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Results of Additional Studies of Instrumentation and Flow
Mixing in the ZrH 19-Element Test Bundle

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ABSTRACT

Results are reported for a series of tests recording injected salt concentrations in the instrumented ZrH nineteen element test bundle. These results are presented as plots versus axial location of the fraction of calculated injected salt tracer detected by probes along the bundle flow channels. Data were recorded for different probe-to-flow-channel orientations and are interpreted both to evaluate the ability of probes to detect average channel salt concentration and to identify flow characteristics in the test bundle. A portion of the results presented are for improved data recorded after instrumentation was modified to eliminate signal interactions in the electrode leads.

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I. INTRODUCTION

To improve the understanding of mixing data previously recorded (Refs. 1, 2 and 3), additional tests were conducted. These tests were run using the available Configuration 8 hardware from the previously completed nineteen element mixing tests (see Refs. 2, 3 and 4). The initial tests were run to attempt a mass accounting (balance) of the calculated fraction of NaNO_3 tracer solution injected into one channel of the bundle flow. Unsatisfactory mass balances prompted further testing to attempt to resolve the causes of the differences.

This additional testing involved not only sampling the same flow channels with electrodes in different types of element, but also modifying the test bundle components to allow the electrodes to be used to make salt wt % measurements at flow channel entrance or exit gaps (see Ref. 5). As sufficient data were recorded, evidence of an interaction between the electrodes in each instrumented element became apparent. Modifications to the instrument lead configuration and reduction of the electrode excitation frequency eliminated this interaction.

II. TEST RESULTS

Results of these tests are presented as plots (Figs. 1 - 14) of the variation with distance down a flow channel of the ratio of the measured increment in solution NaNO_3 wt % (ΔC) to the calculated injected increment in solution wt % (ΔC_I). Several arrangements of instrumented elements (Fig. 15) were used (Figs. 16 - 21). These different arrangements allowed evaluation of the effects of instrumentation changes, of the effects of sampling at different locations on a flow channel boundary and of the effects of sampling at different locations in the test element bundle.

A. Modifications and Improvements

The initial purpose of these tests was to attempt a mass balance (accounting) of the salt solution injected into a bundle flow

channel as it moved through other bundle flow channels. As testing progressed however, the observation and correlation of voltage changes which occurred in both the electrode calibration data and raw data indicated interactions were occurring between signals from electrodes in the same instrumented element. Capacitive coupling between signal leads was suspected as the cause of these interactions and changes in system connections were made to eliminate these interactions. These modifications consisted of:

1. Separation of the unshielded instrument lead wires to reduce capacitive coupling.
2. Reduction of probe excitation frequency from 200 KHz to 50 KHz.

Checks of the system operation and the results of injection tests performed after these modifications (see Figs. 1, 2 and 3) indicated the modifications were successful. The following indications of the independence of probe signals was observed:

1. Analog records of individual probe signals showed a time delay between the indicated arrival of salt at probes remote from and near to the injection point.
2. Probes located where flow in the bundle would not be expected to carry the injected salt did not indicate any salt was present. (see data from channel gap 10 to 4 in Fig. 3).
3. Readings of other probes were not affected when a decade resistance box was connected to the instrumentation leads in place of one probe and used to simulate variations in probe conductivity to ground.

The effects of these interactions, since they occurred in a somewhat random manner depending upon which leads were connected, cannot be evaluated. Comparison of results from tests prior to the elimination of interactions (see Figs. 4 and 5) with results after elimination of interactions shows the general trends and behavior of the injected salt

solution are similar in each case. Thus, although the absolute magnitude of the measured concentration variations does not agree before and after the elimination of lead interactions, data with interactions present can still be used to interpret flow behavior in the test bundle.

B. Concentration Measurements in a Flow Channel

Initial tests were made with electrodes oriented to measure the salt concentration in flow down a coolant channel (see Fig. 16). The mass balances made from these tests were not satisfactory (see Figs. 6 and 7). Additional tests were made with instrumented elements repositioned to provide different sampling configurations (see Figs. 17 and 18). Data from these new configurations were compared (Figs. 8, 9 and 10) with data from Configuration A (Fig. 16). Results indicated that the salt distribution in a flow channel was not uniform - the salt concentration measured at an axial location in a channel depended on which of the three surrounding elements the electrode was located (see Channel 24 data, Figs. 8, 9 and 10).

These data indicate there are two types of flow in the bundle of R-L-N elements: a rotating flow in the fin-wrap direction around the finned elements and an axial flow along the surface of the unfinned elements. The electrode reading is apparently biased by the salt concentration near the surface of the instrumented element. Thus, if fins are sweeping "salty" water from an adjacent channel across electrodes on a finned element these electrodes will read a higher salt concentration than electrodes at the same channel location, but on an unfinned element (see Channel 24 data, Figs. 8, 9 and 10). Conversely, if the fins are directing fresh water into a "salty" channel the electrodes on the unfinned element will indicate the higher concentration (see data for Channel 1, Fig. 9).

C. Concentration Measurements in a Channel Gap

Since the flows in a channel were apparently separated into axial and spiral flows which were not mixed at the center of the channel,

the instrumented elements were rotated slightly to locate the electrodes at the element gaps between channels (see Fig. 19). This relocation, by increasing the likelihood of flow mixing, would allow measurement of a salt concentration more representative of the channel average concentration. Also, the shortest distance to ground for the electrode surface was across the ~ 0.024 " gap between adjacent elements (see Fig. 22). Thus, these measurements, although not in a flow channel, would be more representative of concentrations at an axial position than those in the channel sample runs. In the channel sample runs the distance to circuit ground was great enough (see Fig. 22) to allow salt solution above and below the electrode axial position to have a stronger effect on the concentration measurements than in the runs where the channel gap was sampled.

Location of the probes at flow channel exits required reorientation of all elements to maintain proper fin alignment between instrumented and uninstrumented elements. Results of the measurements made could therefore not be treated strictly as additional data on the flow channel sampling configurations. These test results, however, generally showed the same trends as the channel sampling data (compare Figs. 6 and 11, and 7 and 12).

The possibility that proximity of some of the channels to the test section wall might affect the data was checked by rearranging the bundle of elements. The instrumented elements and the surrounding uninstrumented rods were relocated in the same relationship at the opposite side of the test bundle (see Fig. 20). Results of these tests (compare 4 and 11, and Figs. 5 and 12) were not clear cut because of the interaction effects of the leads but, if there was a wall effect it was more pronounced for an injection in channel 7.

An additional test was run with some instrumented elements reoriented (see Fig. 21). Results of tests with this configuration indicate that finned element spiral flows do not mix even at the gaps

between channels. The salt concentrations indicated by measurements from electrodes on a finned element sweeping "unsalty" water into the gap are lower than those determined from measurements by an electrode on a finned element sweeping "salty" water into the gap (compare Channel 5 to 11 gap data, Figs. 13 and 14).

Data from tests on the configuration (Fig. 20) with the lead interaction eliminated also support the conclusion that spiral flows do not mix. Data from the 11 to 20 channel gap peaks at a higher salt concentration than data from the channel 5 to 11 gap (see Fig. 1). The injected salt, however, has to travel further from the injection point to the channel 11 to 20 gap than from the injection point to the channel 5 to 11 gap. Thus the injected salt would be expected to be more diluted at the channel 11 to 20 gap and would result in a salt concentration below that at the channel 5 to 11 gap.

This discrepancy between expected and observed peak concentrations is consistent with stratified unmixing flows of "salty" and "fresh" water passing through the channel 5 to 11 gap while the channel 11 to 20 gap sees only a "salty" flow. This could occur because there is only one finned element at the channel 11 to 20 gap and it has a "salty" spiral flow. For this situation the concentration data from the channel 5 to 11 gap would then be lower than those from the channel 11 to 20 gap because the electrodes in the channel 5 to 11 gap are located on the finned rod sweeping the "fresh" water flow into the gap. This "fresh" water flow at the surface of the instrumented element causes the measured concentration values to be below the salt concentration near the surface of the adjacent finned element. Thus, if this "salty" spiral flow on the adjacent element does not mix markedly with "fresh" water before it reaches the channel 11 to 20 gap the concentration measured there will be higher than that measured at the channel 5 to 11 gap - as the experimental data indicate.

III. TEST DESCRIPTION

A. Flow System and Operating Procedures

The flow system and basic operating procedures have been described previously (see Refs. 1 and 2). The flow system provided 40 gpm of 110°F water for all tests. The operating procedure for recording data was modified slightly by combining the separate calibration run for the electrodes with the recording of data from injection runs. This was done by using the background data prior to each injection as calibration data and then at the completion of running beginning a standard calibration by incrementally adding salt solution until the range of electrode voltages recorded in the data runs had been covered.

B. Data Reduction

The data presented are ratios, $\Delta C / \Delta C_I$'s, of indicated salt wt % increment, ΔC , to the calculated injected salt wt % increment, ΔC_I , for each electrode. The terms in the $\Delta C / \Delta C_I$ ratio are determined separately from the following expressions: $\Delta C = C - C_o$

$$\Delta C_I = \left[\frac{\rho_o V_n Q_o + \rho_I V_I Q_I}{\rho_o V_n + V_I} - Q_o \right] \times 100\%$$

where, C = salt wt % read from individual electrode calibration curve at the average electrode voltage during the injection.

C_o = wt % of salt flowing in solution before injection (determined from commercial probe).

ρ_o = density of salt solution before injection (~ 1.0 gm/cc)

V_n = calculated flow in one bundle coolant channel, cc/min.

ρ_I = density of injected 20% x weight salt solution at 70°F, 1.142 gm/cc.

Q_o = weight fraction of salt in solution prior to injection, $C_o/100$, (determined from commercial probe used for calibration).

Q_I = weight fraction of salt injected, 0.20.

V_I = measured flowrate at which 20% x weight salt solution was injected, cc/min.

These calculated ratios were then plotted versus the electrode position (see Fig. 15) where data were measured to give the axial variation of concentration in a channel.

IV. SUMMARY

Interpretation of measurements of the distribution of injected salt concentration in the nineteen element R-L-N test bundle indicated flow through the bundle has two components. The measurements made from instrumented elements indicated that the salt concentration levels sensed by a probe were dependent on whether the flow being swept over the probe was "salty" or "unsalty". This probe sensitivity to adjacent "salty" and "unsalty" flows was seen not only in the flow channels but in the gaps between channels. This observation indicated that finned elements had a spiral flow moving around the element in the direction of the fin wrap, without a great deal of mixing with flow on adjacent elements, while unfinned elements were surrounded by axial flows in each adjacent flow channel.

Investigations of instrumentation improvements indicated that with suitable connection and operational changes probe circuit interactions could be eliminated. These changes consisted of the separation of unshielded probe leads and the reduction of probe excitation frequency from 200 KHZ to 50 KHZ. These two changes eliminated interactions between signal leads and thereby improved the measurement of actual salt concentrations, eliminating those electrically induced probe signals which changed the actual concentration signals.

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FIGURE 6

INJECTION IN CHANNEL 1
MEASURED FRACTION OF INJECTED SALT AS
FUNCTION OF AXIAL POSITION IN
NINETEEN ELEMENT BUNDLE

(SIGNAL INTERACTIONS NOT ELIMINATED)

AVERAGED DATA FROM: RUNS 5 THRU 7 - 133 THRU 4 (CH 23 THRU 247)
RUNS 12 AND 13 - 4 THRU 8 (CH 23 THRU 533)

MEASURED FRACTION OF INJECTED SALT AS

16
14
12
10
8
6
4
2
0

FIGURE 7

FOR INJECTION IN CHANNEL 7
INDICATED FRACTION OF INJECTED SALT
AS FUNCTION OF AXIAL POSITION
IN NINETEEN ELEMENT BUNDLE
FLOW CHANNELS

(SIGNAL INTERACTIONS NOT ELIMINATED)

AVERAGED DATA FROM : RUNS 8-10-133 THRU 4 (CN 4 THRU 12.67")
RUNS 14-16 4" THRU 8 (CN 25 THRU 15.33")

FIGURE 8

INDICATED FRACTION OF INJECTED SALT IN BUNDLE FLOW CHANNELS FOR DIFFERENT INSTRUMENTATION LOCATIONS
(SIGNAL INTERACTIONS NOT ELIMINATED)

REV 05
11-16-71 5-6-71

FIGURE 9

INDICATED FRACTION OF INJECTED SALT IN BUNDLE FLOW CHANNELS FOR DIFFERENT INSTRUMENTATION CONNECTIONS
(ORIGINAL INTERACTIONS NOT ELIMINATED)

FIGURE 10
FRACTION OF SALT INJECTED IN FLOW CHANNEL 7
INDICATED IN FLOW CHANNELS 13 AND 24
FOR VARIOUS INSTRUMENTATION ORIENTATIONS AND CONNECTIONS
(SIGNAL INTERACTIONS NOT ELIMINATED)

K-8-11

FIGURE 15
SECTION OF INSTRUMENTED FUEL ELEMENTS
(DIMENSIONS IN INCHES)

FIGURE 16 INSTRUMENTATION CONFIGURATION A

RUNS 5-16

INV. CH. 1 RUNS 5-7 AND 11-13

INV. CH. 7 RUNS 8-10 AND 14-16

FIGURE 17
INSTRUMENTATION
CONFIGURATION B
RUNS 17-43

RUNS	CH. INJ.	SAMPLE CH. 24
17-22	1	FROM ROD 2
23-25	7	FROM ROD 2
26-30	1	FROM ROD 10
31-33	7	FROM ROD 10
34-39	1	ELECTRODE-TO-ELECTRODE
40-43	7	ELECTRODE-TO-ELECTRODE

FIGURE 18
INSTRUMENTATION
CONFIGURATION C

INJECT CH. 1 RUNS 44-47, RUNS 48-51, RUNS 58-61

INJECT CHANNEL 7

RUNS 52-56 RUNS 62-63

FIGURE 22

RELATIVE PROPORTIONS OF CHANNEL
WALLS AND ELECTRODE AND INSULATOR
SURFACES

SCALE: $\frac{1}{60}'' = 0.001''$

NOTE: NO TESTS WERE RUN WITH
BOTH ELECTRODE ORIENTATIONS USED
SIMULTANEOUSLY - THEY ARE SHOWN
TOGETHER ONLY FOR CLARITY