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REPORT ON PRELIMINARY LABORATORY
EXPERIMENTS INVESTIGATING CONSEQUENCES
OF FAILURE OF FRONT HYDRAULIC FITTINGS
IN K REACTOR GEOMETRY.

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G. M. Hesson
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REPORT ON PRELIMINARY LABORATORY EXPERIMENTS
INVESTIGATING CONSEQUENCES OF FAILURE OF FRONT
HYDRAULIC FITTINGS IN K REACTOR GEOMETRY

By C. M. Hesson and D. E. Fitzsimmons

September 10, 1959

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REPORT ON PRELIMINARY LABORATORY EXPERIMENTS
INVESTIGATING CONSEQUENCES OF FAILURE OF FRONT
HYDRAULIC FITTINGS IN K REACTOR GEOMETRY

Purpose

The purpose of this report is to present the results of a brief series of transient heat transfer experiments directed toward determining the possibility of damage to a K reactor should a front hydraulic connector fail to a tube containing I & E fuel elements.

Introduction

The failure of a front face hydraulic connector could have serious consequences to a reactor. While such an incident would immediately initiate a scram, the power reduction is not immediate, but is dictated by the time required for insertion of the VSR's and by post-scram delayed fission and fission product decay. Although the post-scram heating is small, the only coolant available is that of hot water forced back through the tube by the low pressure of the rear header. This may provide insufficient cooling, particularly at low rear header pressures.

This problem has been investigated for "C" reactor OCD geometry,^(1, 2) and conditions under which a reactor would not suffer serious damage following loss of a front hydraulic connector were defined. While it was not expected that this quantitative definition would also apply to K reactors, the possibility existed that the concepts developed for C OCD geometry would apply. The experimental program reported in this document was of a scouting nature made to determine if this were so and to determine the rear header pressures necessary to achieve adequate cooling.

Summary

Nuclear heating of a train of 32 I & E slugs was simulated by electrically heating a rod in a K geometry process tube. Failure of a front fitting to such a tube was simulated by simultaneously and rapidly closing a valve in the water supply to the tube and opening a valve in a line which permitted discharge from the inlet of the tube through a front nozzle to atmosphere. Two to three seconds after the valve operation, a power reduction was initiated. The power reduction was in accord with an 800 inhour scram, except for two runs at 1500 inhours. The reverse flow, rear header pressure and eight rod thermocouples, as well as other less important variables, were monitored. A test was continued until rod temperatures of 450 to 500°C were reached or until conditions of adequate cooling were established. With the exception of one run at 750 KW, all runs were with an initial tube power of 1000 KW. The experimental program was terminated by failure of the test section.

1. HW-60164, "Results of Reverse Flow Experimental Tests for C Operational Charge - Discharge Tube at Low Tube Powers", D. E. Fitzsimmons and G. M. Hesson, April 30, 1959.
2. HW-60287, "Interim Report on Laboratory Experiments Investigating Consequences of Failure of Front Hydraulic Fittings in 'C' OCD Geometry", D. E. Fitzsimmons and G. M. Hesson, May 6, 1959.

Conclusions

Although the experiments were of a preliminary nature and the results may be subject to further verification, the data indicate:

1. A tube of "K" I & E geometry operating at 1000 KW can suffer a loss of coolant from a front fitting failure if its rear header pressure were greater than about 30 psig.
2. These results differ from those found for the "C" reactor operational charge discharge geometry tests wherein a rear header pressure of about 10 psig was found to be adequate. In the K geometry tests the high rod temperatures were found to continue increasing even after reverse flows of 10 to 15 gpm were reached. These flows are many times greater than those required for adequate cooling. This behavior is believed to be due to a low velocity stratified flow in the regions where steam quality is low. Such a phenomenon was also found in the "C" reactor geometry tests, but to a much lesser degree.

Experimental Apparatus and Procedures

The experiment apparatus consists of the test section, the water recirculation system and the electrical generating equipment. The test section is a reasonably accurate prototype of a K reactor process tube from the beginning of the active section to the rear header with the exception that the active section is offset from the dummy section to permit the electrical connections to the heater rod. The upstream end of the test section connects to a T, and then through either of two air-operated valves for operation either normally or with simulated front fitting loss. The air valves operated in conjunction and in opposite directions, i. e., when one opens the other closes. For normal operation, the valves connect the test section to the pump discharge and water circulates through the test section and water recirculation system. For front fitting failure simulation, the test section is connected to a K front nozzle, whose inlet port is connected directly to a 3" pipe which in turn discharges at atmospheric pressure to drain.

The heater rod is heated electrically by three DC generators. The power output of the generators was controlled by function generating equipment which was used to control the power in accord with the first 150 seconds of a 500 inhour scram. Two runs deviated from this in that a 1500 inhour scram was simulated. If a run was continued for longer than 150 seconds, the power was held constant at the 150 second value.

The heater rod was of K I & E design, 1.457" OD by 0.39" ID by 23.5 ft. long. The outside diameter was reduced 0.010" to correct for the 0.005" thick insulating varnish on the inside of the process tube. The rod was made of sections of brass and copper-nickel alloys of different electrical resistivities welded together to give a step-wise form of heat generation which approximated a cosine heat generation. Ten thermocouples were imbedded near the top surface at approximately equally spaced intervals along the rod. These gave temperatures related to but somewhat higher than the top surface temperature. Six hold-down pins were inserted through the top of the process tube at approximately equally spaced intervals to restrain upward bowing of the rod.

Loss of a front hydraulic connector was simulated in the following manner: Normal flow was established and the test section operated with 1250 C outlet water temperature until steady state conditions were reached. Water was bypassed into the rear header to maintain its temperature at 100 to 105°C. The air-operated valves were then actuated. Approximately two seconds after the valve actuation a power reduction was started in simulation of a reactor scram. The rear header

pressure, reverse flow and nine rod thermocouples were monitored with high speed recording instruments. The runs were continued until temperatures which were feared might damage the test section or until adequate cooling conditions were reached and all rod temperatures were decreasing.

Experimental Results and Discussion

The experimental results are presented in Table I, which gives the time from front failure simulation to time of scram (start of power reduction), the time to the termination of the run, the range of rear header pressures during the run, the reverse flow at the time of termination of the run, and identifies if conditions of adequate cooling were achieved by the end of the run. It may be pointed out again that the runs were terminated either when rod temperatures were reached which were thought might damage the equipment or when conditions of adequate cooling were reached as was evidenced by decreasing rod temperatures. Not shown in the table is the fact that the hottest points on the rod occurred in the region roughly from the center of the rod to about three-quarters of the distance to the rear header end of the rod.

The first conclusion to be drawn from the data is that if a front hydraulic connector should fail to a tube operating at 1000 KW, adequate cooling conditions were not achieved unless the rear header pressure were about 30 psig or greater. Furthermore, inadequate cooling conditions persisted even though the reverse flow had built up to quite high values, 5 - 15 gpm.

This behavior found in the K reactor geometry differs significantly from that found in C OCD geometry in three respects. First, a much higher rear header pressure is required to achieve adequate cooling in K geometry, 30 psig as compared with 10 at 1000 KW initial tube power. Second, the hottest points on the K geometry heater rod tended to occur further toward the front face than was found on the C rod. And, finally, high and increasing rod temperatures persisted when much higher reverse flows were reached in the K geometry than was found to be the case for the C OCD geometry.

These differences are but a matter of degree, not absolute differences. In both cases, the hot points on the heater rod were found to be in the rear face half near the inlet of the reverse coolant flow where cooling would be expected to be most effective. Furthermore, the heater rod temperatures were found in both cases to persist after flows were obtained which should have provided adequate cooling. The differences between the two geometries is, then, that the high rod surface temperatures in the K geometry existed over a greater length of the rod, and persisted longer and until greater reverse flows were reached. This apparently anomalous position and persistence of high rod temperatures in the C OCD geometry tests was tentatively ascribed to a stratified flow near the inlet of the reverse flow. That is, near the reverse flow inlet, the upper part of the rod is in a stagnant steam atmosphere and cooling is very poor. Farther downstream past the point of significant steam formation, the high specific volume of the steam results in high velocities and relatively good heat transfer. The results found in these K geometry tests are consistent with this hypothesis. The larger annulus of the K geometry would render stratification more severe, i. e., a larger portion of the rod would be in the stagnant steam region and the stratification would extend over a greater length of the rod.

A further comment regarding the test results is warranted. Two runs were made with a simulated 1500 inhour scram compared with the typical K reactor scram of 800 inhours which was used for the rest of the runs. The rod temperatures for these two runs agreed with those of comparable runs using an 800 inhour scram within 10 to 20° C.

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This probably arises from the fact that the post scram heating after 30 to 60 seconds comes from fission product decay alone, which is independent of VSR poison strength.

In conclusion, it may be pointed out that these tests show that a K reactor tube operating at 1000 KW may experience damaging fuel element temperatures as a result of the failure of a front hydraulic fitting if the rear header pressure were less than about 30 psig. This is a somewhat imprecise determination, but it serves to show that quite high rear header pressures are necessary to protect the fuel elements against this type incident. The tests further show that high fuel element temperatures would not result from failure to achieve adequate reverse flow coolant rates, but rather from a two-phase flow mode which provides poor heat removal from the elements. Further tests, both steady-state and transient, are required to develop understanding of the flow and heat transfer processes in the tube under these conditions and to more accurately define the rear header pressure necessary to provide adequate cooling.

G. M. Hesson, Engineer
Thermal Hydraulics Operation

D. E. Fitzsimmons, Engineer
Thermal Hydraulics Operation

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TABLE I

SUMMARY OF EXPERIMENTAL RESULTS

Initial Tube Power KW	Time of Start of Power Reduction, (a) Sec.	Time of Termination of Run, (a) Sec.	Rear Header Pressure, (b) Psig	Flow at Termination of Run Gpm	Adequate Cooling Achieved (c)
1000	1 1/2	28	16-20	12	No
1000	1	90	37-38	Not known	Yes
1000	3	44	Nominal 30 ^(e)	13	No
1000	2	160	34-36	18	Yes
1000 ^(d)	5 1/2	140	34-36	14	Yes
1000 ^(d)	1	40	24-25	6	No
750	3	150	24-25	10	Yes
1000	1 1/2	6000	27-29	10	Yes
1000	Nominal 2 ^(e)	150	21-30	15	Yes

-
- a. Times are from operation of the air operated valves to simulate front pigtail failure.
 - b. Rear header pressures ranged between these values during the course of the run.
 - c. Adequate cooling was considered achieved when and if all rod temperatures were decreasing.
 - d. These runs used a power reduction approximately that of a 1500 inhour scram.
 - e. Malfunctioning instruments prevented determination of these values. The values indicated are the nominal values which were experimentally attempted.

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