Development of a Thermal Plant Indicator for Boiler Headers

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Abstract

Verve Energy has a large portfolio of power stations in the south west of Western Australia. The majority of these power stations contain boiler headers which operate at elevated temperatures and exhibit creep damage (which is a function of temperature and stress). The current Australian Standard AS/NZS 3788 specifies the procedure of how to predict operational life (if the failure occurs through creep) for a known temperature but does not specify how and where one should determine this temperature. From Verve Energy's experience the critical locations exhibiting high temperatures and stresses are where the ligaments attach to a boiler header.

The objective of this project is to develop a thermal health indicator for boiler headers under the assumption that failure would occur due to creep. In order to achieve this objective the temperature at critical locations must be determined. This paper looks at using finite element method (FEM) to predict temperatures in a test rig, which represents a boiler header. The initial FEM results are found to reasonably reflect the temperatures collected directly from the test rig. Verve Energy has the potential to save in excess of $100,000 for every year that a boiler header's operational life can be extended.

1. Introduction

Verve Energy owns four major power stations in Western Australia (Kwinana, Cockburn, Muja and Collie) as well as a range of smaller power stations. The majority of these power stations contain boiler headers which operate at elevated temperatures and exhibit creep. Creep is the time dependent permanent defamation of materials subject to constant load or stress, which tends to be accelerated at elevated temperatures. Each of the power stations comprise of one or more power generation units, these units contain two boiler headers which may be affected by creep; the final stage re-heater and the final stage super heater. The boiler headers are normally designed for 200,000 hours and cost approximately $4 million for material and labour. Verve Energy requires a thermal health indicator for these boiler headers with respect to creep. Ideally this would be in the form of an equation that could be adapted to apply to a range of typical boiler arrangements and thus be applicable across Verve Energy's power stations.

Currently Verve Energy employs the Australian Standard AS/NZS 3788 in assessment of creep and the resulting remaining life of its boiler headers. This method involves a three stage approach; the first stage uses design conditions, the second uses maximum operating conditions and the third is based on testing and inspection analysis (Standards Australia/Standards New Zealand 2006, p 168). However, the code does not provide sufficient details of how and where to determine temperatures. Actual conditions can vary significantly from design temperatures as headers of this type exhibit a temperature profile along their longitudinal axis as well as on their through planes. At Verve Energy's recommendation it is the through planes that will be of greatest concern to this project. It is proposed that the thermal profiles result in temperatures at critical areas (places with high temperatures and stress) that are not obvious from thermocouple readings alone (as these can only be placed on the surface of the pressure vessel). From Verve Energy's experience the areas of concern is the internal interface between the ligaments and the boiler header. It is believed this is where creep damage results, and ultimately failure occurs. Therefore, this area is the primary focus of the project and is investigated through modelling using the finite element method (FEM) as well as through empirical data from a test rig in a laboratory.

A refined method for predicting boiler life with respect to creep is beneficial to Verve Energy as it will provide a vehicle to reduce the irreversible creep damage to boilers by being able to adjust operating conditions early in the life of components. Thus it has the potential to provide economic savings for Verve Energy and the potential to increase safety, as more confidence should be attained with respect to the safe remaining life of the units.

2. Process

FEM is to be used in the project in order to determine the temperature at critical locations on boiler headers. FEM was chosen because temperature readings cannot be taken directly at the critical locations as boiler headers are closed pressure vessels. Also, the complex geometry lends itself well to FEM. Firstly this method was used to simulate the temperature behaviour of a test rig. The test rig was designed to represent a boiler header section in such a way that detailed temperature readings could be taken from the apparatus. The results of this simplified analysis are intended to validate the use of FEM on a boiler header in a power station.

2.1 Test Rig

A test rig has been designed, detailed and manufactured to represent a typical section of a boiler header and ligament arrangement. The test rig comprises of a 60mm thick steel plate (which represents the boiler header) and has six pipes protruding from the surface (which represents the ligaments). The steel plate is attached to the front of a kiln in order to produce a temperature difference between the inner and outer surface (see Figure 1 below). The test rig enables temperature readings to be taken from a large number of locations on the geometry, in order to identify the temperature profile. Holes have been drilled in the steel plate to allow temperatures to be recorded from inside the plate as well as on its surface.

The test rig is also designed in such a way that air flow can be introduced which creates a distinct temperature difference between the ligaments, which more closely represents the situation in power station boiler headers. The test rig is used to validate that a FEM model can accurately represent the temperature distribution of the header and ligament arrangement by cross checking the temperatures recorded by both methods.

The design of this apparatus went through a number of revisions before the final form was agreed upon. The 60mm steel block is representative of the thickness of a boiler header whereas the tubes were scaled down (by approximately 50%) in order to fit an array of six into the available space. Technical drawings were produced to convey the design and it was necessary to liaise with the manufacturer to ensure correct construction.

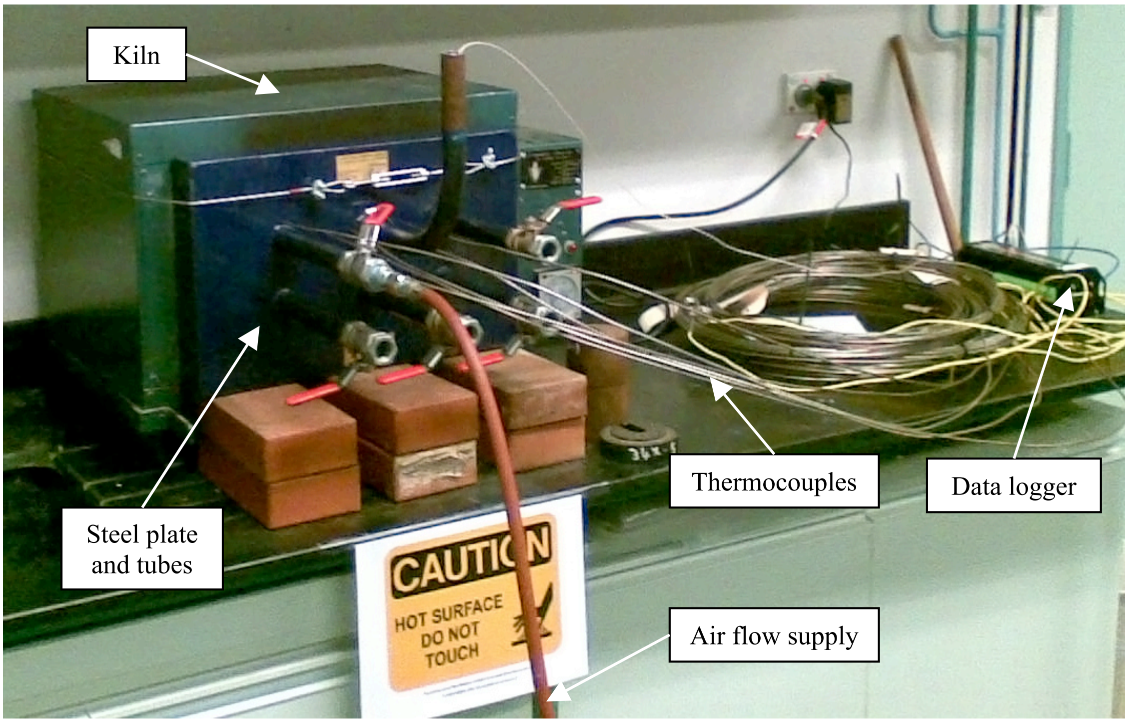

Figure 1: test rig setup

2.2 FEM Model

Initial tests were undertaken using SolidWorks and its FEM solver COSMOS to determine the software's suitability for this problem. Preliminary findings showed that the software does have the appropriate functionality for the heat flow and thermal stress FEM analysis.

A three-dimensional computer model of the test rig was constructed using SolidWorks. Boundary conditions were formulated based on the data collected from the physical test rig and from recommended convection coefficients found in literature. The meshing used solid elements and is shown below in Figure 2.

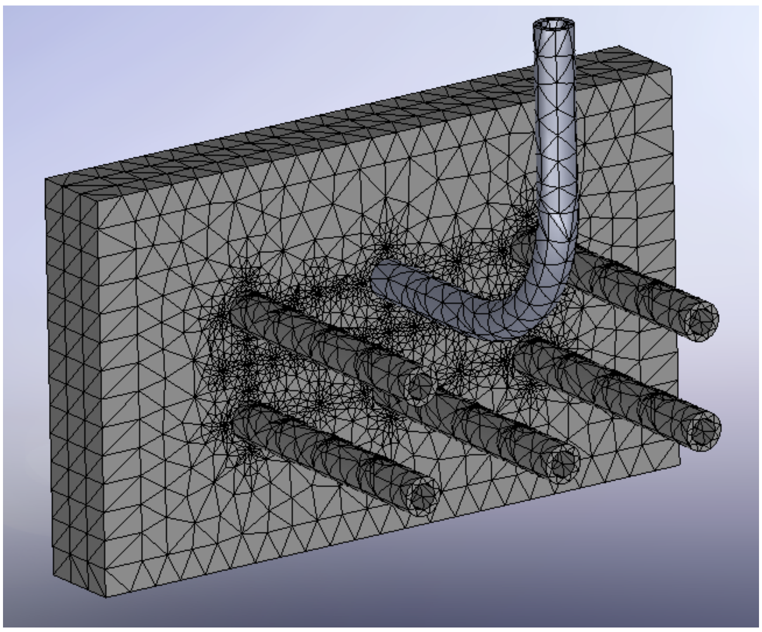

Figure 2: Finite Element Model of test rig

2.3 Power Station (Installation of Thermocouples)

The final part of the project will be to implement the thermal plant indicator on a boiler header at a power station. The Muja Power Station near Collie, Western Australia, has been chosen as an appropriate site as the thermocouples can be installed during a scheduled shutdown. Thermocouples will be installed on the superheater of Unit 6. The positioning of these thermocouples has been specified and an attachment method decided upon (Figure 3). The attachment requires manufacturing of some components and sourcing of others.

In order to have the work considered for the power station, a scope of work and specification drawings were required. Therefore, detailing was necessary before results were obtained from the tests. Thermocouple positions were recommended based on initial observations of the test rig behaviour and from heat transfer principals. They may vary from the locations suggested at the conclusion of the project.

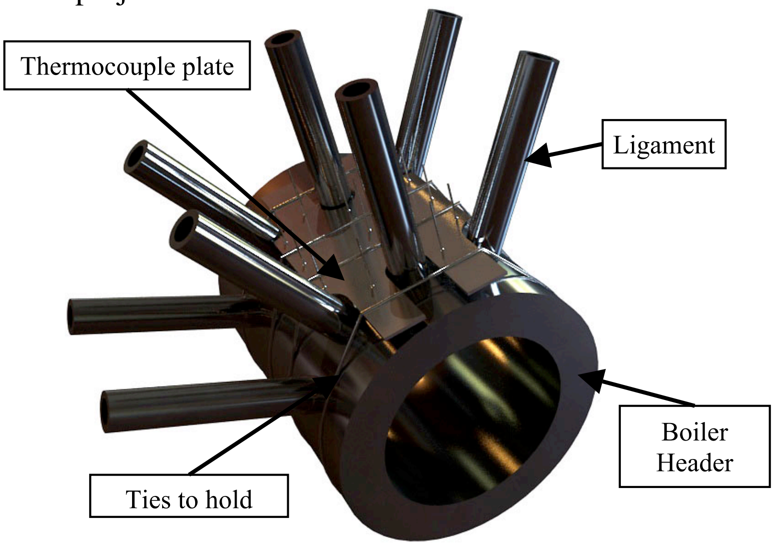

Figure 3: Schematic of thermocouple installation at Muja according to specifications

3. Results and Discussion

A number of experiments using the test rig have been conducted to date. Some of these have been compared to FEM results and are outlined below. Figure 4 shows the location of thermocouples placed on the test rig. It also indicates the depth into the plate that the temperature readings have been taken.

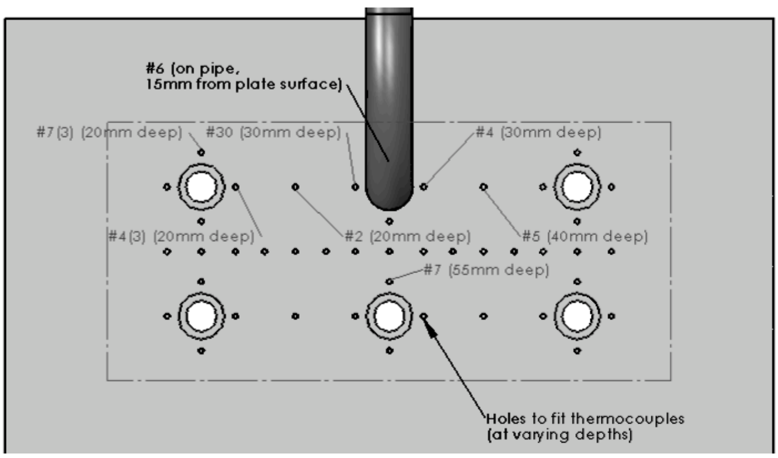

Figure 4: location of thermocouples for tests

In the test outlined below the kiln was set to 300°C and the ambient temperature was approximately 20°C. The system reached a steady state after approximately 3 hours, 50 minutes. The response is displayed in Figure 5.

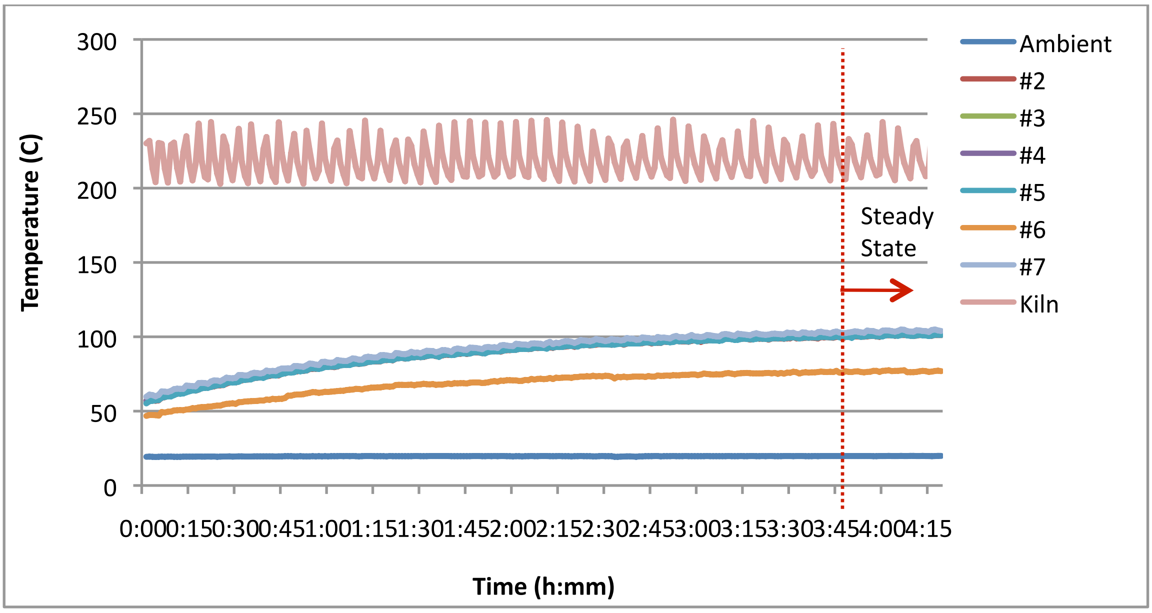

Figure 5: Test Rig reaching steady state condition at 3 hours, 50 min

To replicate this result a FEM test using convection boundary conditions was used. The kiln side of the test rig FEM model was set to have a far-field temperature of 259°C. This is approximately half way between the set kiln temperature and the average recorded temperature at the kiln floor. It is justified as the kiln's temperature switch is located at the ceiling of the kiln whereas the thermocouple (#8) is located on the floor of the kiln. The outside surfaces of the test rig were set to have a far field temperature of 20°C. A convection coefficient of 25 W/m^{2}K was used for both boundary conditions as a value of 2-25 W/m^{2}K is recommended for natural convection of air (Cengel & Turner 2005, p723).

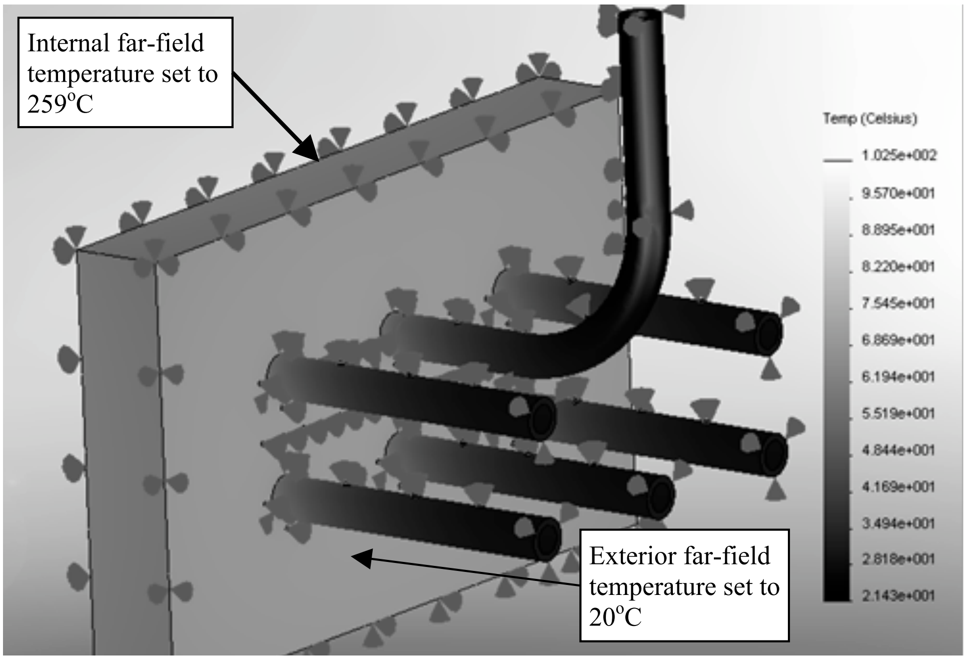

Figure 6: FEM results

Temperatures (°C)	Ambient	#2	#3	#4	#5	#6	#7	Kiln
Test Rig at steady state (3:50-4:20)	(#1) 19.8	100.7	101.5	101.5	100.8	76.8	103.8	(#8) 218.7
Finite Element Method (COSMOS)	Set to 20.0	99.37	99.88	99.83	100.8	84.82	102.0	259
Error between values	-	1.3%	1.6%	1.6%	0%	10.4%	1.7%	-

Table 1: Comparison of average recorded temperatures at steady state and FEM results

From Table 1 it can be seen that this initial test shows the errors to be very small between the results for all locations except #6; which is on the ligament itself. However, this is still deemed to be within an acceptable error margin for this initial test. The problem with the above method is that it may be difficult to record interior temperature of a boiler header as it is a closed pressure vessel. Also, the convection coefficient is largely dependent on the flow rate and is generally found experimentally for complex situations (Holman 1992). Forced convection of air or superheated steam (which is present in a boiler header) has a convection coefficient ranging between 20 and 300 W/m^{2}K (Dassault Systemes 2008). However, the method may be suitable to use as a basis of further analysis of the temperature profile.

4. Conclusions and Future Work

Preliminary results indicate that it is possible to replicate the test rig's behaviour to a reasonable degree using FEM analysis. However, this still needs to be verified with further tests and in particular in the case of forced airflow in the system as this will greatly increase the complexity. Further investigation is needed on the possibility of using spot temperature data to increase the accuracy of FEM solutions for specified locations. To complete the thermal health indicator, locations for thermocouples to be installed on typical boiler headers need to be determined. These locations will be based on the findings of the FEM and empirical data, and chosen in such a way that predictions of the temperature at the critical locations are possible.

5. Acknowledgements

Acknowledgements also go to Prof. Y Liu for the use of his laboratory, and to Ivan Sevelj for his help to set up the data recording device.

6. References

Cengel, Y & Turner, R 2005, *Fundamentals of Thermal-Fluid Sciences,* 2nd ed. McGraw Hill, New York.

Dassault Systemes 2008, *SolidWorks Office Premium*, U.S.

Holman, J 1992, *Heat Transfer*, 7th ed. McGrew Hill, Singapore.

Standards Australia/Standards New Zealand 2006, AS/*NZS 3788: Pressure equipment – In-service inspection*, AS/NZS, Sydney/Wellington.