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BULK OUTLET TEMPERATURE LIMITS AND INCREASED REACTOR POWER LEVELS

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BULK OUTLET TEMPERATURE LIMITS

AND INCREASED REACTOR POWER LEVELS

INTRODUCTION

In a recent report by J. R. Young, means of circumventing the present bulk temperature limits are suggested. These have definite merit but do not present an over-all picture of the problem. Therefore, this bulk temperature limit is reviewed in order to place the problem in its full perspective. A program of action is suggested that should lead to:

1. Revised operating conditions and process piping to obtain higher power levels at the same bulk outlet temperature.

2. The completion of production tests to permit higher bulk outlet temperatures with no significant changes in reactor piping, or

3. Redesign of the effluent system to eliminate bulk temperatures as a reactor operating limit.

SUMMARY

The current reactor bulk outlet temperature specifications will actually limit reactor power levels three to four months in 1958 and possibly all year in 1959. Since a reactor bulk temperature increase of 1° C at constant flow represents increased production valued at about $7,700 per month per old reactor, or $16,300 per month per K reactor, there is real incentive for either raising this limit or circumventing it by changes in the reactor system operation or piping.

Two interim measures for increasing this production are:

1. Increasing the fringe zone reactor flow by opening the orifice diameter.

2. Raising the bulk outlet temperatures under carefully controlled production test procedures.

Increasing the fringe zone flow is relatively simple, but its value is not clear cut, and depends upon the interaction of process pump flow capacity and the central zone and fringe zone flow resistances. Since the central zone flow resistance is in the process of being changed, a power level increase by this method may be worthwhile in 1958 and of little value in 1959.

The present bulk effluent temperature limit is based upon a theoretical balance between the value of production gains attributed solely to this limit and the estimated costs of possible effluent system damage. In view of the theoretical nature of this limit, a production test is proposed to explore the possibilities of increasing it. The first part of this testing program will serve to substantiate the current limits through verification of the major reactor temperature transients. Upon completion of this and a possible bulk temperature limit revision, a further production test is proposed to investigate further outlet temperature increases. Power level gains from this latter test are considered temporary because of the basic undesirability of operating the reactor continuously near to the effluent line failure conditions.

Three methods of circumventing this bulk temperature limit on a permanent basis are recommended for study. These are:

1. Add cold water quench to the bottom of the reactor risers.

2. Vent the liberated gas and vapor from the top of the downcomer to the exhaust air stack.

3. Completely pressurize the effluent piping system.

The most desirable of these methods cannot be selected until a study of their feasibility and value is completed. Such a study is outlined in this report along with the probable general advantages and defects of each. However, we can say that the pressurization method, although costly, is the only one that will allow really significant increases in reactor production and will eliminate the many problems now associated with bulk temperature limits.

In addition, a program of laboratory testing is outlined for securing basic experimental data pertinent to reactor bulk outlet temperature limits and the system flow stability.

DISCUSSION

Problem

Specifically, our problem is to determine how we can safely raise the reactor bulk outlet temperatures to increase reactor production or obtain the equivalent increased production by other means within the present temperature limits. It may be possible to operate a reactor at 100° C bulk outlet with only minor operating problems. On the other hand, our present limited knowledge indicates, and safety dictates, lower bulk temperatures. Therefore, bulk temperature limits should only be increased under carefully controlled Production Test conditions. The production value of such an increase, however, amounts to $7,700 per °C per month at an old reactor, or $16,300 per °C per month at a K reactor. This supplies the incentive for a detailed study of this problem.

Actually, the true production value of increased bulk outlet temperatures is by no means a simple clear-cut picture. A two-degree increase in the bulk effluent temperature limit may result in actual increased production only 3 to 4 months of the year. This would be in the summer months when the high inlet water temperatures yield the limiting bulk temperature at power levels only 80 percent of the winter time bulk limit values. However, in the case of fuel rod ruptures and corrosion limits, the actual tube power level is controlling. Therefore, the most probable situation is operation on bulk limits during the summer months and on rupture and corrosion limits in the winter. This considerably reduces the potential annual value of increased bulk outlet temperatures.

In addition to this condition of limited application of a bulk temperature increase, we have the further problem that the increased costs at the elevated outlet temperatures come not only from damage to the reactor effluent system, but also from increased fuel rod ruptures and increased process tube corrosion. Consequently, these and any other increased reactor costs associated with the higher power levels considerably decrease the value of the production increase that we can associate with increased bulk outlet temperatures.

An over-all economic evaluation of this problem has not been made. But, depending upon the nature of these costs, the obvious situation of increased reactor production value with increased bulk temperatures may occur through only a limited range of temperature increases.

History

The original operation of the Hanford reactors was under the concept of "Excess Header Pressure."[1] This required that sufficient header pressure be available to sweep steam from a process channel if some temporary condition should cause it to be formed. This requirement suffered from the implicit assumption that the condition causing boiling was very transient. It considered that essentially full excess header pressure was available to remove the steam in a matter of a few seconds after its occurrence in the process tube. Because of the inherent instability of the reactor with respect to boiling, i.e., the gain in reactivity upon loss of water to a tube, tending to cause vaporization in surrounding tubes, etc., the prevention of outlet boiling was a cardinal requirement of reactor operation.

In 1954 the excess header pressure requirement was relaxed to a requirement of trip-before-instability.[2] The Panellit gauges were revised and their maintenance improved. As improved slugs and water with improved corrosion properties were developed and as the graphite expansion problem was alleviated, the reactor power levels were raised to the point where tube outlet water temperatures approached 100° C. The bulk outlet temperatures under transient conditions approached saturation temperatures at the top of the downcomer and the problem of bulk water boiling was considered.[3]

It was pointed out that numerous potential problems were involved at 100° C bulk outlet temperatures; namely:

1. Unstable bulk flows at 100° C that might cause tube boiling.

2. Cavitation erosion and fatigue failure at the Parker fittings and in the rear cross-headers.

3. Radioactivity problem from escaping "hot mist."

4. Loss of power level measurement wherever two phase flow occurred upstream of the outlet temperature monitor.

As the program of increased reactor flows and power levels continued, the 100° C bulk temperature problem shifted in emphasis from consideration of over-all effluent problems to the problems of the reactor tubes and charges. It

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(1) W. K. Woods and H. Worthington, "Boiling in the Pile," DUH-10169, April 1, 1943.

(2) K. G. Toyoda, "Tube Temperature Limits by Trip-Before-Instability Concept," HW-32151, June 16, 1954.

(3) S. S. Jones, "Temperature Limits of the Pile Effluent System," HW-31733, May 5, 1954.

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was concluded in a survey[4] that a failure in the effluent system would create no serious problem and that sufficient data could be obtained in 4 to 6 weeks to operate D-Pile at 100° C on a Production Test basis.

Fundamentally, however, in the design of all the Hanford reactors the criteria of no bulk boiling has existed[5] [6] and in a more recent program report the unsolved problems with respect to operation at 100° C bulk temperature are again emphasized.[6]

To summarize the history of this problem, its development has consisted of a gradual approach to the point where bulk boiling considerations may soon actually limit power level combined with a wide variation in concern about the problems that exist and finally, very little progress towards the determination of the actual magnitude of these problems and their best solution.

Potential Problems

At the present time the following problems are foreseen as potential stumbling blocks to safe or satisfactory operation at 100° C. Other problems may appear as this program proceeds toward the achievement of this goal of 100° C bulk outlet temperature.

1. Pressure Surges

   We have made some top-of-downcomer pressure measurements that indicate that the system pressure at this point is essentially at atmospheric pressure at bulk effluent temperatures up to 95° C. Our measurements, however, were made with high inertia manometers and do not give us any accurate picture of high frequency vibration or pressure surges. In addition, as the effluent temperatures reach the minimum effluent boiling point, the vaporization effect may produce marked pressure surging conditions. Such surges increase the probability of damage to this structurally weak effluent piping system. At the C, DR, and H reactors this situation is further complicated by suction heads in the discharge line to the downcomer that causes the minimum effluent boiling point to be less than 100° C.

2. Bulk Effluent Temperature Measurement

   At the present time, the bulk effluent temperature is measured downstream of the reactor downcomers. Whenever vaporization occurs at the top of the downcomer with the release of vapor to the atmosphere, the measured bulk temperature is in error. This error consists in the liquid cooling produced by the flashing of water to steam. In addition to this error, we have the problem of a 15 to 30 second time-lag between a coolant temperature change at the reactor and the indication of this change in the control room. The various problems posed

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(4) W. D. Gilbert and S. Goldsmith, "Pile Operation at Higher Bulk Outlet Temperatures," HW-36415, April 29, 1955.

(5) M. H. Russ, "Design Criteria," Vol. 1, Rev. 1, B-C Areas, HW-30401 V-1, R-1, September 15, 1955.

(6) L. P. Bupp, V. R. Cooper, F. W. Woodfield, "100 Areas Process Improvement Program for Period April '56 - Sept. '56," HW-43040, March 31, 1956.

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by this flashing error and time-lag are discussed in the following sections.

3. Effect of Reactor Operating Transients

a. Electrical Outage Effects

The loss of electrical power to a process pump or pumps causes an unavoidable outlet temperature surge as the process flow decreases before the reactor can be effectively scrammed. By requiring a rapid electric trip of the reactor for the loss of power to any pump or pumps, this transient temperature surge can be reduced to a minimum. However, it will always occur and must be allowed for in establishing reactor bulk outlet temperature limits. If this surge carries the effluent temperature above 100° C, then two-phase flow with a large increase in fluid velocity will occur or the system will become sufficiently pressurized to suppress this boiling. The worst condition that might occur would be an intermittent occurrence of both of these effects. This would present us with both momentum and pressure stress effects on the low strength effluent system.

b. Power Level Surges

These can occur by inadvertent control rod movement, or poison discharge, by excessive tube power levels and/or boiling in the central zone. They again pose the problem of boiling and/or pressurization in the effluent system. With power level surges we have the added problem that immediate reactor scram will not be obtained. At the present time there would be a 10 to 15 per cent increase in power level before the reactor would receive a scram signal. This means that power level surge effects are important parameters in considering reactor bulk temperature limits. This is described in detail in a report to be issued,(7) and is summarized in a recent document.(8)

c. Power Level Distortion

In addition to the problem of transient power level surges, we have the further problem of power level distortion. Under certain operating conditions, a considerable difference can exist between the total power level of the tubes on the near and/or the far side of the reactor. This means that for a constant bulk outlet temperature as measured at the present location beyond the downcomer, we can have a considerable difference in the

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(7) S. S. Jones "Preliminary Analysis of Bulk Outlet Temperatures," HW-51327.

(8) S. S. Jones, "Reactor Bulk Outlet Temperature Limits," HW-52793, March 6, 1958.

temperature of the water leaving the near and far risers. Since we dare not assume any temperature mixing in the short pipe run between the near riser and the downcomer, we are limited by the highest riser temperature. At the present time this is not measured, and little information is available concerning the variation in the outlet riser temperatures with reactor operation. Certainly, before proceeding with a production test to raise bulk outlet temperatures, the individual riser temperatures must be determined.

d. Reactor Flow Decreases

Aside from pump problems reactor flow decreases can occur either through process line valving or piping damage. The valve closing rates are slow enough so that rapid transient problems do not exist. However, unless the proposed bulk water temperature monitor system(9) is in effect, we can have process flow decreases of as much as 5 to 10 per cent before a Panellit trip of the reactor. This would cause a corresponding increase in the bulk effluent temperature. At the present time, no power level allowance is made for the possible effects of a process line rupture. This represents a calculated risk that involves a very low probability of failure combined with the possibility of considerable reactor damage. This risk has been assumed on the basis of the importance of plutonium production.

4. Strength of the Effluent System

A detailed analysis is in progress both of the strength of the effluent system and the pressurization effects produced by boiling in the effluent system at bulk temperatures in excess of 100° C.(10) These calculations indicate allowable working pressures of 1 to 2 psig and maximum bulk temperatures of 104° C at the B, D, F, and K reactors, and somewhat less at the C, DR, and H reactors.

There are four critical points with respect to boiling in the effluent system.

a. The approach section to the downcomer.

b. The top of the downcomer.

c. The downcomer first cascade tray.

d. The bottom walls of the downcomer.

In the approach section to the downcomer at all but the F-Reactor, the effluent makes a 90° bend from horizontal flow to vertical flow down into the top of the downcomer. This introduces considerable momentum forces upon the elbow that turns the flow downward. As soon as boiling

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(9) S. S. Jones, "Proposal for Improved Control of Bulk Effluent Temperature Surges," HW-55486, March 25, 1958.

(10) O. E. Adams and S. S. Jones, "Critical Flow and Allowable Working Pressures at the Top of Hanford Reactor Downcomers," HW-54447 to be issued.

occurs with two-phase flow, we have a relatively large increase in velocity with the same mass flow rate. This in turn means a significant increase in momentum forces on the elbow. Static stress calculations of this value indicate allowable working pressures in the range of 1 to 3 psig, which corresponds to 2 to 5° C above the saturation pressure. Effluent system calculations have shown that after an initial transient boiling effect, pressurization will occur with liquid phase flow into the downcomer.

Unfortunately, the top-of-downcomer at the B, C, D, DR, F, and H reactors is itself a very weak point and it also has allowable working pressures in the range of 0.5 to 2 psig. Thus, the pressurization that will relieve the elbow stresses may very well cause the top-of-downcomer to fail. This will eliminate the pressurization and again produce severe entrance elbow stresses if the bulk outlet flows and temperatures are still at full level.

A further point of potential difficulty is the downcomer top cascade tray. This is present at all but the K reactors, and although there is controversy as to its probability of failure, there can be no question as to the serious nature of such a failure event. Such a failure would probably take out all the successive cascade trays and tend to stop the effluent flow. This would severely damage the downcomer walls; and just where the water would go from here in uncertain, but it could cause considerable reactor damage. Stress calculations on these downcomer walls have indicated maximum allowable working stresses equivalent to that produced by a static head of water standing in the downcomer to an elevation of 20 to 30 feet above the reactor zero level. At the F reactor the static level is already close to the limit because of the water back-up in the up-hill line to the retention basin. It would seem desirable at this reactor to take advantage of the possible syphon action in the discharge section of the effluent line from its high point down to the retention basin. At the present time there is an open vent at this point which prevents the discharge syphon action from reducing the static level in the downcomer.

To summarize our current knowledge of this effluent piping system, we may say that it is fundamentally weak, that its failure in itself should not cause reactor instability or burnout. However, the damage caused by 72,000 to 170,000 gallons of water per minute falling 50 feet onto alluvial fill is not very encouraging with respect to building and personnel safety. Consequently, considerable conservatism is recommended with respect to reactor operation that would cause severe effluent system damage.

5. Radioactivity Hazards

One further problem that may exist is the radiation hazard of large quantities of steam coming off the top of the downcomer immediately after its exposure in the reactor. A conservative calculation of this effect could certainly indicate the magnitude of this hazard and whether any special precautions would be necessary. Already, over-all building contamination is experienced at H reactor when they attempt to use their far downcomer which apparently has accumulated various leaks.

Besides radioactivity problems at the top of the downcomer, we also have the problem of increased radioactivity at the retention basins. This could no doubt be handled by appropriate personnel restrictions adjacent to these basins.

This represents the problems that are foreseen as potential difficulties in obtaining the desired 100° C bulk outlet temperature. Ways to circumvent all of these problems appear feasible, but the first step is to establish the actual magnitude of each one. Only after this has been done for these problems, plus any additional ones that appear as this program progresses, can we reach sound conclusions as to the best manner to proceed toward our 100° bulk outlet goal.

Possible Solutions

Although the full picture of the problem involved in achieving this 100° C bulk outlet temperature is not known, it seems desirable to examine possible solutions. This should serve to expedite the program of reaching the 100° C goal. It should also present a clearer picture of the problems by indicating both the operating difficulties involved and the manner in which they can be controlled or eliminated. For instance, the problems of 100° C bulk outlet temperatures can be eliminated by quenching with cold raw water. Therefore, a number of different means of achieving the desired goal of increased production are presented and analyzed in the following section.

1. Increase in Bulk Outlet Temperatures Under Production Test Conditions

Because the present bulk temperature limits are based upon a considerable amount of theory with respect to the effects of various reactor operating conditions upon the effluent flows and temperatures, it will be very much in order to experimentally verify the magnitude of these effects before proceeding with the main test of increasing the bulk outlet temperatures. Thus, the following preliminary program is recommended.

a. Test Location

In choosing the reactor it is essential that it have maximum flexibility of operation and two downcomers. Therefore, C or H reactor will be selected. DR fits this requirement, but its downcomer is somewhat weaker and therefore undesirable for initial testing.

b. Test Instrumentation

Because this is an exploratory test to determine the operating problems and possible effluent system damage associated with higher bulk outlet temperatures, very complete reactor instrumentation will be required. The following instrumentation changes or additions to the reactor are anticipated:

(1) New bulk outlet temperature sensing elements.

(2) Transducer type pressure sensing elements to be installed in the cross-over line and the downcomer.

(3) Install five solid downstream dummy charges in widely spaced central tubes and install new high sensitivity (< 1 sec) calibrated tube outlet temperature elements. The temperatures of these elements should be simultaneously recorded on a high speed oscillograph or similar instrument during the transient tests.

(4) Install numerous strain gage elements at critical points in the cross-over and downcomer. Again these gages should be simultaneously recorded during the transient tests.

(5) Install appropriate vibration instrumentation on the cross-over and downcomer to monitor any dynamic stress conditons.

(6) Install any required upper cross-header orifices to handle the problems of possible cross-header boiling because of local high temperatures.*

(7) Install braces under the top cascade tray in the downcomer to positively ensure that this tray failure does not occur.

c. Preliminary Tests

The following preliminary tests should be made with this completely instrumented reactor to confirm our present theories with respect to reactor transient effects and effluent system conditions:

(1) BPA Outage

(a) During the first ~ 30-hour reactor shutdown after completion of the described instrumentation, complete instrumentation data should be obtained.

(b) Upon start-up, the reactor should be brought up to 45 to 55 per cent of full level as rapidly as is permitted and then held at this level for 2-3 hours.

(c) At this time, the electrical power to the 190 Annex process pumps should be tripped and the resulting BPA outage transients followed by the special reactor instrumentation.

(d) The results of this test should be studied carefully and compared with the theoretical results of HW-51327.[7]

(2) Process Pump Trip-Out Test

The flow characteristics and frequency of this transient are sufficiently different from that of a BPA outage, that two

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(7) Op. Cit. page 7.

* The cross-header orifice requirements will be established by laboratory tests discussed on page 18.

tests are justified; particularly when they both can be made with only minor production losses. The suggested procedure for this test is:

(a) At the time of the first scheduled reactor outage after completion of the over-all test instrumentation, the reactor should be shut down by first tripping the power to a process pump which has its reactor trip signal by-by-passed.

(b) One minute later, the reactor should be scrammed if it has not already been shut down by the low-pressure trip of a process tube Panellit gage.

(c) Again, the test results should be studied and compared with theory.

(d) A review of thest two tests should indicate whether any changes can be made in the bulk temperature limits within the present basic analysis.

d. Experimental Bulk Water Temperature Increase

This test proposes to carry a reactor up into a range of operation where possible effluent piping damage may occur. A detailed analysis of this problem has indicated that even with conservative estimates of the gross costs associated with higher temperature operation, there is strong indication that higher temperature operation will be worthwhile, at least on a short-term basis. Consequently, this production test could serve to permit a production increase during the period of study and development necessary to make more permanent and satisfactory increases in the effective bulk temperature limit.

The anticipated test procedure would be as follows:

(1) Obtain both "cold" and "hot" instrumentation base-points readings.

(2) With the reactor at equilibrium full flow, and 90° C bulk outlet temperature, run a controlled power level surge up to 96° C and down to 92° C over a 10 minute elapsed-time period.

(3) After complete analysis of the experimental data, i.e., 24 to 48 hours, repeat this power surge test from 92° to 98° and back to 94° C.

(4) Repeat these transients for steps of 94 to 100, 96 to 102, and 98 to 104° C, with careful data analysis after each step.

(5) Stop testing whenever data is obtained that indicates the probability of effluent system damage.

(6) If this testing procedure is successful up to 104° C, permit a bulk water temperature increase from 94° to 96° C.

(7) After a months' successful operation at this new temperature, these transient tests should be repeated up to 110° C and reactor bulk outlet temperatures of 98° C permitted if this second set of tests is successful. Because of the inherent problem of unavoidable temperature surges, it will always be necessary to operate the reactor some x degrees below the peak allowable value. The purpose of this test is to evaluate the problems associated with these transients and to establish both a peak temperature limit and a reasonable value for x (the required decrease in nominal bulk limit below this peak temperature).

2. Fringe Zone Quenching

As suggested by J. R. Young,[11] it is possible to increase reactor power level without an increased bulk outlet temperature by increasing the water flow through the fringe tubes and allowing a small increase in the outlet temperature and power level of the central zone tubes. In considering this proposal, the following basic properties of the system are pertinent:

(a) With a fixed bulk outlet temperature any given increase in total reactor flow will give a constant increase in production, no matter how the reactor flow is distributed, provided other tube limits are not exceeded.

(b) The increase in reactor flow gained by opening the fringe zone tubes will cause a decrease in central zone flow corresponding to the effect of decreases in pump discharge pressure that occur with increased total flow.

(c) The same power level increase can be obtained by reducing in some manner the over-all reactor central zone flow resistance, i.e., larger nozzles and pigtails, thin-skinned fuel elements, etc.

(d) The only time reducing the fringe flow resistance is of sure value in increasing production is when:

(1) The bulk temperature limit is fixed.

(2) The central zone flow resistance cannot be reasonably decreased.

(3) The reactor water plant can adequately provide the increased flow.

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(11) J. R. Young to T. Prudich, "Avoiding the Bulk Outlet Water Temperature Limit," February 24, 1958.

(e) For any other conditions, an economic study of the advantages of decreased fringe or total resistance as a function of central and fringe zone flows, rupture limits, corrosion limits, trip-after-instability limits, top-of-annulus boiling limits, and cross-header pressurization effects must be made.

It should be emphasized, however, that on a short-term basis, opening the fringe orifices may be a convenient way of increasing production at constant bulk outlet temperature.

3. Rear Riser Quenching

A second means of maintaining a constant effective bulk outlet temperature while increasing the reactor power level would be to add cold quench water to the rear risers. This method of increasing production was mentioned in a survey report(3) and is again suggested by J. R. Young.(11) Let us first consider the general case and, in light of this, examine Mr. Young's proposal. For the case of a complete cold water quench, it would be added to the bottom of both rear risers. Under these conditions, the cold water would mix with hot effluent all the way up the risers; and it is quite reasonable to expect an effective mixing and quenching of the effluent temperature. The problems associated with this system are as follows:

(a) This raw water flow would have to be at least as reliable as the reactor flow and have similar flow decay characteristics. In other words, a raw water quench that permitted a 5 per cent increase in reactor power level for the same effective bulk outlet temperature would require a lower permissible bulk outlet temperature if the nature of this raw water supply would mean an increase in the frequency of bulk effluent temperature surges.

(b) Even with a well backed-up raw water system, the very nature of the system with an increase in the multiplicity of valves, pumps, controls, etc., that could fail would indicate the need for some decrease in the allowable bulk effluent temperature.

(c) The only time that the use of this system is surely indicated is as follows:

(1) The bulk temperature limit is fixed.

(2) No further increase in reactor flow can reasonably be obtained because of water plant or reactor limitations.

(3) An economical means of providing effluent quench water is available.

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(3) Op. Cit. page 5.

(11) Op. Cit. page 13.

(4) This quench water can be provided with assured adequate mixing with the effluent before reaching the top of the risers and with assured flow reliability.

There is one possible advantage of this system in comparison with just an increase in reactor flow. If this system were not affected by a BPA electrical outage, then it would tend to diminish the BPA outage effects by supplying a proportionally increasing amount of cold water quench as the reactor flow decayed. This condition would tend to cancel the frequency effect mentioned earlier and permit the bulk temperature limit to remain unchanged.

Use of Hot Water Recirculating System to Quench Water in Near Rear Riser

The specific use of this hot water recirculating system as an effluent quench has several drawbacks. These are:

(a) Insufficient mixing distance.

(b) No quench water added to one-half the effluent in an effluent piping low-pressure region, i.e., the near riser.

These drawbacks are serious in that adequate mixing of the whole effluent with quench water must be provided in a manner that will limit effluent boiling at any point in the effluent system. Otherwise, the quench is ineffective in permitting higher allowable outlet water temperatures.

The temperature mixing distance requirements are not known; however, their order of magnitude may be estimated from data giving the (L/D) requirements for reaching fully-developed heat transfer conditions in a smooth tube. This turns out to be about 25 to 30 feet, according to charts presented by Deissler[12] for the development of full Nussett values in a tube. This is only qualitative, but it does indicate that we cannot now assume adequate temperature mixing in a few feet of riser piping.

4. Venting of the Top-of-Downcomer

A system of an open vent line from the top of the downcomer to the reactor purge-gas stack has been suggested as a means of permitting an increased bulk outlet temperature. This has the advantage of reducing system pressures to prevent top-of-downcomer failure, but it only increases the probability of inlet elbow failure. This is because depressurization increases the momentum effects. This venting should eliminate the radiation problems from radioactive steam. However it has numerous disadvantages, including the following:

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(12) R. G. Deissler, "Analysis of Turbulent Heat Transfer, Mass Transfer, and Friction in Smooth Tubes at High Prandtl and Schmidt Numbers," NACA 1210, (1955).

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(a) The outlet temperature monitor should be moved to the rear risers to avoid the decrease in bulk temperatures beyond the downcomer as steam is flushed from its top. The present monitor would indicate a constant bulk outlet temperature even though the reactor bulk temperature was rising. Two further reasons for moving this monitor are to measure riser temperatures and obtain a more rapid bulk temperature response.

(b) With the top-of-downcomer vented to yield atmospheric pressure ($<$.5 psig), the momentum effects induced by cross-over boiling would be their greatest. There would be maximum stress on the entrance elbow and on the top cascade tray.

(c) The vent line would have considerable capacity requirements and might well require shielding. For instance, it is estimated that a 4-foot-diameter vent line would be required to handle the steam venting at 110° C with a maximum top-of-downcomer pressure of 0.5 psig. This does not include an allowance for the significant volumes of air and gases that would also be vented.

(d) This large influx of steam into the regular exhaust air stack would tend to reduce the normal exhaust of reactor gases and might even cause a temporary reversal of the contaminated air flow.

Consequently, it can be concluded that the bulk effluent problem cannot be adequately handled merely by using a 10-inch vent line from the top-of-downcomer to the pile exhaust stack. On the other hand, a larger short vent line might release the steam without pressurization and top-of-downcomer failure. This would not, however, eliminate the momentum or radioactivity problems.

5. Effluent System Pressurization

One further manner of increasing reactor production, with respect to bulk temperature limits, is to pressurize the effluent piping system. This will probably involve installing complete new effluent piping from the top of the rear risers to the retention basin. It will involve a study of the effects of a marked increase in vapor emission from the retention basin, and one further problem will be the pressurization produced by two-phase flow at the discharge to this effluent system. With this effluent system pressurized, there will be a time lag of about a minute between an increase in bulk effluent temperature caused by a power surge or a water loss and the effluent pressurization effect. By this time, in every transient condition except a flow or power change too small to cause a Beckman or a Panellit trip, the reactor will be scrammed seconds before there is any increase in system pressurization. Therefore, except for the following difficulties, this system poses no serious operating problems.

(a) A marked increase in vapor loss from the basin as the bulk outlet temperatures are increased.

(b) A significant installation cost.

Such a system has been designed for the H reactor with a water quench to eliminate the vaporization.(13)

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(13) R. E. Johnson, "Rear Face Pressurization Applied to 100-H Area", HW-41298, February 6, 1956.

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A Proposed Program for Increased Production Through Bulk Effluent Temperature Increases or Bulk Temperature Limit Circumvention

1. General

At the present time we do not have answers to the many problems posed in the earlier sections of this report. Therefore, before a specific schedule can be decided upon for increased production by any of the proposed methods, it is necessary to secure answers to many of these problems.

In other words, it is important to make an over-all study of this problem before we can decide with any engineering accuracy the best means of securing this production increase. This will require a program of laboratory experiments, in-pile testing, and engineering study. In the following sections this program is presented in sufficient detail to start our program studies.

2. Laboratory Studies

(a) Washington State Hydraulics Laboratory

(1) Water Temperature Mixing

One of the important problems with respect to the bulk effluent problem is determining the rapidity of temperature mixing in the water after the confluence of two water streams at different temperatures. Little experimental information on this subject appears available, yet it has a significant bearing upon the degree of flashing that we could obtain at the top of the rear risers and at the entrance to the downcomer. Therefore, a theoretical and scaled-down model study should be made of these temperature mixing effects. Basically, we need to know the effect of velocity, temperature, cross-sectional area, and geometry upon the degree of water temperature mixing at various distances downstream from the confluence of the mixing streams.

A suggested means of completing this investigation would be to construct several models simulating the effluent system using clear plastic components. These should range in size from 6 inches to 12 inches diameter or larger. A careful analysis of the flow problem involved would be required to decide upon the relative importance of the various fluid dimensionless numbers, (Reynold's Number, Fronde Number, etc.). With these different sizes, and with flow velocities adjusted to approach model simultude, then it may be possible to extrapolate to reactor conditions. At least our knowledge of mixing conditions should be improved.

Probably the biggest difficulty in such a testing program will be satisfactory measurement of the fluid local temperatures. The information from this study will be useful in three months' time, and certainly should be required by April of 1959.

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(2) Scale Model Boiling

With these scale models for water temperature mixing, it would be very desirable to model effluent pressurization effects. The purpose of these tests would be to measure the degree of pressure surges produced by various degrees of transient boiling and the momentum effects produced upon critical components of the piping model. With various nominal operating water temperatures and flows, a sudden increase in water temperature would be imposed. High speed sensing elements would then be used to measure pressure and momentum effects.

The purpose of these tests would be to apply the pressure and momentum effects to an analysis of the maximum allowable operating conditions for present effluent piping system, and also to any design of a pressurized system. These tests should be performed with and without top-of-downcomer venting.

(b) Thermal Hydraulic Operation

In addition to the hydraulic laboratory studies proposed, it may be necessary or desirable to run the larger flow or higher temperature parts of this effluent mock-up study in the 189-D Thermal Hydraulics Laboratory. In this case, it is anticipated that the downcomer mock-up could be moved to Hanford for these studies.

(c) Mechanical Development Operation

There is now a cross-header mock-up under the direction of C. W. Botsford in the 108-D Building. This mock-up should be used to test the following conditions:

(1) Effect of introducing one or several orifices in the header upon tube outlet pressures, and possible cavitation erosion downstream of these orifice plates.

(2) Cavitation erosion in the cross-header at points where cavitation may occur, i.e. opposite the pigtail entrances and just downstream of the elbows.

(3) The effect of supplying part of the cross-header flow from simulated tubes 5 to 20° C above the cross-header saturation temperature with the bulk cross-header fluid near saturation.

With these problems to be solved the following general testing procedure is suggested:

(1) With the cross-header loop circulating at 90° C and with no cross-header orifice plates, raise the loop temperature to 100° C with not more than 8 psig pressures at the cross-header outlet and circulate for a time sufficient to give indications of cavitation. A careful comparison of all

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system pressures should be made at the 90° point and the initial and final 100° C point.

(2) Similar tests should be run at cross-header temperatures up to 120° C and cross-header outlet pressures as low as 8 psig.

(3) With the increased temperature parameter investigated in an open cross-header, the same tests should be repeated with various cross-header orifices in order to determine the desirable rear cross-header orificing for higher temperature reactor operation.

The results from these tests will be needed for the H or C Reactor Bulk Outlet Temperature Production Test. This test is tentatively scheduled for July or August of 1958.

In order to achieve the desired cross-header temperatures at low enough pressures, it will be necessary to quench the pump inlet to prevent pump cavitation. This will require reheating the loop between the pump and the test section. Therefore, plans should be started for loop modifications such as:

(1) Insertion of quench water far enough away from the pump to ensure adequate mixing.

(2) Insertion of a steam heated heat-exchanger between the pump and the simulated cross-header.

(3) Installation of suitable controls including temperature measurements to permit automatic operation of the loop with only routine inspection about twice a shift.

d. Instrument Development Operation

There are a number of instrument development facets of this proposed increase in bulk outlet temperatures. One important problem is in the proper location of revised bulk effluent temperature elements. For the proposed production test and for several of the other proposals for increasing the bulk-limited production, the present bulk outlet temperature elements will not give a true indication of outlet temperatures whenever any significant steam evolution occurs from the top of the downcomer. Therefore, new temperature elements should be installed at several positions in the rear risers between the top cross-header and the cross-over. The desirable location is one high enough above the top cross-header to ensure a reasonably mixed water temperature and a position far enough below the cross-over to be away from effluent boiling conditions. Since these requirements are probably incompatible it will be necessary to place temperature elements at several points on the risers.

Two other development problems are high speed pressure measurements in the effluent system and strain-gage stress measurements at critical structural points. With this production test tentatively programmed for the summer of 1958, it will be necessary to organize the necessary equipment and know-how on both of these problems to carry out the production test operation.

(e) Mechanical Development Operation "B"

One of the most important problems associated with this increased temperature operation is the possibility of cavitation erosion limiting the service life of the effluent system and causing serious losses in production. As another approach to this problem, that does not require full scale operation or any reactor downtime, it is recommended that cavitation studies be made using the method proposed by Robinson, Holmes, and Leith.(14) This equipment is generally used to compare the cavitation resistance of different materials. However, it may be possible to adapt this equipment to studying the effect of operating changes upon the same material. An indication of the effect of outlet temperature increases may be determined by making these cavitation tests at various conditions of temperature, pressure, and pH.(15)

3. Design Studies

(a) Reactor Modification Design Operation

In connection with the suggested alternatives to increased bulk outlet temperatures, it will be necessary to clearly define the design and construction costs associated with each proposal. Therefore, it is recommended that these proposed methods be studied and a suitable design for each case be obtained. The two methods that involve the minimum amount of effluent piping changes are:

(1) Adding quench water to the bottom of the rear cross-headers.

(2) Venting the top of the downcomer.

Pressurization will involve considerably higher installation costs, but will yield a considerably greater increase in production and will eliminate the present effluent system low strength problems that are the basis for our current bulk temperature limit.

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(14) Robinson, Holmes, & Leigh, "Progress Report on Standardization of the Vibratory - Cavitation Test," ASME-56-A-85. (1956)

(15) J. M. Fox, Jr., Personal Communication. 4-3-58.

Actually a fairly detailed study of this problem has already been prepared for the 100-H reactor.(13)(16) These reports include numerous reactor modifications that go along with pressurization. Because of the significant increase in reactor power levels and temperatures, more recent information on the need for and the expected costs associated with these changes should be available. In addition, the production value in these reports was based upon the production cost value of $15/gm of Pu rather than the current A.E.C. maximum payment value of $30/gm. This drastic revision would permit pressurization, as presented in these documents, to be carried out at a cost, per reactor, of about $15,000,000 with a production gain of about 30 per cent. These costs may be considerably reduced if quench water is not required to reduce the effluent water below its boiling point before discharge into the retention basin.

In considering pressurization, major factors should be evaluated:

(1) In addition to the obvious increase in safety obtained from the elimination of the weak effluent piping system, an overall safety analysis should be made which includes the effects of increased flow and power level upon the reactor safety.

(2) The actual increases in production that we obtain will not necessarily be the maximum permitted from the new bulk limit considerations. In fact, unless we can considerably reduce the fuel rod rupture problem and the corrosion problem, our actual gains from this major reactor modification will be small.

(3) The value of production gains that may accompany this pressurization must be distributed to the several different developments that permit the increase in power level. This reduces the value of any one project or modification. However, it reflects the true value of any one project.

4. Engineering Studies

(a) Reactor Engineering Operation

It will be necessary at all times for R & E to have the safety aspects of this problem well in hand. It will be our obligation to analyze proposed operation and potential problems and to indicate the safe limits for any proposed design and procedure. At the same time it will be important to look for possible

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(13) Op. Cit. page 16.

(16) R. E. Johnson, "Budget Study for Production Increases Through Reactor Rear Face Pressurization," HW-40985, January 19, 1956.

relaxations or operating improvements that will permit safe reactor operation at even higher power levels.

(b) Process Analysis Operation, or Reactor Modification Operation

Certainly in the case of fringe zone cooling, and probably in the choice of an alternate to increased bulk outlet temperatures, it will be necessary to make a complete analysis of the relative merits of the different methods of increasing production. In fringe zone cooling, we must consider the merits of sacrificing some central zone flow in order to obtain a net increase in reactor flow and thus power level at a constant bulk outlet temperature. Here, care must be taken to consider the pump characteristics and the various individual tube limits that may be more restrictive than the bulk outlet temperature limit.

In the case of the alternate piping methods, it is important to consider not only the design costs but the potential hazard costs associated with each. These are discussed briefly in pages 14 to 16 of this report.

In the case of the effluent system pressurization, the increased costs should be considered in conjunction with the possibility of a considerable increase in production. Here again, the increased production will depend upon raising other limits beside the reactor bulk outlet temperature. Therefore, the value of effluent pressurization will depend upon the success of development efforts to raise these other limits associated with reactor operation.

CONCLUSIONS

At the present time, our bulk temperature limit is based upon an analysis of the costs to be associated with possible problems at elevated bulk temperatures combined with the high value of increased production. However, both the damage effects of temperature surges and their frequency are only estimates and the present costs estimates do not include rupture and corrosion costs. Consequently, our cost data is inherently inaccurate although considered to be conservatively high.

In raising this bulk temperature limit, therefore, there are three important considerations. First, it is essential that more fundamental reactor data be obtained before we are justified in raising reactor bulk limits further. Secondly, because these limits are based upon possible effluent damage conditions, it is essential that a careful production test procedure be adopted. And thirdly, because we are considering the operation of the reactors up in the range of progressive effluent system damage it is not recommended that such operation be considered on a permanent or long term basis. In other words, it is not considered good operating practice, despite the economic incentive, to operate the reactors for long periods at a point where any severe transients will cause piping damage. It can be concluded that such operation with cumulative effects of smaller transients is inherently damaging to the piping system and prolonged operation under these conditions could lead to more severe effluent damage than the short term tests would indicate. This does not mean that Production Test operation of the reactors at high bulk temperatures for several years is not feasible, but it does suggest that for a 5 to 10 year operation a more complete solution to this bulk problem should be developed.

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Along with the production test for increasing the bulk outlet temperatures, several methods have been proposed for gaining the equivalent production increase by other means. Before the best means of obtaining a long-term solution to this problem can be reached, studies of all the various proposals must be completed, at least in sufficient detail to estimate production gains, installation costs, and reactor safety considerations. Therefore, we should perform an analysis of:

1. Fringe zone quenching.

2. Rear riser quenching.

3. Top-of-downcomer venting.

4. Effluent system pressurization.

It should be noted that this last method should eliminate bulk temperatures as a reactor limit and permit 10 to 30 per cent temperature increases with no effluent system problems. Therefore, in any program for significant increases in old reactor production, it becomes almost mandatory to consider effluent system pressurization as a part of the reactor modification program. These should be completed by the appropriate IPD organization to the extent necessary to reach firm economic and safety conclusions concerning the best of the four methods.

In this respect the suggested laboratory studies of:

1. Cross-header high temperature flow studies.

2. Effluent system scale studies.

3. Water temperature mixing studies.

are all important adjuncts to the actual production test itself in establishing maximum bulk operating limits.

In a report of this nature involving the programming of possible work for many different Hanford groups it is obvious that allowance must be made for many different points of view and for the fitting in of this suggested work with many other problems. Therefore, it is hoped that this report will serve to point out the basic problems, and their possible solutions; and to stimulate the development of an active organized effort towards the achievement of the desired production goals.

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