EVALUATION OF TEMPERATURE MEASUREMENT SYSTEMATIC ERRORS IN PHTS OF EMBALSE NGS

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Abstract

Systematic errors of temperature measurement of inlet header and fuel channel outlet feeders of PHTS were evaluated in this paper. These errors are needed for thermal power maps calculations from thermal measurements.

A linear dependence between the outlet temperature systematic errors and channel outlet temperature was found.

The average systematic error at full power was –4ºC and –0.6ºC at zero power hot condition. No systematic errors were found in inlet temperature measurements.

A correction of temperature measurement of single outlet feeders were made based on the dependence of the average outlet temperature systematic errors.

Introduction

The systematic errors of Embalse NGS Primary Heat Transport System inlet header and outlet channel temperature measurements were evaluated in this work. These uncertainties are used to evaluate the thermal channel power transferred to the coolant and then are compared with the ones evaluated from neutronics codes.

In a simple thermohydraulic model, channel power *i*, Pot_i, is written as follows:

$$Pot_i = Q_i \cdot \left(h_{sal,i} - h_{ent,i}\right)$$

where: Q_i is the coolant flow for fuel channel *i*.

$h_{ent,i}$ is the specific enthalpy of coolant at inlet of channel *i*.

$h_{sal,i}$ is the specific enthalpy of coolant at outlet of channel *i*.

In single phase condition specific enthalpies at fuel channel inlet and outlet are functions of inlet and outlet temperatures respectively and inlet and outlet pressures in a less dependent way.

Temperatures were measured using the PHTS normal instrumentation [1]:

- Inlet header RTDs (3 sensors for each header). Figure 1 show the RTD layout in the headers.
- Outlet feeders RTDs (380 sensors, one per channel). Figure 2 show the RTD layout in the feeder.

The systematic error involved in the RTDs measurements are due to

- Measurement bridge calibrations.
- Poor thermal contact between the sensor and the coolant.

In order to evaluate the thermal channel powers is necessary to determine the systematic errors.

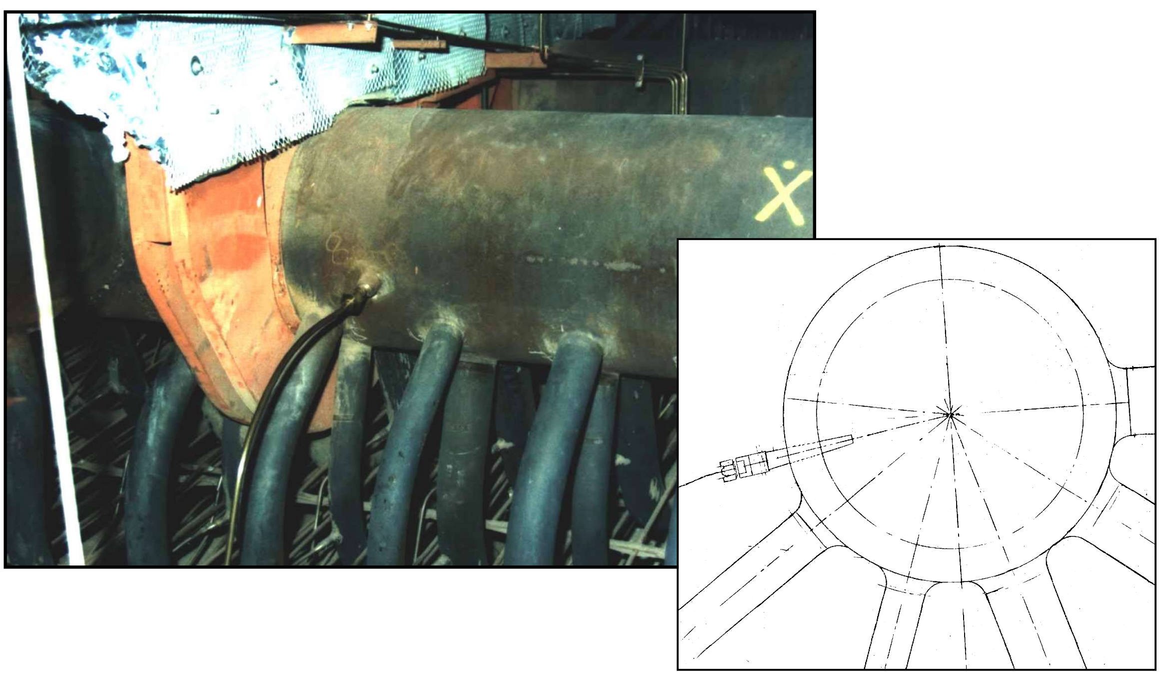

Figure 1: The pictures show the RTD layout in the reactor inlet header

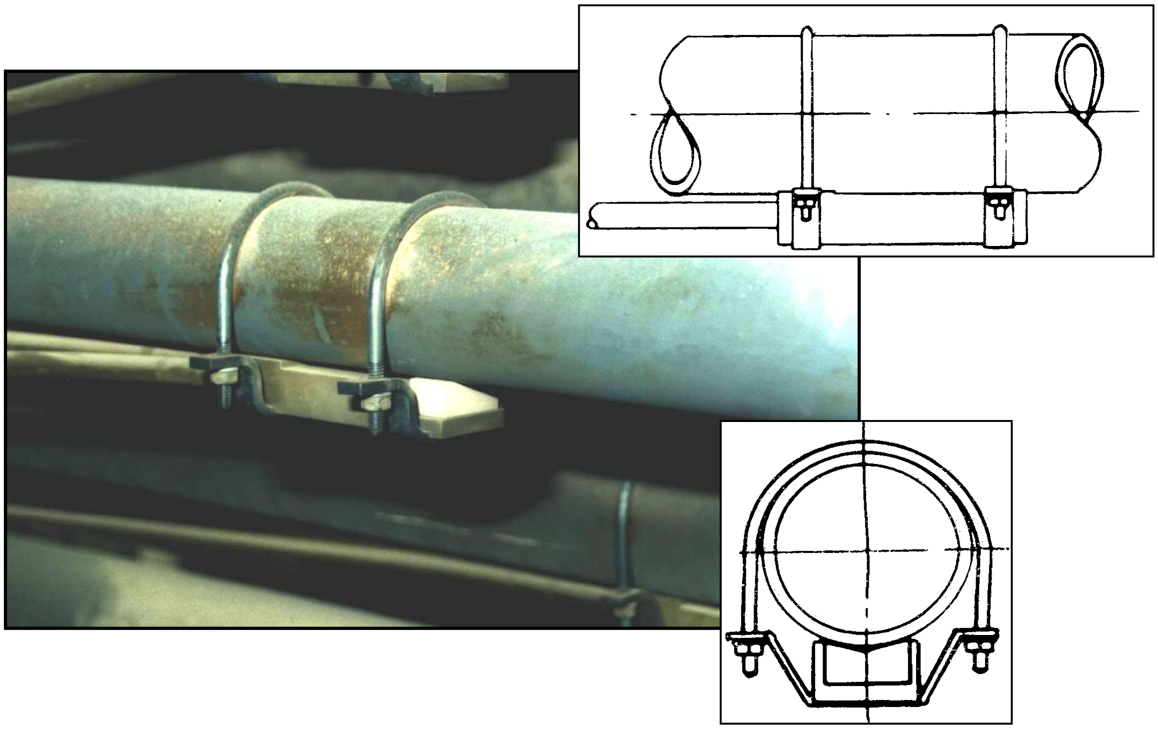

Figure 2: The pictures show the RTD layout in the reactor outlet feeders

Systematic error evaluations

A methodology for the evaluation and correction of inlet and outlet temperature systematic error is presented. A study of the discrepancy between the change of temperature measured by the RTDs and the one calculated from neutronic power and coolant flow was done. This analysis was performed globally, i.e., from a reactor thermal balance in different power levels at nominal reactivity device configuration.

The change of coolant enthalpy through the reactor is:

$$\Delta h_{cal} = h_{sal} - h_{ent} = \frac{Pot_{RTOT}}{Q_{TOT}\left(Pot_{RTOT}\right)}$$

where: Δh_{cal} is the calculated specific enthalpy change

h_{ent} is the inlet specific enthalpy of coolant

h_{sal} is the outlet specific enthalpy of coolant

Pot_{RTOT} is the total thermal power transferred to coolant

Q_{TOT} is total coolant flow in the circuit

Single phase specific enthalpy is dependent of temperature and pressure. For temperatures ranges from 260ºC to 310ºC and pressures ranges from 10 to 12 MPa it could be approximated to [2]:

$$h(T,P) = \alpha(P) \cdot e^{\beta(P) \cdot T}$$

where $\alpha(P)$ and $\beta(P)$ are dependent on pressure

$$\alpha(P) = 106{,}305 \frac{\mathrm{kJ}}{\mathrm{kg}} + 1{,}207 \frac{\mathrm{kJ}}{\mathrm{kg \cdot MPa}} \cdot P$$

$$\beta(P) = 0{,}00436 \frac{1}{\mathrm{K}} - 0{,}00002 \frac{1}{\mathrm{K \cdot MPa}} \cdot P$$

The inlet temperature was calculated as

$$T_{ent,med} = \frac{T_{CE2} + T_{CE4} + T_{CE6} + T_{CE8}}{4}$$

where T_{CE2}, T_{CE4}, T_{CE6} and T_{CE8} are inlet temperatures of the header 2,4,6, 8 respectively.

In same way, the inlet and outlet pressure are:

$$P_{ent} = \frac{P_{CE2} + P_{CE4} + P_{CE6} + P_{CE8}}{4}$$

$$P_{sal} = \frac{P_{CS1} + P_{CS3} + P_{CS5} + P_{CS7}}{4}$$

where P_{CE2}, P_{CE4}, P_{CE6} and P_{CE8} are the inlet pressures of the headers 2, 4, 6, 8 and P_{CS1}, P_{CS3}, P_{CS5} and P_{CS7} are the outlet pressure of the headers 1, 3, 5, 7 respectively.

Then,

$$T_{sal,cal} = \frac{1}{\beta(P_{sal})} \ln\left(\frac{Pot_{nTOT}}{\alpha(P_{sal}) \cdot Q(P_{nTOT})} + \frac{\alpha(P_{ent})}{\alpha(P_{sal})} \cdot e^{\beta(P_{ent}) \cdot T_{ent,med}} \right)$$

Finally, the calculated temperature change between inlet and outlet is:

$$\Delta T_{cal} = \frac{1}{\beta(P_{sal})} \ln\left(\frac{Pot_{RTOT}}{\alpha(P_{sal}) \cdot Q(Pot_{RTOT})} + \frac{\alpha(P_{ent})}{\alpha(P_{sal})} \cdot e^{\beta(P_{ent}) \cdot T_{ent,med}} \right) - T_{ent,med}$$

In the other hand, with the temperatures measured in 380 outlet feeders and the flows in each of them was possible to evaluate the average outlet temperature weighted with coolant flow for each channel.

Then a new temperature change through the reactor, a measured change $\Delta T_{med,}$, was calculated as follows:

$$\Delta T_{med} = \frac{\sum_{i=1}^{380} T_{sal,i} \cdot Q_i}{\sum_{i=1}^{380} Q_i} - T_{ent,med}$$

A ***'discrepancy between temperature changes'*** *DT* could be defined in the following way:

$$DT = \Delta T_{cal} - \Delta T_{med}$$

As a consequence of the good layout of RTDs in the RIHs a systematic error in the temperature measurement could be only related to a problem in a calibration of the associated electronics.

Taking into account that the temperature of the RIHs has small variation in the operation range the systematic error could be assumed independent of the reactor power. In this way:

$$T_{ent,real} = T_{ent,med} + B_{ent}$$

Where B_{ent} is the systematic error in the measurement of inlet temperature, $T_{ent,med}$ is the measured inlet temperature and $T_{ent,real}$ is the real inlet temperature.

In the case of the outlet temperature, the most probably source for a systematic error is the layout of RTDs in the outlet feeder. This is a consequence that RTDs have not a good thermal contact with coolant. For this case it is made the supposition that the systematic error of outlet temperature has a linear dependence with outlet temperature. That is,

$$T_{sal,real} = T_{sal,med} + B_{sal}(T_{sal,med})$$

Where $B_{sal}(T_{sal,med})$ is the systematic error in the outlet temperature measurement, $T_{sal,med}$ is the measured outlet temperature and $T_{sal,real}$ is the real outlet temperature.

In this way, ΔT_{med} could be written as:

$$\Delta T_{med} = \Delta T_{real} + B_{ent} - B_{sal}(T_{sal,med})$$

Then,

$$DT = \Delta T_{cal} - \Delta T_{real} - B_{ent} + B_{sal}(T_{sal,med})$$

where: B_{ent} is the systematic error of inlet measured temperature.

$B_{sal}(T_{sal,med})$ is the systematic error of outlet measured temperature.

ΔT_{real} is the real temperature change in the coolant.

If it is supposed that $\Delta T_{cal} = \Delta T_{real}$, due to ΔT_{cal} has not systematic errors, then:

$$DT = B_{sal}(T_{sal,med}) - B_{ent}$$

In this way, it is possible to see that the discrepancy between the change of temperature *DT* is the difference between inlet and outlet temperature systematic error.

Data corresponding to startup after the 1997 outage (June 2nd) were used for the evaluation. Values of *DT* were taken in nominal steady state condition, coolant in single phase for the following power levels: 0%, 8%, 25%, 40%, 50% and 80%FP. Then, an evaluation of $DT=B_{sal}(T_{sal,med})-B_{ent}$ with measured outlet temperature $T_{sal,med}$, was found. It was fitted with a linear function as follows:

$$DT(T_{sal,med}) = A + B \cdot T_{sal,med}$$

and the result of the parameters were:

$$A = (-16{,}4 \pm 0{,}4)^{\circ}\mathrm{C} \qquad \text{and} \qquad B = (0{,}068 \pm 0{,}001)$$

In the chart of the Figure 3 the fit is shown:

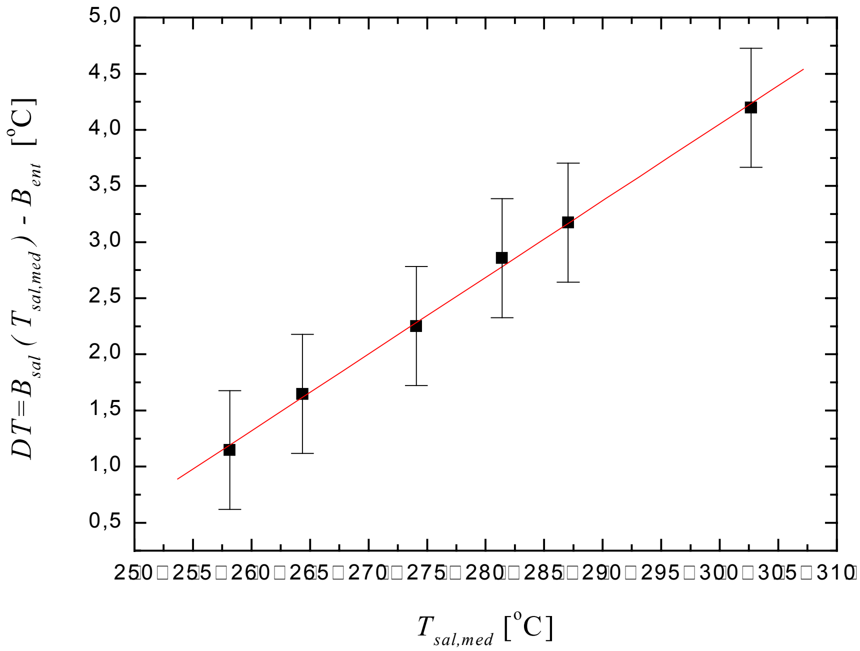

Figure 3: The chart shows the calculated values of *DT* as function of the reactor outlet temperature. The lineal approximation fits this behavior.

As the reactor operates at full power (FP) the coolant in all channels are at two phase saturated condition. This was verified checking that de $T_{sal,i}$ do not change from 100%FP to 95%FP. According to this, the difference between the measured feeder outlet temperature and the saturation temperature of coolant was the measured systematic error of channel at 100%FP. This value, $B_{100,i}$, was defined as follows:

$$B_{100,i} = T_{sat} - T_{sal,i}$$

where T_{sat} is the saturation temperature for the outlet pressure P_{sal}.

The systematic error of reactor outlet temperature having all channel at saturation condition could be supposed as the average of systematic error of channels. Taking into account that outlet temperature at saturation condition is $T_{sal,med}$=(306,4±0,1)°C, follows:

$$B_{sal}\left(306{,}4^{\circ}\mathrm{C}\right) = \frac{\sum_{i=1}^{380} B_{100,i}}{380} = \left(4{,}0 \pm 0{,}1\right)^{\circ}\mathrm{C}$$

Then B_{ent} is:

$$B_{ent} = B_{sal}(306{,}4^{\circ}\mathrm{C}) - DT(306{,}4^{\circ}\mathrm{C})$$

$$B_{ent} = (-0{,}4 \pm 0{,}5)^{\circ}\mathrm{C}$$

and the systematic error of the average outlet temperature is:

$$B_{sal}(T_{sal,med}) = DT(T_{sal,med}) + B_{ent}$$

$$B_{sal}(T_{sal,med}) = (0{,}068 \pm 0{,}001) \cdot T_{sal,med} - (16{,}9 \pm 0{,}6)^{\circ}\mathrm{C}$$

It is seen that B_{sal} ranges from 0,6°C in zero power hot condition to 4°C at full power. According to this a functional dependency to the systematic error with $T_{sal,med}$ is found instead of using a flat correction as in the previous estimations.

The behavior of B_{sal} with $T_{sal,med}$, is a consequence of RTDs layout in the reactor outlet feeders.

Systematic error for single outlet channel temperatures

With the functional dependence of the systematic error of $T_{sal,med}$ could be proposed a correction for temperature measurement for each single outlet feeders.

The assumption is based on an extension of the linear behaviour of the systematic error of $T_{sal,med}$ to the systematic error in temperature measurement of each single outlet channel.

It is observed that the systematic error $B_{sal}(T_{sal,med})$ varies linearly in term of $T_{sal,med}$ from a maximum value B_{sal}(306,4°C) at 100%FP to a minimum B_{sal}(258,1°C) a 0%FP.

With the systematic error of the outlet temperature of each channel at 100%FP, that was called $B_{100,i}$, and assuming that they have the same proportional behaviour of the global balance, then:

$$B_{sal,i}(T_{sal,i}) = B_{100,i} \cdot \left[0{,}846 \cdot \frac{T_{sal,i} - T_{sal,i}(0\%PP)}{T_{sal,i}(100\%PP) - T_{sal,i}(0\%PP)} + 0{,}154 \right]$$

where $B_{sal,i}(T_{sal,i})$ is the systematic error in the outlet temperature measurement of each single channel in term of $T_{sal,i}$.

Using this estimation the corrected reactor outlet temperature is:

$$T_{salc,i} = T_{sal,i} + B_{sal,i}$$

With $T_{salc,i}$ as *corrected* outlet temperature of the channel i.

Discussion

A linear dependence between B_{sal} and $T_{sal,med}$ was postulated instead of using a flat correction. The reason of this behavior is the RTD outlet feeders layout. This has not a good thermal contact with coolant. It was found that there is a gap between the RTD and the feeder tube. Because of this the measurement temperature is less than the coolant temperature with the systematic error dependent of it. No systematic errors were found in inlet temperature measurements

This analysis was made for global reactor outlet temperature and single channel outlet temperature and permit correct the measured temperatures in order to evaluate the thermal power channel at single phase conditions from thermal measurements.

References

[1] Design Manual : Channel Temperature Monitoring Instrumentation DM-18-63102-Rev.3, AECL Company, June 1983

[2] P.G.Hill, R.D. MacMillan, V. Lee, Table of thermodynamic properties of heavy water in S.I. Units, AECL, December 1981