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RESULTS OF REVERSE FLOW EXPERIMENTAL TESTS FOR C OPERATIONAL CHARGE-DISCHARGE TUBE AT LOW TUBE POWERS

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RESULTS OF REVERSE FLOW EXPERIMENTAL TESTS FOR C OPERATIONAL
CHARGE-DISCHARGE TUBE AT LOW TUBE POWERS

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D. E. Fitzsimmons and G. M. Hesson

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RESULTS OF REVERSE FLOW EXPERIMENTAL TESTS FOR C OPERATIONAL
CHARGE-DISCHARGE TUBE AT LOW TUBE POWERS

PURPOSE

The purpose of this report is to present the results of laboratory experiments in which coolant water flowed backwards through a "C" reactor process tube with operational charge-discharge front fittings under conditions of typical reactor rear header pressures and post-scrum rear header water temperature and tube powers. This information is of value in planning and interpreting transient experiments investigating the consequences of the rupture of reactor front face piping to a single tube.

INTRODUCTION

A reactor accident with potentially very serious consequences is the rupture of the front face piping to a process tube. Such an accident would result in an immediate scram signal. However, two to three seconds would elapse before the power reduction would start. Furthermore, the power reduction, while rapid initially, is not instantaneous and does not go to zero power, but instead decays in a manner dictated by delayed neutron emission and fission product decay. The only cooling available during this time is from the relatively hot water from the rear header which is forced backwards through the tube by the low rear header pressure. For a period of some time after the incident, until the rear header water has cooled and the power level decayed sufficiently, inadequate cooling conditions exist.

A series of transient experiments were run under C reactor OCD geometry and reported in HW-57740⁽¹⁾. The results of these experiments were somewhat inconclusive except they indicated that very high temperatures could be reached and slug jacket melting might occur if front piping should fail. For a variety of reasons these tests gave conservatively high answers toward defining under what conditions excessively high temperatures might be reached.

As the next step in investigating the consequences of the failure of front face piping a series of steady state tests were planned and performed. The tests were under C reactor OCD geometry and at post-scrum conditions. While the results of a front face piping failure can only be determined by transient experimentation, the steady state experiments were deemed necessary because of the aid they would give in planning succeeding transient experiments and in interpreting the results of such experiments. This document reports the results of the steady state tests.

SUMMARY

Nuclear heating of a 32 slug train was simulated by electrical heating of a 1.464" OD by .375" ID rod in a "C" process tube internally coated with a 5 mil layer of electrical insulation. The flow was directed backwards through the tube and was discharged to the atmosphere from the front nozzle to simulate the loss of a front pigtail. Post-scrum conditions were used: i.e., tube powers from 10 to 200 KW,

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(1) HW-57740 - Results of Preliminary Tests Simulating Rupture of a Front Pigtail on C Reactor, D. E. Fitzsimmons, G. M. Hesson, October 10, 1958.

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rear header water temperatures of ambient to 150°C and flow from 1/4 to 6 gpm. For each set of conditions chosen the rear header pressure required to maintain the flow was measured. In addition eight rod surface temperatures, various water temperature and pressures along the test section were measured.

CONCLUSIONS

The data secured in these tests give rise to several conclusions which will be useful in planning and analyzing the results of future transient tests concerning C reactor OCD geometry:

1. The prime variables in establishing a required rear header pressure are flow and enthalpy of the exit coolant. The enthalpy of the inlet coolant is of second order importance.
2. In general, heat transfer characteristics were good. Extremely high rod surface temperatures were obtained only under two conditions:
  - a) When the water was heated to superheated steam. Under these conditions the steam temperature got high, and, even though heat transfer characteristics were reasonable, the rod got very hot.
  - b) In a few cases, cyclic periods of high rod surface temperatures were incurred near the normal downstream end of the test section; i.e., near the inlet of the reverse flow. This is postulated to arise from cyclic periods of stratified flow wherein the upper part of the rod is in a stagnant steam region and heat transfer is poor.
3. With these data and a knowledge of the decay of the power and rear header water temperature after a scram, it is possible to calculate a reverse flow boiling curve at any time after a scram.
4. From the calculated boiling curves it is possible, for any given rear header pressure, to estimate how long after the front fitting failure conditions of adequate cooling are reached.
5. These results are valid for C reactor operational charge-discharge geometry only. Application of these results to other geometries is probably non-conservative.

EXPERIMENTAL APPARATUS AND METHODS

The experimental apparatus consists basically of an external water recirculation system, an electrical generating system and the test section. The test section consists of a 23.5 ft. long heated section discharging into a dummy section and discharge fittings which are prototypes of reactor geometry. The active section is offset from the dummy section to permit the electrical connections to be made. The piping connecting the active and dummy sections is of a size to have a negligible affect upon the hydraulic characteristics of the system. At the front face end, the hole and annulus connected to 1" pipes which were tee'd together into a 2" pipe approximately 4 ft. long. The 2" pipe connected to a "C" OCD nozzle, the inlet fitting of which was connected to a 3" pipe which, in turn, discharged into a drain at atmospheric pressure.

The experimental tests were made by establishing the flow, rear header water temperature and tube power with the flow going in the reverse direction through the tube and discharging to drain at atmospheric pressure. The rear header pressure as well as other pressures along the test section were measured. The heater rod surface temperature was measured at eight points along the top of the rod. Water temperatures at various points along the test section were also measured.

EXPERIMENTAL RESULTS

The most important of the experimental results is presented in Figure 1. This is a plot of the rear header pressure versus the enthalpy of the exit coolant with parameters of flow and inlet coolant enthalpy. This plot makes apparent that the rear header pressure required to maintain a given reverse flow is determined primarily by the flow and the enthalpy of the exit coolant with a minor affect of the enthalpy of the inlet coolant. As a reasonable approximation, then, the required rear header pressure may be said to be determined by the reverse flow rate and the enthalpy of the exit coolant regardless of the source of heat which established the exit enthalpy.

In general, the rod surface thermocouples did not exceed the calculated corresponding coolant temperature by more than 50°C , indicating that reasonable heat transfer coefficients existed. In a few cases an exception was noted to this. In these cases the rod surface near the rear face end of the active section showed high surface temperatures, usually cyclic. Corresponding to the high surface temperatures of the cycle, the rear header pressure decreased indicating a decrease in the input of heat to the coolant. There was an insufficient number of these cases to permit definition of what conditions are required for their occurrence, except that it occurred only when low rear header water temperatures were used. The reason for this behavior is postulated to be that at the low flows used, the flow is insufficient to fill the tube and a stratified flow condition exists near the water inlet. The upper part of the rod in the stagnant steam area is poorly cooled and the top of the rod gets hot. Farther downstream in the direction of the reverse flow sufficient heat has been added to vaporize some of the water. The high volumes of this vapor causes high vapor velocities, perhaps with a mist flow, and relatively good heat transfer rates result.

DISCUSSION

These tests were made to obtain information to be used in planning and interpreting the results of future transient tests investigating the consequences of the loss of front fitting. The tests show that reasonably good heat transfer rates exist unless a stratified flow condition occurs and, in general, excessively high temperatures are not found until conditions of superheated steam are reached. The tests also give the rear header pressures necessary to maintain a given reverse flow for a variety of tube powers and rear header water temperatures.

To make the rear header pressure requirements more meaningful, a cross plot of the data of Figure 1 is presented in Figure 2, which is a plot of flow versus rear header pressures with parameter of exit coolant enthalpy. As was indicated above in this document, Figure 1 includes a minor effect of rear header water enthalpy. In making the cross plot of Figure 2, a rear header water enthalpy associated with 100°C water was used. This gives a reasonable, but conservative, approximation to the rear header water temperatures following a scram. The dotted lines represent extrapolation of the data from Figure 1.

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Figure 2 is useful because it can be used to construct boiling curves. For a given tube power and rear header water enthalpy, the exit coolant enthalpy can be calculated for any flow. Figure 2 can be entered with this flow and exit enthalpy to obtain the required rear header pressure. Report HW-33870⁽²⁾, supplies information as to tube powers and rear header water temperatures following a reactor scram. This information can be used to construct a boiling curve for the conditions existing at any time after a scram. Such curves were constructed and are presented in Figures 3, 4, and 5 for initial tube powers of 750, 1000 and 1250 KW respectively. Boiling curves are presented for conditions existing at periods of time from 10 to 200 seconds after a scram. A 1500 inhour scram and an initial rear header water temperature of 125°C were assumed. In addition to the boiling curves, a constant enthalpy line at the enthalpy of 100 per cent quality steam is included in these figures.

Figures 3, 4, and 5 can be used to estimate how long after the scram initiated by a front pigtail rupture it would be before adequate cooling conditions are reached. These boiling curves are the demand curves for reverse flow at given times after a scram. The supply curves in this case would be horizontal lines from a given rear header pressure and the intersection of a supply curve and a boiling curves gives the operating point for the given rear header pressure and for conditions of a given time after a scram. It must be emphasized that these intersections do not give the operating points at given times after the scram. Rather they give operating points which would be reached if the scram power and water temperature decay could be stopped and held at the conditions of the given time long enough for steady state to be reached. In other words, the series of such calculated operating points for progressive time give a series of equilibrium points toward which the actual operating point is moving.

At short times after a scram the boiling curves peak above normal rear header pressures. In these cases, there are three intersections of the supply curve and the boiling curve. If one of these were the case following the failure of a front fitting the equilibrium operating point would be the left intersection point. If this intersection point lies to the left of the 100 per cent steam quality line it would be associated with very high slug surface temperatures. If the intersection point lies to the right of the 100 per cent steam quality line, it would be associated with gross steam generation and discharge, but not with high slug surface temperature. The intersections of various supply lines with the 100 per cent steam quality lines give the time required to reach conditions of reasonably adequate cooling conditions as a function of the rear header pressure. Such a relationship is shown in Figure 6.

At longer periods of time after a scram the peaks of the boiling curves lies below normal rear header pressures. In such cases the equilibrium point lies on the non-boiling isotherm, is at flows of several gpm, is not associated with any steam generation, and is associated with slug surface temperatures not much greater than ambient water temperature. The points of tangency of the various supply curves with the peaks of the boiling curves give the time required to reach completely adequate cooling conditions as a function of the rear header pressure. Such a relationship is shown in Figure 7.

(2) HW-33870 - Heat Generation and Total Heat Output from the Pile After Shutdown, S. S. Jones, November 23, 1954.

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Extreme caution must be used in using results from these steady state data to even qualitatively predict the transient course of events following the failure of a front pigtail. Figures 6 and 7 predict how long after the failure conditions are such that adequate cooling could be reached. They do not tell how fast the system will recover once adequate cooling conditions are established. However, in earlier transient runs, reported in HW-57740, under some highly conservative conditions, times in excess of a minute were required before extremely high temperatures were reached. Using this period of time as a criterion together with Figures 6 and 7, it would appear that at initial tube powers of 750, 1000, and 1250 KW would require rear header pressures of 4 to 8, 8 to 12, and 12 to 16 psig respectively to prevent melting of slug jackets. Future transient tests will be directed in these regions.

Heat transfer characteristics were reasonably good except in a few instances where it is believed a stratified flow condition existed. Future transient experiments should be examined to determine, if possible, if the same flow modes exist under the transient condition as were found in the steady state tests. Furthermore, any bowing upwards of the rod from the ribs would aggravate any stratification tendencies and effects. Care must be taken to minimize as much as possible the bowing which occurs with the test section rod.

In conclusion the fact that these tests were made with C reactor operational charge-discharge geometry must be pointed out. This is probably the most conservative geometry inasmuch as it offers the greatest flow discharge area to atmosphere and therefore has the least restriction to flow at the discharge. Any application of the results presented in this document to other geometries is highly questionable.

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Figure 1

Rear Header Pressure Required to Maintain Reverse Flow Through a "C" OCD Tube as a Function of the Enthalpy of the Exit Coolant

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Figure 2

Rear Header Pressure Required to Maintain Reverse Flow
Through a "C" OCD Tube as a Function of the Flow Rate

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Figure 3

Reverse Flow Boiling Curves at Various Times After the Failure of a Front Fitting to a "C" OCD Tube Operating at 750 KW

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Figure 1

Reverse Flow Boiling Curves at Various Times After the Failure of a Front Fitting to a "C" OCD Tube Operating at 1000 PSI

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Figure 5

Reverse Flow Boiling Curves at Various Times After the Failure of a Front Fitting to a "C" OCD Tube Operating at 1250 KW

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Figure 6

Time After the Loss of a Front Fitting to a "C"
OCD Tube Required to Reach Equilibrium Condition
With Less than Superheated Steam

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Figure 7

Time After the Loss of a Front Piping Fitting on a "C" OCD Tube Required to Reach Equilibrium Conditions of Excess Header Pressure

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