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A METHOD TO SIMULATE INTERCHANNEL FLOW THROUGH
FUEL ELEMENT JUNCTIONS DURING LABORATORY TESTS ON A
C-REACTOR FUEL MODEL

By

A. M. Sutey

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A METHOD TO SIMULATE INTERCHANNEL FLOW THROUGH
FUEL ELEMENT JUNCTIONS DURING LABORATORY TESTS ON A C-REACTOR FUEL MODEL

INTRODUCTION

Interchannel flow through fuel element junctions can occur in production reactor fuel columns as a result of different pressure loss patterns in the two coolant subchannels. This interchannel flow is most significant during boiling conditions because, generally, the boiling length in each subchannel is different. These different boiling lengths result in divergent pressure loss characteristics in the subchannels and cause differential pressures to exist across the fuel element junctions. These differential pressures are the predominant driving forces for interchannel flow.

The extent to which interchannel flow exists, and its effect on the thermal hydraulic characteristics of reactor flow channels has long been a question of concern in the design of electrically heated models of reactor fuel columns for laboratory experiments. Interchannel flow is quite unpredictable and subject to considerable variation due to mechanical and alignment changes at the junction. It is also very important because it significantly affects the total thermal-hydraulic performance of the fuel column. Therefore, it is necessary to have a good understanding of the quantitative effects of interchannel flow so that it can be adequately simulated in laboratory experiments.

The purpose of this investigation was to analytically evaluate the effects of interchannel flow on the predicted thermal-hydraulic performance of a production reactor fuel channel and to develop accurate methods by which it could be simulated in electrically heated laboratory models.

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Principal consideration was given to the C-overbore geometry because of the possibility of immediate application to FY-68 experiments on the boiling demand characteristics of this geometry.

SUMMARY AND CONCLUSIONS

The pressure-flow characteristics of the active length of a typical C-overbore fuel column were analyzed with various uniform interchannel flow areas ranging from 0 to 0.0123 in² per fuel element junction for both boiling and non-boiling conditions. For the purpose of calculation, each interjunction flow hole was considered as a uniform slit with the same total flow area and extending along the entire length of the fuel element. Calculations were made to give subchannel pressure, enthalpy, flow and quality at increments along the uniformly heated length. All calculations were made by means of COBRA¹, a computer program for cross-flow mixing between parallel flow channels during boiling.

This analysis showed that the effect of interchannel flow is to balance the coolant subchannels with respect to enthalpy and pressure drop. If no interchannel flow occurs, unstable flow conditions would probably exist in the subchannels during bulk boiling conditions. As the interchannel flow area is increased, the calculations revealed that the balancing effect would increase also. When a 0.0062 in²/junction interchannel is reached, the subchannels are completely balanced; and the enthalpy and

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¹"Cross-Flow Mixing Between Parallel Flow Channels During Boiling Part I COBRA-Computer Program for Coolant Boiling in Rod Arrays." DNWL-371 PT 1 (March 1967) by D. S. Rowe.

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pressure at each corresponding axial station are approximately equal. Further increases in interchannel flow area would not produce significant additional effects.

Estimates of maximum interchannel flow area based on manufacturing tolerances revealed that 0.0127 in²/junction could exist in a C-overbore fuel column, and this area is approximately double that required for completely balanced flow.

On the basis of this analysis, it was concluded that the experimental boiling demand curves for C-Reactor can best be obtained by providing simulated interchannel flow passages in the electrically heated test section. These interchannel flow passages should each consist of one or two round holes with a combined cross-section area of 0.00613 in² (e.g., two 1/16 in diameter holes) located at axial position corresponding to the fuel element junctions in an actual fuel column.

It was also found that accurate boiling demand curves could be obtained using no interchannel flow simulation provided that the typical inlet flow split is forced on the system. Flow splits other than the typical flow split will result in unrealistic flow-pressure drop behavior.

Results

Interchannel flow is most significant under two-phase flow conditions. Therefore, this analysis was based on a set of possible reactor operating conditions which would result in bulk boiling in the fuel. The conditions considered are as follows:

Tube Power	2000 kw
Total Flow	25 gpm
Inlet Pressure	300 psia
Inlet Temperature	68°F

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Calculations of subchannel pressure, enthalpy, flow and quality distribution along the active length were made using the computer code COBRA for various interchannel flow areas. In these calculations, the interchannel flow passage at the fuel junctions was idealized as a continuous uniform slit of the same area of the channel extending along the entire length of the fuel column. Typical results of these calculations are given in the Appendix. The results of these calculations are summarized in Figures 1 to 3 and in Table I.

Discussion

Interchannel Flow in a C-Reactor Fuel Column

In Figure 1, the pressure drop is presented versus the heater length with interchannel flow area as a parameter. Over the initial length of the column, the pressure drop is attributed to single phase flow. As boiling occurs, the pressure drop increases rapidly as shown by the abrupt change in slope in Figure 1. With increasing interchannel flow area, the characteristics of the individual channels approach one another so that the system functions more like a single channel. It can be seen from Figure 1 that the system is essentially balanced from the pressure standpoint by any interchannel flow area greater than $.00613 \text{ in}^2/\text{junction}$.

In Table I, the enthalpy, quality and flow rate at the end of the active length is given for various interchannel flow areas. From this table, it can be seen that although the two subchannels are balanced from the pressure standpoint at interchannel areas greater than $.00613 \text{ in}^2/\text{junction}$, differences still exist in enthalpy and quality at the outlet. However, the effect of the interchannel flow is to reduce disparities in these quantities observed in the no flow case.

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The effects of interchannel flow may be further analyzed by the graphical construction of Figure 2 which is a plot of subchannel pressure drop versus the entrance flow split for a given upstream pressure and total flow rate. It should be noted that entrance flow split is a fictitious variable used here only as a reference. Since the subchannels have identical upstream and downstream pressures, the only possible flow split under steady flow conditions occurs at the intersection of the pressure drop curves. Therefore, only the flow splits at points A, B, and C in Figure 3 can occur normally. At point A, the coolant at the exit of both subchannels is saturated. At points B and C, the coolant at one of the subchannels is superheated steam.

Although the flow through each of the coolant subchannels is normally considered as a constant value under steady flow conditions, it actually fluctuates slightly about the mean value due to the effects of turbulence. Therefore, the operating point does not stay at point A, for example, but fluctuates a small distance on both sides of A. Since the subchannel operating lines for the case of no interchannel flow cross A at a very steep angle, the fluctuations in flow split will cause very large pressure drop fluctuations in the individual flow passages. These pressure drop fluctuations will tend to cause re-entrant-type flow fluctuations at the ends of the fuel column, and thereby cause large variations in total pressure drop across the process tube. With interchannel flow areas of .00613 and .0122 in²/junction, the subchannel operating lines are tangential at A. From the shapes of these curves, it is obvious that large flow

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fluctuations can be accommodated without significant pressure drop variations. Therefore, the boiling with interchannel flow through $.00613 \text{ in}^2/\text{junction}$ could be characterized as being "stable."

To determine the significance of this information with regards to the operation characteristics of a reactor process channel, it is necessary to establish typical interchannel flow areas which can occur in the reactor. This interchannel flow area can depend on many factors, such as manufacturing tolerances, damage during handling, corrosion, and process tube bowing. The latter three factors are difficult to estimate, however, the range of values possible as a result of manufacturing tolerances could be identified with fair accuracy.

With the assistance of DUN personnel, it was determined that manufacturing tolerances could range from 0 to $0.0127 \text{ in}^2/\text{junction}$. Information showing how this estimate was obtained is presented in the Appendix. Of course, the actual interchannel flow area varies from slug to slug, and an average value would be somewhere between. It was assumed that this mean flow area would be the arithmetic average of the possible range, $.00635 \text{ in}^2$. Since other factors will tend to increase the mean interchannel flow area, it can be said with fair certainty that the interchannel flow area would be greater than $.00635 \text{ in}^2$. This result compares well with an interjunction flow area of 0.00686 in^2 experimentally determined by E. D. Waters² for I&E slugs and used extensively in electrically simulated fuel rods.

If the estimated interchannel flow area is compared to the minimum value required for stable boiling and balanced pressure in the subchannels,

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²"Special I&E Slug Interjunction Flow Tests for Design of I&E Heater Rods A-020-2." E. D. Waters, October 8, 1957 (Thermal Hydraulics Internal Document.)

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it is immediately apparent that under typical boiling conditions in the C-Reactor overbore fuel column, the boiling would probably be stable; and the subchannels would be balanced.

The Significance and Simulation of Interjunction Flow
in Heat Transfer Modeling

In the design and construction of electrically heated fuel columns for heat transfer experimentation, the exact degree of simulation is limited by cost and practical considerations. One particularly serious problem exists at the inlet and outlet of the heated length. At these points, it is necessary to bring both water and electrical current into the test section at the same point. The necessity of providing a large current path into the model normally requires some nontypical restriction of the water passages to the coolant subchannels. In the C-overbore fuel column model being constructed for FY-63 work, an elaborate outlet electrical connection is used at the outlet end. This connector allows an almost exact simulation of the fuel column outlet. Extreme cost, however, precluded the use of this type of connector at the inlet, and the inlet simulation is poor. Inlet valving is required to balance subchannel flow because of the additional flow resistance introduced by this nontypical inlet. The type of flow system used is shown in Figure 3.

In this flow system, it is required that the inlet valving be adjusted so that a prototypic entrance flow split be provided to the model. By reference to Figure 2, it can be seen that the average pressure drop behavior of the model without interchannel flow area will accurately simulate that of the fuel column. However, in similar fashion as described earlier,

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boiling would probably be "unstable," i.e., accompanied by extreme pressure and flow fluctuations. This is consistent with past experience.*

Another problem could arise in a model with no interchannel flow area. This problem is related to the effects of error in inlet flow split adjustment. Suppose, for example, that a 20 percent error is made in the presetting of flow split during the adjustment of the flow system. Also, suppose this error occurs because of excessive flow resistance due to misadjustment of the inlet valve to the outer flow channel. This additional resistance will shift the characteristic curve for this channel (Curve 2 in Figure 2) upwards. In a region around point A, this displacement can be considered as a simple upward shift of curve 2. It can be immediately seen that this 20 percent misadjustment will result in approximately a 5 psi (12.5 percent) error in the pressure drop. This could possibly result in serious errors in the boiling demand curve.

If interchannel flow passages are provided, Figure 2 shows that considerable errors can be tolerated in inlet flow adjustment without serious errors in total pressure drop of the simulated fuel column. It is estimated that 20 percent error in flow split adjustment will result in less than 2 percent error in the pressure drop if $.00613 \text{ in}^2/\text{junction}$ interchannel flow area is provided.

Conclusions

From the results of this analysis, the following conclusions are drawn:

- The effect of interchannel flow through fuel element junctions is to balance the pressure drop in the coolant subchannels

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*G.M. Hesson and D.E. Fitzsimmons, Personal Communication.

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and to "stabilize" boiling, i.e., to minimize pressure fluctuations during boiling.

- In a C-overbore fuel column, subchannel pressure drop is essentially balanced and boiling stabilized for inchannel flow areas greater than $.00613 \text{ in}^2/\text{junction}$. Greater areas result in diminishing returns.
- Actual interchannel flow area in a C-overbore would probably be greater than $.00613 \text{ in}^2/\text{junction}$.
- In heat transfer experiments with electrically heated test sections, the pressure drop behavior can be accurately simulated if no interjunction flow area is provided only if the inlet flow split is accurately adjusted. Significant errors could result from misadjustment.
- Serious pressure fluctuations could result during boiling if no interjunction flow area is provided in electrically heated test sections.
- Heat transfer experiments to determine the C-overbore boiling demand curves can best be obtained if flow passages simulating the fuel element junctions are provided in the electrically heated test section. Two $1/16$ in holes (total area $.00613 \text{ in}^2$) at locations corresponding to the fuel element junctions should be provided.

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TABLE I

COMPUTATION RESULTS FOR EACH CHANNEL

INLET CONDITIONS:

P = 300 psia

Power Level = 2000 kw

Entrance Flow: (1.14)

T = 68°F

Total Flow = 25 gpm

Channel (1) 5860.0 lb/hr
Channel (2) 6670.0 lb/hr

CONDITIONS AT THE END OF THE HEATED LENGTH

Interjunction Hole Size (in.)	(CHANNEL 1)		X	(CHANNEL 2)		X
	Enthalpy Btu/lb	Flow lb/hr		Enthalpy Btu/lb	Flow lb/hr	
0	550.89	5857.3	.203	606.59	6672.7	.271
.00076	556.44	5764.7	.210	601.10	6765.3	.265
.00306	539.87	5243.1	.251	573.85	7286.9	.231
.00613	594.38	5181.2	.256	570.80	7343.3	.228
.0122	594.63	5201.5	.257	570.57	7328.5	.227

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FIGURE 12

Flow Diagram

Figure (3)

INPUT FOR CASE 4

DATE 19 JUL

HEAT FLUX DISTRIBUTION

X/L RELATIVE FLUX

.000 1.000
1.000 1.000

ADJACENT CHANNEL SPACING

INTERJUNCTION FLOW HOLE

two (1/16")

CHANNEL INPUT DATA

CHANNEL NO.	AREA (SQ-IN)	WETTED PERIM. (IN)	HEATED PERIM. (IN)	HYDRAULIC DIAMETER (IN)	ROD SPACING BETWEEN ADJACENT CHANNELS (ADJ. CHANNEL NO. (IN))			
1	.4780	6.8900	6.8900	.2775	.0008(2)	-.0000(-0)	-.0000(-0)	-.0000(-0)
2	.7840	16.0100	7.7000	.1959	.0008(1)	-.0000(-0)	-.0000(-0)	-.0000(-0)

ROD INPUT DATA

ROD NO.	DIAMETER (IN)	RADIAL POWER FACTOR	FRACTION OF POWER TO ADJACENT CHANNELS (ADJ. CHANNEL NO.)					
1	4.6400	1.0000	.4420(1)	.5580(2)	-.0000(-0)	-.0000(-0)	-.0000(-0)	-.0000(-0)

CALCULATION PARAMETERS

TURBULENT INTENSITY .0000
TRANSV. FRICTION (FT.) .0001
MOMENTUM DIVERSION FACTOR .0000
MOMENTUM TURBULENT FACTOR .0000
DIVISION FOR PRINT-OUT 24
CALCULATION SUBDIVISION 2

CHANNEL OPERATING CONDITIONS

SYSTEM PRESSURE = 275.0 PSIA
INLET ENTHALPY = 36.0 BTU/LB
AVG. MASS VELOCITY = -1.419 MILLION LB/(HR-SQFT)
AVG. HEAT FLUX = .239 MILLION BTU/(HR-SQFT)
CHANNEL LENGTH = 282.00 INCHES
CHANNEL ORIENTATION = 90.0 DEGREES
CALC INCREMENT = 6.13 INCHES
AVG. EXIT ENTHALPY = -513.1 BTU/LB

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COMPUTATION RESULTS FOR EACH CHANNEL

CASE 4

DATE 19 JUL 67

TIME

CHANNEL 1

CHANNEL 2

DISTANCE in.	PRESSURE lb/in ²	ENTHALPY Btu/lb	X	MASS VEL fraction to surface	FLOW lb/hr	FLUX Btu/in ² hr	PRESSURE	ENTHALPY	X	MASS VEL	FLOW
0.00	.000	36.05	.000	1.765	5860.0	.223	.000	36.05	.000	1.225	6670.0
12.26	.566	58.48	.000	1.754	5821.0	.223	.481	60.80	.000	1.232	6709.0
24.52	1.076	81.14	.000	1.732	5749.3	.223	.938	85.31	.000	1.245	6780.7
36.78	1.544	104.11	.000	1.707	5667.0	.223	1.380	109.52	.000	1.261	6863.0
49.04	1.977	127.42	.000	1.682	5581.9	.223	1.810	133.42	.000	1.276	6948.1
61.30	2.381	151.09	.000	1.657	5499.6	.223	2.231	157.03	.000	1.291	7030.4
73.57	2.760	175.10	.000	1.634	5425.2	.223	2.643	180.38	.000	1.305	7104.8
85.83	3.121	199.41	.000	1.615	5361.0	.223	3.049	203.53	.000	1.317	7169.0
98.09	3.471	223.98	.000	1.601	5315.8	.223	3.448	226.52	.000	1.325	7214.2
110.35	3.817	248.67	.000	1.600	5310.4	.223	3.832	249.44	.000	1.326	7219.6
122.61	4.168	273.29	.000	1.609	5342.2	.223	4.201	272.41	.000	1.320	7187.8
134.87	4.517	297.74	.000	1.621	5380.4	.223	4.558	295.50	.000	1.313	7149.6
147.13	4.864	322.00	.000	1.633	5419.6	.223	4.904	318.72	.000	1.306	7110.4
159.39	5.210	346.09	.000	1.644	5455.6	.223	5.241	342.06	.000	1.299	7074.4
171.65	5.552	370.02	.000	1.652	5485.1	.223	5.572	365.51	.000	1.294	7044.9
183.91	6.282	393.88	.011	1.653	5487.8	.223	6.154	389.04	.005	1.293	7042.2
196.17	8.344	417.93	.040	1.631	5413.6	.223	7.790	412.48	.034	1.307	7116.4
208.43	11.039	442.35	.070	1.604	5324.3	.223	10.235	435.67	.062	1.324	7205.7
220.70	14.420	467.16	.101	1.577	5236.4	.223	13.606	458.59	.090	1.340	7293.6
232.96	18.390	492.41	.132	1.554	5157.1	.223	17.796	481.27	.118	1.354	7372.9
245.22	22.890	517.98	.163	1.536	5100.2	.223	22.691	503.73	.145	1.365	7429.8
257.48	27.977	543.69	.194	1.536	5099.4	.223	28.131	526.01	.173	1.365	7430.6
269.74	33.689	569.15	.226	1.548	5139.9	.223	33.985	546.34	.200	1.357	7390.1
282.00	39.945	594.58	.256	1.561	5161.2	.223	40.217	570.80	.228	1.350	7348.8

($F/\mu K = 0.252$)

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DIVERSION(W) AND TURBULENT(WP) CROSSFLOW BETWEEN ADJACENT SUBCHANNELS (I,J)

CASE 4

$w_2/w_1 = 1.14$
two (1/16") holes

DATE 19 JUL 67

DISTANCE	W(1, 2)	WP(1, 2)
.00	.0	.0
12.26	61.0	.0
24.52	76.9	.0
36.78	63.0	.0
49.04	62.9	.0
61.30	77.6	.0
73.57	67.5	.0
85.83	55.7	.0
98.09	31.2	.0
110.35	-24.8	.0
122.61	-35.2	.0
134.87	-38.7	.0
147.13	-37.4	.0
159.39	-32.7	.0
171.65	-24.7	.0
183.91	53.2	.0
196.17	64.9	.0
208.43	88.6	.0
220.70	82.1	.0
232.96	69.9	.0
245.22	38.8	.0
257.48	-33.3	.0
269.74	-41.5	.0
282.00	-37.6	.0

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