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INTERIM REPORT ON TESTS SIMULATING THE
TRANSIENT RESPONSE OF INDIVIDUAL PROCESS
TUBES TO INADVERTENT PLUGGING

by

A. Batch, G. M. Hesson, W. L. Thorne, K. G. Toyoda

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PURPOSE

This report presents some high spot results from the latest experiments concerning the protection afforded by the Panellit system against hazards associated with the inadvertent plugging of a process tube.

INTRODUCTION

The Panellit pressure sensing system is depended upon for the primary protection against high uranium temperatures which result when individual process tube flow is reduced due to inadvertent tube plugging. The upper limit of this protection which the Panellit system provides has never definitely been determined. As indicated in previous reports^{1,2} the degree of actual protection is probably sufficient to justify tube powers considerably higher than those now being permitted at the present reactors.

Current Panellit protection procedures, termed instability limits, come from calculations based on steady state experiments. However, the actual conditions in a process tube following a plugging occurrence sufficient to cause unstable flow are transient rather than steady state, and cannot be determined with great precision except by transient state experimentation. As a result, a program was initiated by the Thermal Hydraulics Operation of HLO to perform a series of transient heat transfer experiments which would define the process tube response to (1) rapid plugging in the process tube assembly, (2) slow plugging in the process tube assembly, and (3) power excursions above normal of varying amounts. Transient heat transfer experimentation on a large scale is not common and many difficulties have been encountered. After preliminary runs were made and reported^{1,2} a further series of runs were planned and run which would include K as well as BDF type data and would define more closely the upper limit of the Panellit protection. During the test runs, data from these transient experiments are recorded on high speed recording instruments, each of which has a calibration which is subject to change regardless of the efforts expended by the experimenters. This means that checking and presenting the data in final form is a monumental job which requires considerable time. However, the results of these experiments are of considerable current interest; and, for that reason, certain high spots of the data are presented here at this time. Some discrepancies have been found in the data and as yet are unexplained; therefore, the results are presented with no claim to their accuracy. Complete results of all runs will be presented at a later date.

SUMMARY

An experimental assembly was used which utilized D.C. electrical heating of a metal rod to simulate nuclear heating of a 32 slug train of standard solid slugs in BDF and K geometry. Simulated rapid plugging experiments were performed on the BDF and K geometry by suddenly closing a throttle valve upstream

1. HW-48519, G. M. Hesson and W. L. Thorne, "Pressure, Flow, and Temperature Responses to a Rapid Plugging of a Process Tube", February 18, 1957.
2. HW-49813, G. M. Hesson and W. L. Thorne, "Preliminary Experimental Results of Pressure and Temperature Response to Slow Plugging of a Process Tube", April 25, 1957.

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of the Panellit tap. Simulated slow plugging experiments were performed using the BDF geometry by impressing a 5 to 20 per cent step increase in tube power on a tube in which the flow had slowly been throttled to the point of incipient unstable flow.

In both types of tests, steam formation lead to further self-induced flow reductions with resulting increases in the heater rod surface temperature. When it appeared that the temperature of the heater rod was increasing at a rate sufficient to exceed 400 °C, power to the heater rod was reduced at a rate corresponding to a pile scram. During each test, data was recorded on individual strip charts for values of front header pressure, Panellit tap pressure, tube inlet pressure, tube outlet pressure, rear header pressure, tube outlet temperature, and a heater rod surface temperature.

Test results from a selected number of the runs are shown in Figures 1 through 8 which report flow, Panellit tap pressure, and heater rod surface temperature as a function of time. In each figure the point marked scram indicates the initiation of the actual power decrease. This does not allow for the approximately 2 1/2 second time delay between trip and start of power decay as experienced at the reactors. The conditions for each figure are as follows:

Figure Number	Process tube Type	Initial Power	Type of Plugging	Initial Outlet Water Temp.	Per cent Flow Reduction
1	BDF	750 KW	Fast	103 °C	71
2	BDF	750	Fast	128	63
3	BDF	1000	Fast	126	80
4	BDF	1000	Fast	125	62
5	BDF	1250	Fast	155	64
6	BDF	1250	Slow	176	---
7	K	750	Fast	121	63
8	K	750	Fast	120	87

CONCLUSIONS

If it is granted that the laboratory tests constitute an effective and accurate simulation of a similar event occurring in a reactor process tube, the following conclusions may be made:

1. For the case of the fast plugging in both the BDF and K tubes, the change in Panellit tap pressure from initial was sufficient to pass through the low trip and cause a power shutdown in time to prevent the heater rod surface temperature from exceeding 420 °C even though the low trip was set as much as 100 psi from the initial operating pressure. For the BDF tube this was true for tube powers of as high as 1250 KW, initial outlet water temperatures up to 148 °C, and flow reductions from 60 to 80 per cent of initial. For the K tube this was true for a tube power of 750 KW, initial outlet water temperature of 120 °C, and flow reductions from 63 to 87 per cent.

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2. For the case of fast plugging in the BDF tube, the change in Panellit tap pressure from initial was also sufficient to pass through a high trip even though the trip was set as much as 70 psi above the initial operating pressure. However, for the case of 1250 KW tube power and initial outlet water temperature of 148 °C, it was undetermined as to how high the heater rod surface temperature would rise should there be a 2 1/2 second delay between a high trip and start of effective power decrease.
3. For the case of fast plugging in the K tube, it is doubtful if the change in Panellit tap pressure from initial was sufficient to pass through a high trip as well as a low trip.
4. For the case of slow plugging in the BDF tube, the increase in Panellit tap pressure was sufficient to pass through the high trip and cause a power reduction in time to prevent the heater rod surface temperature from exceeding 400 °C even though the high trip was set as much as 100 psi above the value at incipient instability (i.e., start of the test.) This was true for a tube power of 1250 KW and an outlet water temperature at start of the test of 176°C.
5. A comparison of Figures 1 and 2 shows that the effect of higher initial outlet water temperature is to cause an earlier response of the systems to temperature and pressure increases after the initial reduction of flow.
6. A comparison of Figure 2 and 4 shows that the effect of higher initial power level is to cause a faster response of the system to temperature and pressure increases after the initial reduction of flow.
7. From the results of the experiments it appears that the Panellit system as it is now applied at BDF type reactors provided satisfactory protection for sudden plugging occurrences over the range of conditions studied experimentally. It also appears likely that adequate protection would exist even if the present Panellit system requirements were relaxed significantly.
8. Further tests, and especially slow plugging type tests, should be run on the K type tubes before final conclusions are made on the limit of the Panellit system to provide protection at the K reactors.
9. Tests of a similar sort should be run on C type process tubes.

DISCUSSION

The experimental equipment was essentially the same as described in HW-48519 under the heading of experimental equipment.

Tests involving rapid plugging of the process tube were simulated in the following manner. Initial conditions were established and the system allowed to reach steady state. The tube flow was then suddenly reduced by rapidly partially closing a valve upstream of the region of heat generation. The degree of closing was fixed by a pre-set stop on the valve. Flow, front header pressure, Panellit tap pressure, tube inlet pressure, tube outlet pressure, rear header pressure, tube outlet temperature and heater rod surface temperature were monitored by individual high speed recording instruments. Each run was continued at full power until it appeared that the temperature of the heater rod surface would exceed 400 °C, after which a power decrease was initiated. The power to the heater rod during the power decrease was controlled by a cam to simulate neutron flux decay during a pile scram.

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Test involving slow plugging of the process tube were simulated in the following manner. Initial conditions were established at a flow pre-determined to be incipient instability and the system allowed to reach steady state. The power was then suddenly increased 5 to 20 per cent to simulate the increase in reactivity associated with steam formation. Measurements and power decrease were then the same as outlined for the fast plugging tests.

Results of a few selected runs are shown in Figures 1 through 8 where flow, Panellit tap pressure, and the temperature of the heater rod surface, are shown as a function of time. The conclusions stated earlier in this report were obtained directly from these figures. The results shown are typical representatives of all of the runs made. A total of 90 separate runs have been made in this last series of tests. Of these, 50 apply to BDF type reactors, 13 apply to K type reactors, and 27 were made to determine specific characteristics of the apparatus. Results of all of the runs as well as a complete analysis will be reported at a later date.

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APPENDIX

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Nomenclature used in Figures 1 through 5, 7 and 8

- F_i Initial flow prior to the sudden plug, gpm
 F_f Flow immediately after insertion of the plug, gpm
FH Front Header pressure, psig
Q Tube power, KW
 T_{oi} Initial outlet water temperature prior to the sudden plug, °C

Nomenclature used in Figure 6

- F_i Flow prior to start of unstable flow, gpm
FH Front Header pressure, psig
 Q_i Tube power prior to unstable flow, KW
 Q_f Tube power after the tube power increase used to initiate unstable flow, KW
 T_{oi} Initial outlet water temperature prior to start of unstable flow, °C

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TIME (seconds)

Figure 1

Response of a BDF Process Tube to Sudden Flow Reduction

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Flow (gpm)

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TEST DATA

F_i - 25.9 gpm
F_f - 9.6 gpm
P_H - 525 psig
T_{ol} - 128 °C
Q_{ol} - 750 KW

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Pressure (psig)
Temperature (°C)

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TIME (seconds)

Figure 2

Response of a BDF Process Tube to Sudden Flow Reduction

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Pressure (psig)
Temperature (°C)

Figure 3
TIME (seconds)

Response of a BDF Process Tube to Sudden Flow Reduction

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Pressure (psig)
Temperature (°C)

TEST DATA

F₁ - 34.3 gpm
F_f - 13.0 gpm
F_H - 525 psig
T₀₁ - 123 °C
Q - 1000 KW

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TIME (seconds)

Figure 4

Response of a BDF Process Tube to Sudden Flow Reduction

Pressure (psig)
Temperature (°C)

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TEST DATA

F₁ - 33.1 Gpm
F_f - 12.0 Gpm
P_H - 525 psig
T_{o1} - 148 °C
Q_{o1} - 1250 KW

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Response of a BDF Process Tube to Sudden Flow Reduction

Figure 5

Flow (gpm)

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TIME (seconds)

Figure 6
Response of a BDF Process Tube to Slow Flow Reduction

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TEST DATA

F_i - 27.4 gpm
F_f - 10.0 gpm
P_H - 390 psig
T_{o1} - 121 °C
Q - 750 KW

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TIME (seconds)

Figure 7

Response of a K Process Tube to Sudden Flow Reduction

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Figure 8

Response of a K Process Tube to Sudden Flow Reduction