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A STUDY OF MIXING IN A SPECIAL CHANNEL

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A STUDY OF MIXING IN A SPECIAL CHANNEL

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INTRODUCTION

Diffusion of heat into the coolant flowing through an array of fuel pins is being studied for the FFTF core. A test is underway using a simulated fuel sub-assembly, geometrically similar to the present core design. The array consists of 0.23 in. diameter pins spaced at 0.286 in. centerline to centerline with helical wire wraps. Each pin is centered on apexes of equilateral triangles, with common sides. Each fuel pin is thus equally spaced from all its six neighbors. The objective of the experiment to be conducted is to measure the rate at which heat from a fuel pin is diffused into the bulk stream flowing parallel to the array of fuel tubes. A soluble tracer, simulating a source of heat, is to be injected through a small orifice into a channel at a selected height in the sub-assembly. The concentration of tracer (salt solution) will be determined by many conductivity probes located throughout the simulated sub-assembly. It was necessary in the design of the test assembly to provide a good method for point injection of the tracer. Ideally, the tracer should be completely mixed in the channel within an inch or two so as to properly represent an initial condition which could be effectively modeled.

The brief work to be described had as an objective to determine the degree of mixing in a channel identical to the injection channel to be used in the simulated heat diffusion experiments.

EXPERIMENTAL

The channel was furnished for the experiment. Figure 1 is a sketch showing the principal features. The channel was formed in the lucite assembly by carefully machining the profile of one-third of the channel in each apex of the three 120° sector blocks. When the three blocks are assembled and fastened together, the channel of the correct cross-section is generated. This is shown in section X-X. In the first group of experiments the injection orifice in the wall of the channel was drilled 0.042 in. in diameter. In the later experiments this was reduced to 0.023 in. by cementing a short section of a #20

FIGURE 1

FLOW CHANNEL ASSEMBLY

hypodermic needle in the former orifice, then grinding the needle section flush with the channel wall.

The channel and flow lines, etc., were arranged as shown in Figure 2 and further shown in the photograph, Figure 3.

FIGURE 2

EXPERIMENTAL ARRANGEMENT

The experiments to be performed were to demonstrate mixing effectiveness immediately downstream of the injection port. The flow conditions to be simulated were 1 gallon per minute (gpm) through the channel and 0.1 gpm through the injection port. An orifice just upstream of the injection port was provided to extract 0.1 gpm to compensate for the 0.1 gpm injected.

FIGURE 3

GENERAL ARRANGEMENT OF EXPERIMENTAL APPARATUS

Uranine (the sodium salt of fluorescein) dissolved in water was the tracer material employed. A concentration of 1.1×10^{-8} g/ml was used. A fluorimeter was used to measure the fluorescence of samples taken.

In a typical experiment the flow through the channel was adjusted to 1 gpm using cold water from a sink faucet. The tracer flow was adjusted to 0.1 gpm by adjusting the air pressure on the uranine feed reservoir, and a like flow of water was drawn from the channel through a vacuum chamber. After flows were stabilized, a 6 in. sampling hypodermic needle was inserted vertically through a septum into the channel. The needle was held at a different height above the injection point for each measurement. When a sample was to be taken, a vacuum was drawn on the syringe cylinder to which the needle was attached. A sample of the bulk flow was taken at the same time the channel sample was taken. The first experiments were made with the needle held in the crease of the channel (or apex) opposite the injection port. The needle could be held in this position without movement. In other experiments the apex of the channel was used to support the needle whose tip was offset to bring it onto the center-line.

The first experiments gave quite variable readings in regard to mixing. The source of the variability was not isolated, but it was believed to be in part due to variability in lateral positioning of the sample needle. Possible differences of fluorescence in distilled and tap water may have contributed. In subsequent experiments uranine solutions were prepared with tap water. In later experiments the needle was held in a fixed position by three vanes soldered to the needle one-half inch back from the point. The vanes were guided into the 3 apexes of the channel. When samples were to be taken in the apex or at the channel wall, the end of the needle was offset to draw the sample from this region. This was more satisfactory and with replicate sampling at each distance from the injection port better consistency was achieved.

RESULTS

Experiment 1

<u>Distance Above Injection Port, In.</u>	<u>Concentration in Channel</u>		
	<u>Concentration in Bulk</u>		
	(1)	(2)	(3)
0	0.04	0.04	0.05
0.75	0.38	0.32	0.34
1.25	0.31	0.30	0.36
1.75	0.32	0.29	0.34
2.25	1.06		1.33
2.00 (separate run)	0.44	--	0.53

- (1) First readings on fluorimeter.
- (2) Second readings on fluorimeter (15 minutes later).
- (3) Readings 2 days later by different operator.

Experiment 2

<u>Distance Above Injection Port, In.</u>	<u>Concentration in Channel</u>	
	<u>Concentration in Bulk</u>	
0	0.08	
0.5	1.76	
1.0	1.89	
1.5	1.83	
2.0	1.65	
2.5	0.91	

Experiment 3

<u>Distance Above Injection Port, In.</u>	<u>Concentration in Channel</u> <u>Concentration in Bulk</u>
0.	0.04
0.5	0.71
1.0	1.16
1.5	1.23
2.0	0.97
2.5	1.00

Experiment 4*

(Same arrangement as in Experiment 3)

Inlet Orifice - 0.023"

<u>Distance Above Injection Port, In.</u>	<u>Concentration in Channel**</u> <u>Concentration in Bulk</u>		
	<u>A</u>	<u>B</u>	<u>C</u>
0	0.05	(0.9)	0.05
0.5	0.58	1.06	1.31
1.0	1.03	1.00	0.58
1.5	0.70	0.62	1.12
2.0	0.87	1.15	2.08
2.5	0.78	1.45	1.07

* In this and subsequent experiments the injection flowrate was 0.08 gpm. The extraction flow matched this at 0.08 gpm. Excessive pressure would have been required to reach 0.10 gpm through the smaller orifice.

** A, B, C are results from 3 separate runs. There was some concern that bulk sample may not have been thoroughly mixed. In remaining experiments much care was taken to insure complete mixing.

Experiment 5

(Same arrangement as in Experiment 3)

Inlet Orifice = 0.023"

In this experiment quadruplicate samples were taken from each position.
 Tabled value is average of the four samples.

<u>Distance Above Injection Port, In.</u>	<u>Concentration in Channel</u> <u>Concentration in Bulk</u>
0.	(Not taken)
0.5	1.15
1.0	0.95
1.5	0.95
2.0	1.02

Experiment 6

<u>Distance Above Injection Port, In.</u>	<u>Average of Triplicate Samples</u> <u>Concentration in Channel 1</u> <u>Concentration in Bulk</u>
0.	(Not taken)
0.5	0.49
1.0	0.85
1.5	0.94
2.0	0.89

Experiment 7

<u>Distance Above Injection Port, In.</u>	<u>Average of Triplicate Samples</u> <u>Concentration in Channel</u> <u>Concentration in Bulk</u>
0.	(Not taken)
0.5	1.48
1.0	1.02
1.5	1.01
2.0	0.87

Experiment 8

<u>Distance Above Injection Port, In.</u>	<u>Average of Triplicate Samples</u> <u>Concentration in Channel</u> <u>Concentration in Bulk</u>
0.	(Not taken)
0.5	0.40
1.0	0.77
1.5	0.77
2.0	0.92

DISCUSSION

In Experiment 1 the results indicate that mixing was complete at a distance of 2.25 inches downstream from the inlet orifice. Samples were drawn from along the wall opposite the injection port. Variation was significant, but when one considers that for zero mixing the ratio of channel concentration/bulk concentration would be either 10 or 0 and for complete mixing the ratio would be 1.0, values around one represent nearly complete mixing. Available time did not permit an exhaustive check of the errors in each part of the experiment, so that statistical fluctuations could be evaluated. The fluorimeter was stable, but there may have been some time-dependent variation in the fluorescence of the solutions themselves. The uranine tracer solution was made with distilled water in the first two experiments, but in the remaining experiments the solution was prepared from tap water. Although the tap water alone showed a measurable fluorescence, it was not enough to materially affect the results. Of more concern was the possibility that some quenching or enhancement of the uranine fluorescence from that of the tracer in distilled water may be occurring. Changing to tap water for the solution makeup water should have removed this potential difference in channel and bulk concentration.

Experiment 2 showed reasonably complete mixing was occurring near the channel centerline at distances beyond 2 inches downstream. The sample taken at closer distances show a higher concentration in the channel centerline than in the bulk.

The subsequent experiments were carried out using a smaller injection orifice, 0.023". More immediate mixing across the flow channel was anticipated by increasing the jet velocity.

The two photographs making up the Appendix show in a qualitative way that the jetting action was not sufficient to carry the tracer directly across the fast-flowing channel stream.

Mixing was complete within 2 inches as shown in Experiments 3 through 8. Attention was given to careful mixing of the bulk sample and replicate samples were taken to give better average values. More stable positioning of the sampling hypodermic needle was also possible with the vane arrangement indicated. There are a few inconsistencies, but in general, the data show that in

experiments 5, 6, 7, and 8 the only position in which mixing may not have been virtually complete within one inch downstream was in the crease (or apex) of the channel adjacent to the injection port. Even so, the mixing was approaching completeness, the channel sample showing 77% of the bulk concentration.

CONCLUSIONS

The results of these brief channel mixing tests showed that mixing was complete within 2 inches from the injection orifice. At 1 inch mixing is also virtually complete except in the crease adjacent to the injection port.

APPENDIX

In an attempt to visualize the mixing pattern, potassium permanganate solution was injected into the 0.023" port at 0.08 gpm. Photographs were taken and are presented as Figures 4 and 5. The photographs give some indication of the completeness of mixing, but could not be used for a detailed study.

FIGURE 4

VISUALIZATION OF TRACER MIXING USING POTASSIUM PERMANGANATE

FIGURE 5

CLOSE-UP VIEW OF TRACER ENTERING THE CHANNEL THROUGH 0.023" ORIFICE.
POTASSIUM PERMANGANATE USED AS TRACE MATERIAL.