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K REACTOR PANELLIT PROTECTION AGAINST PLUGGING
INCIDENTS WITH LOW FRONT HEADER PRESSURE

D. E. Fitzsimmons and G. M. Hesson

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K REACTOR PANELLIT PROTECTION AGAINST PLUGGING
INCIDENTS WITH LOW FRONT HEADER PRESSURE

PURPOSE

The purpose of this report is to present the results of experimental tests made to determine the degree of protection offered by the Panellit system to accidental flow reductions caused by plugging incidents to a K reactor process tube operating at low front header pressures.

INTRODUCTION

The Thermal Hydraulics Operation, HLO, has been and is continuing an extensive series of transient experimental tests to determine the adequacy of the Panellit protection system to guard against the hazards of accidental plugging of the coolant flow system to a single tube. The results of these tests have led to a significant relaxation in the Panellit protection procedures^(1,2). The tests have further shown that these relaxed procedures are still quite conservative.

The tests to date have been made at normal reactor front header pressures, 350 psig in the K reactor case. The possibility exists that conditions may arise wherein it might be desirable to operate the K reactors at a much lower front header pressure, as low as 240 psig. A brief transient experimental program was conducted to determine if there is any justification for the application of Panellit protection concepts developed for 350 psig front header pressures to the case of 240 psig pressures. This document reports the results of these tests.

SUMMARY

Electrical heating of a metal rod was used to simulate nuclear heating of a 32 slug train of I & E slugs in a 23.5 foot long K process tube. The heater rod was made of several different copper-nickel alloy pieces welded together to provide a stepwise approximation to a cosine heat generation. To such a system operating at 500 to 1250 KW tube power, a sudden plug upstream of the Panellit tap was simulated by use of air-operated valves. The front header pressures was maintained at 240 psig. The flow, venturi throat pressure, tube inlet pressure, rod surface temperatures and other variables were monitored with high speed recording instruments. The runs were continued until rod surface temperatures which might damage the experimental equipment were approached. The power was then reduced in accord with a 1500 inhour scram.

CONCLUSIONS

The data show that the concepts developed for a normal K reactor front header pressure, 350 psig, are applicable to front header pressure down to 240 psig. The flow-Panellit pressure-time relationships experimentally determined for the normal front header pressure are valid at the lower pressures.

- (1) HW-51659 - Specification A-020, Process Tube Instability Limits, K.W. Hess, 7/22/57.
- (2) HW-53379 - Method for Empirical Calculations of Instability Limits, K.W. Hess and S. M. Graves, 11/12/57.

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EXPERIMENTAL APPARATUS AND PROCEDURES

The experimental equipment and procedures are described in reports HW-54329⁽³⁾ and HW-56621⁽⁴⁾. The reader interested in the details of the apparatus and its operation is referred to those documents.

The equipment and procedures used in these tests were modified from that of the earlier tests in three respects. First, the plugged condition was set up in a flow system parallel to that used for normal flow. Transition from normal flow to plugged flow was accomplished by the operation of an air-operated valve. Secondly, three hold-down pins were inserted through the top of the process tube to reduce the upward bowing of the heater rod. And finally, the power to the test section was controlled to give a power reduction in accord with a 1500 inhour scram.

THEORY

A qualitative outline of the behavior of a process tube undergoing a flow reduction has been developed elsewhere^(3,4), and will not be repeated here. This discussion will be concerned with the differences in the flow, pressure, time relationships between the case of normal front header pressure and the case of a low front header pressure in event of a flow reduction large enough to result in boiling burnout.

It may be pointed out, parenthetically, that operation at a lower front header pressure than normal increases the flow rate below which boiling burnout could occur. This can be determined from steady state boiling curves⁽⁴⁾ and was not investigated in this program. Also to be pointed out is the fact that the discussion below and the experimental program pertain to plugs upstream of the Panellit tap. The results of a plug downstream of the Panellit tap can be easily calculated from the results of corresponding upstream plugs and in all cases can be shown to be a less severe incident.

The flow-Panellit pressure-time relationships following a plug upstream of the Panellit tap sufficiently severe to lead to boiling burnout were determined for the normal front header pressure case and were reported in HW-56621. The results were presented in graphical form as qualitatively illustrated in Figure 1 which is a plot of Panellit pressure versus the flow squared with the parameter of time after a plugging incident. For the normal front header pressure Case A, the front header pressure is at Point F and the operating point is N. Consider the results of a plugging incident sufficient to reduce the flow to Point P. The immediate consequence of such an incident is to move the operating point to the intersection of line PF and θ_0 . Note that this pressure is not as low as the non-boiling isotherm predicts. Subsequent to this the flow suffers a further self-induced decrease due to steam formation. Coincident with this is a Panellit pressure increase. Line PF describes the course of this flow decrease and pressure increase. The intersections of Line PF and θ lines give the flow-pressure relationship at successively later times. The intersection of Line PF with the film boiling line gives the flow, pressure and time after the plug at which film boiling occurs. Once film boiling is reached, the slug surface temperatures increase at a high rate and jacket melting might be expected to occur in a matter of seconds.

(3) HW-54329 - Results of Transient and Steady State Experiments Investigating Hazards of Flow Reductions in a K Process Tube, G. M. Hesson and W. L. Thorne, 1/2/58.

(4) HW-56621 - Experimental Results of Tests Simulating Plugging of a K Tube with I & E Slugs, G. M. Hesson, D. E. Fitzsimmons, 7/7/58.

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Figure 1

GRAPHICAL ILLUSTRATION OF EFFECT OF LOW FRONT HEADER PRESSURE

Now consider the case of a lower front header pressure, say a pressure at Point F'. The operating point in this case is Point N'. If the tube were to suffer a plugging incident of the same magnitude as was discussed above for the normal front header pressure case, the immediate consequence would be to move the operating point to Point P'. Subsequently, the flow decreases and the Panellit pressure increases as described by Line P'F'. The intersection of Line P'F' with the film boiling line gives the flow, pressure and time after the plug at which film boiling occurs.

Consideration of the above discussion and examination of Figure 1 reveals qualitatively that the results of a plug upstream of the Panellit tap to a tube operating at a low front header differs from that of a plug of corresponding magnitude to a tube operating at a normal front header pressure in three main respects:

- 1) The flow after the plug is less for the low front header pressure case.
- 2) The progress toward film boiling conditions is faster for the low front header pressure case.
- 3) Film boiling is reached at a lower Panellit pressure in the low front header pressure case.

The time-Panellit pressure-flow-film boiling relationships for K reactor I & E geometry have been experimentally determined for the normal front header pressure case. These relationships are reported in HW-56621 as plots of the form of Figure 1. What is not known is whether the qualitative outline of the expected behavior with low front header pressures is true quantitatively. This experimental program was undertaken to determine if the relationships developed for the normal front header pressure case are valid for use for a low front header pressure case.

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EXPERIMENTAL RESULTS

The experimental data are summarized in Figures 2 through 6. Figures 2, 3, and 4 are for 125°C outlet water temperature and tube powers of 750, 1000, and 1250 KW respectively. Figure 5 is for 100°C outlet water temperature and 1000 KW.

The figures are plots of Panellit pressure versus flow with parameters of time. The flow is plotted on a squared scale. Point R is the rear header pressure; Point F is the front header pressure; and Point N is the normal operating point, i.e., 100 psig Panellit pressure and flow necessary to give the desired outlet water temperature. Line NR is the non-boiling isotherm and gives the theoretical minimum Panellit pressure for given plugs upstream of the Panellit tap. The zero time line gives the minimum Panellit pressures actually attained.

Figure 6 compares the results of one run done at a normal front header pressure of 350 psig with the results of a comparable run done in the program investigating the low front header pressure case. This is a plot of Panellit pressure versus time, and is included to give an indication of the reproducibility of experimental data obtained from different test sections at different times.

DISCUSSION

Of most importance, the data from these tests show that under the conditions used, 100 psig initial Panellit pressure, 240 psig front header pressure, 750 to 1250 KW tube power, outlet water temperatures up to 125°C, and plugs resulting in flow reductions down to 3 gpm, Panellit protection is offered against plugs upstream of the Panellit tap, even with a range of 100 psi between the high and low Panellit trips. The Panellit pressure was shown to have passed through either the low trip or high trip in every case and actually through both trips in most cases. These results concur with those obtained for the normal front header pressure.

The second conclusion to be drawn from these tests is concerned with the validity of applying the time relationships developed for the normal front header pressure case to the case of the low front header pressure. A comparison of Figures 2, 3, 4 and 5 with the corresponding figures for the 350 psig front header pressure⁽⁴⁾ reveals that the time sequence of events obtained in this investigation is actually slightly slower than would be calculated using the data obtained for the 350 psig pressure case. This is illustrated in Figures 7 and 8 which are plots of Panellit pressure versus time from the experimental data and from calculations based on the normal front header pressure results. Thus, while decreasing the front header pressure increases the rate of progress of the transient, the rate of increase is not as great as would be calculated from normal pressure data. More important, the start of film boiling lines for the two front header pressure cases are reasonably in agreement. The conclusion may be made, then, that application of the data for normal front header pressure experiments to cases of front header pressures between 240 and 350 psig is valid.

The data from these tests differ from those of the normal front header pressure case in one respect. Namely, the minimum Panellit pressures attained in these tests were more nearly in agreement with the theoretical minimum than were those attained in the normal front header pressure tests. This was also true in the case of the one run done in these tests with a 350 psig front header pressure, as is shown in Figure 6. The reason for this is not known. However, in the report on the normal front header pressure tests, the reason for the discrepancy between the actual and theoretical minimum Panellit pressures was postulated to be caused by the high top-of-annulus water temperatures arising from the upward bowing of the heater rod. In these tests, hold-down pins were used to restrain the bowing, thus mitigating the effect of the high top-of-annulus water temperatures.

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Apart from the difference between minimum Panellit pressure, Figure 6 shows that there are no significant differences between the test apparatuses used in these experiments and those for the normal front header pressure case. The data are reasonably reproducible.

Report HW-56621 discusses in some detail the reliability of experimental results and the general conclusion was reached that the experimental apparatus is a reasonable representation of a reactor process tube and inaccuracies in the representation are such that the experimental results are conservative. These same conclusions apply to these tests. It may be pointed out, however, that the time lines reported for the normal front header pressure case are more reliable than the ones reported here, since they were determined from a greater number of runs.

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Figure 2
Panellit Pressure Responses to a Sudden Plug in K I & E Geometry at Low Front Header Pressures

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Figure 3

Panellit Pressure Responses to a Sudden Plug in K I & E Geometry at Low Front Header Pressures

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Figure 5

Panellit Pressure Responses to a Sudden Plug in K I & E Geometry at Low Front Header Pressures

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Figure 6

Comparison of Results from Current and Previous Experimental Apparatuses

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Figure 7

Comparison of Experimental and Calculated Panellit Pressure Behavior at 240 Psig Front Header Pressure

Figure 8

Comparison of Experimental and Calculated Panellit Pressure Behavior at 240 Psig Front Header Pressure

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