reaction of metallic materials with their environment in which refined metals are transformed into their oxides. The occurrence of corrosion can be confined to small parts of the surface in the form of pits and cracks or may affect larger surface areas. As a result, the properties of the material, including strength, deteriorate and in the worst case, corrosion can lead to a complete failure of the component. Several distinct forms of corrosions are known and while it is usually not feasible to prevent corrosion, it can be reduced or even totally prevented by specifying a suitable base material, surface preparation and surface finish.

Heat exchanger designers need to take into account the short and long term cost of the equipment as well as the overall efficiency of the equipment. This selection requires reliable material information which under the described circumstances cannot be derived from laboratory testing alone. A field based material test rig has been designed to supplement and verify the available information.

1.1 Material test rig

The Above Ground Geothermal and Allied Technologies (AGGAT) programme is an industry led initiative being championed by the Heavy Engineering Research Association to create a platform for above ground geothermal research. One part of this programme is materials scaling and corrosion research. The AGGAT material test rig (MTR) is a critical deliverable of this research. It is a field based test setup that consists of three distinct parts:

- A shell and tube heat exchanger rig
- A double pipe heat exchanger rig
- A coupon rig

The shell and tube heat exchanger unit rig will be used to investigate the performance of different material types and grades for scaling under equal operating conditions.

The double pipe heat exchanger unit, consisting of three individual double pipe heat exchanger units, enables the examination of scaling under different operating conditions.

Materials and coating not available in tubular form can be tested in the coupon rig using coupons for corrosion testing.

2. DESIGN OF TEST RIG

The test rig is designed as a unit that can be used on a wide range of geothermal sites in New Zealand. The rig has been designed to operate with geothermal brine temperatures of up to 200°C and pressures of up to 12.5 bar.

To make the rig transportable the equipment is based on a 20 foot container base. There is one connection for

Figure 1: Setting up the shell and tube heat exchanger rig for hydro-testing

incoming geothermal brine and one for incoming cooling water. The water streams are distributed to the various rigs which can be operated independently of each other. The spent brine is vented to the atmosphere in a silencer then combined with the spent cooling water in a central outlet pipeline.

The equipment falls under the New Zealand Pressure Equipment, Cranes, and Passenger Ropeways Regulations (PECPR) and a central part of the test-rig design was to achieve code compliance. The designs of all parts of the rig have been verified by qualified third parties.

2.1 Shell and Tube Heat exchanger unit

The aim of the shell and tube heat exchanger (Fig. 1) is to compare the performance of different materials under the same operating conditions. The equipment is a single pass design and contains 19 straight tubes of 1 inch outside diameter. In order to facilitate the testing of materials of different type and grade, the tubes are not welded into the tube sheet. Galvanic separation is achieved by using plastic parts which hold the pipes in place, provide a tight seal and allow for an unequal expansion of the different tubes. The plastic componentry needs to be suitable for the maximum design temperature of the equipment.

The geothermal brine runs on the tube side as is common for heat exchangers in a geothermal environment. The heat exchanger is operated in vertical position to ensure complete and equal filling of the tubes. The geothermal brine runs from the bottom to the top while the flow of cooling water on the shell side is opposite, i.e., from top to bottom.

The heat exchanger tubes will need to be exchanged for examination at regular intervals. As they are difficult to remove in the vertical position the heat exchanger can be rotated into a horizontal position. The header lids can be removed and tubes removed and exchanged individually from each side.

The brine flow rate and the cooling water flow rate can be adjusted and will be measured and recorded alongside temperatures at the inlet and outlet for both streams. These measurements will allow the overall performance of the heat exchanger to be calculated and also enable a performance comparison of separate trials.

The unit has been fabricated earlier this year by one of HERA's industry members. After assembling the components, a functional test confirmed that the selected sealing concept is working under static conditions. The unit has subsequently been pressure tested as required by NZ regulation.

2.2 Double Pipe Heat exchanger unit (DPR)

The double pipe heat exchanger unit (Fig. 2) has been designed to research the influence of operational parameters on the material performance and mitigation technologies. Therefore a double pipe heat exchanger containing only a single straight tube has been designed. Three of these units will be built and operated in parallel. The flow of brine and cooling water can be set individually for each entity. The units will be installed horizontally and use heat exchanger tubes with an outside diameter of 1 inch. The heat exchanger tubes are mounted in the header using plastic components, similar to the set up used in the shell and tube heat exchanger, to achieve galvanic isolation of the tubes and the carbon steel body. The brine runs on the tube side and the cooling water on the shell side in a counter flow arrangement.

Provisions have been made with the unit to enable temperature measurement of the incoming and outgoing brine as well as the flow through each unit, individually. Similarly, the cooling circuit has been fitted with measurement points.

Figure 2: Fabrication of the double pipe heat exchanger units

Figure 3: Fabrication of coupon unit

2.3 Coupon unit (CTR)

Material corrosion will be evaluated using the weight loss method based on corrosion coupons. The coupons are mounted on a pre-existing multi-coupon holder which has been designed for 100mm (NB) pipelines. As the main pipes of the test-rig are 50mm (NB) a section of pipe has been designed to house the coupon test holder (Fig. 3). The unit is designed to allow frequent change of the sample specimens. The coupon test unit can also be used to research stress corrosion cracking using a slightly modified version of the test coupons.

The flow of brine through the coupon unit can be set independent of the other two units on the material test rig. Unlike the previous two units, the coupon unit is not cooled. The flow of brine and its temperature will be measured and recorded.

2.4 Pipe spooling

The rig has been designed as a self-contained unit consisting of the three testing units described above and an atmospheric silencer which is required to discharge spent brine into an open drain. The rig has got a total of three connections: one for the incoming geothermal fluid, one for the incoming cooling water, and one for outgoing spent fluids. The piping distributes the fluids to the different units and allows for independent operation and control of each item.

The cooling circuit is connected to the brine side of the heat exchanger units to allow them to be filled with water before the brine tap is opened and operation is started.

High and low points have been fitted with vents and drains respectively. Further sampling points are included in the design.

A thermal stress analysis of the piping has been carried out as part of the design process. The material test rig including piping is depicted during fabrication in Figure 4.

2.5 Deployment site

A first deployment site for the Material test rig has been secured by the AGGAT team at HERA. The site is located near the Ohaaki power station and receives its geothermal brine from Contact Energy. The fluid supplied to the site is a mixture of brine from five or more wells and is separated twice along the way.

The material test rig is located at the back end of an industrial process existing on site. By the time the brine enters the test rig it has reached a temperature of about 135°C and a pressure of 300 kPa.

Figure 5 shows the connection point between the deployment site and the material test rig.

Figure 4 Fabrication of the Material Test Rig

Figure 5: Tie in point installed at deployment site

3. CONCLUSION

A field based test-rig has been designed and built that enables in-situ analysis of materials intended for the use in low-enthalpy geothermal applications. Consisting of a range of test units it enables a comparative and quantitative analysis of material performance. The container based design facilitates easy transport and requires minimal setup on site.

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