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DOCUMENT NO.

BNWL-CC-1534

HANFORD CATEGORY: C-44C

PROJECT

DATE

SERIES AND COPY NO.

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BATTELLE-NORTHWEST

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MIXER SPOOL EFFECTIVENESS
AND PRESSURE LOSS EVALUATIONS
FOR LOW PRESSURE REACTORS

By

A. M. Sutey

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K10-CG-3, Topics A.3.4 & A.3.6
Drawings 101A/82

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MIXER SPOOL EFFECTIVENESS
AND PRESSURE LOSS EVALUATIONS FOR LOW PRESSURE REACTORS

By

A. M. Sutey

INTRODUCTION

Process tube and fuel jacket failures due to corrosion are recurring problems in the operation of nuclear reactors and are generally accentuated by coolant temperature increases. Such failures in the low pressure reactor fuels can be reduced by minimizing the peripheral temperature disparities at any axial position along the tube. High coolant temperatures in the center hole can usually be corrected by designing fuels with a larger hole channel. However, temperature disparities between the top and bottom of the annulus coolant channel in ribbed process tubes are more difficult to eliminate.

Water mixer fuel pieces which mix the subchannel flow streams are used in the production reactor fuel columns to reduce peripheral and hole-to-annulus coolant temperature disparities and, thus, to reduce corrosion problems. The mixer in current use is approximately two inches long and is attached to a six inch fuel piece. This fuel element with attached mixer is generally placed as the seventh fuel element from the downstream end of the charge.

A new mixer design has been proposed and is shown in the drawing H-3-24183. Its basic operation is similar to that of the present design (H-3-17493) in that it exchanges the flow stream in the central hole with fluid in the annulus. The standard mixer utilizes circular interchannels to perform the fluid interchange, whereas, the new mixer uses larger channels of rectangular cross-section. The purpose of this study was to evaluate the mixing effectiveness and pressure loss characteristic of this new mixer and to compare it with the performance of the standard mixer.

SUMMARY

This study compares the mixing effectiveness and pressure losses of two mixer spool designs--a new design and the standard design in current use. These mixer spools are used to reduce peripheral and hole-to-annulus coolant

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temperature disparities within I&E production fuel columns. Both of the mixer designs studied exchange the hole flow stream for water from the annulus as it passes by the mixer.

In this study, a temperature disparity was simulated upstream of the mixer and the effectiveness of the mixer in reducing this disparity was measured in the hole subchannel and at various peripheral locations in the annular subchannel downstream of the mixer. It was found that the overall effectiveness of the standard mixer in balancing the downstream temperatures about a mixed mean was approximately 14 percent greater than the new design. Although the new mixer was capable of reducing the temperature disparities of the hole and the annular rib subchannels, it tended to divert fluid from the hot upstream subchannel to a location downstream without mixing this fluid to a great extent with fluid from other subchannels. On the other hand, the standard mixer caused a higher degree of turbulence which resulted in better overall mixing effectiveness. However, this higher degree of overall enthalpic mixing was accompanied by higher pressure losses. Experimental results showed that pressure losses of the new mixer were less than those of the standard mixer in current use. At a typical flow of 50 gpm, this difference amounted to about 17.5 percent of the total pressure loss of the standard mixer and increased at higher flow rates since the slope of the pressure flow curve of the new mixer is less than that of the standard mixer due to less turbulent drag effects. At typical flow rates, the pressure drop of the new mixer is approximately equal to that of a single uranium fuel element (11.3 psi at 50 gpm).

To determine which mixer type is most applicable to reactor operations, an optimization which includes fabrication costs, pressure losses, and mixing effectiveness must be made. On the basis of pressure losses, the new mixer is best, whereas, on the basis of mixing effectiveness, the standard mixer is better. Neither mixer embodies the unattainable hydrodynamic combination of minimum pressure loss and maximum mixing effectiveness. Gains in mixing effectiveness are accompanied by increased pressure losses, whereas, decreases in pressure losses are accompanied by decreased mixing effectiveness. Therefore, the results of this study, the particular reactor operating improvement desired, and the relative fabrication costs of the mixers will determine the choice of the mixer type to be used.

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EXPERIMENTAL EQUIPMENT AND PROCEDURE

The test equipment for this study was assembled in the 189-D Hydraulics Laboratory. Each test assembly consisted of a mixer spool plus seven 03N I&E fuel slugs, four upstream, and three downstream of the mixer in a standard B-Reactor ribbed process tube. The fuel charge was followed by five 8 in. perfs to complete the fuel train. In the mixing effectiveness study, the fuel charge was simulated using aluminum dummies which were welded to one another and to the mixer in the order mentioned above so that the hole and annulus flow channels were separated before and after the mixer. However, in the pressure drop study, typical single uranium fuel slugs were charged into the process tube in the above order with the two inch mixer "glued" to the downstream end of the fourth fuel slug. Mixing effectiveness and pressure loss studies were performed separately for each mixer type.

In this study, a new mixer design (print H-3-24183) plus the standard mixer design (print H-3-17493) were evaluated. Both of these designs exchange the hole flow stream for water from the annulus as it passes by the mixer. To perform the subchannel fluid interchange, the standard mixer utilizes circular interchannels, whereas, the new mixer utilizes larger slotted interchannels. The new mixer provides a much greater cross-sectional interchannel flow area than that provided by the standard mixer. In order to properly compare the performance of the two mixer designs, the mixer spools were always charged into the ribbed process tube with the same orientation relative to the process tube so that one of the four hole discharging channels would approximately bisect the rib flow channel.

The experimental approach used in this study to determine mixing effectiveness was essentially the same as that outlined in HW-75489¹. Fluid in one subchannel was maintained at an elevated temperature with respect to other subchannels upstream of the mixer. Fluid and enthalpy interchange occurred within the mixer, and fluid temperatures were obtained via thermocouples located both

¹HW-75489 Mixing Effectiveness and Pressure Drop Measurements for Water Mixer Pieces" by E. D. Waters, November 5, 1962.

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upstream and downstream of the mixer. Temperatures were measured upstream at the top annulus, between the ribs, and in the hole, and downstream in the hole and at six equally spaced locations around the annulus. Temperatures of the upstream hole and annular streams were regulated to simulate temperature imbalances prior to the mixer. Also, steam was injected into the rib subchannel upstream of the mixer to simulate a hot rib imbalance. Typical total flow rates were used with subchannel flow being adjusted according to a typical annulus/hole flow split of 2.45. The same procedure was repeated to measure mixing effectiveness for each type of mixer spool. Preliminary isothermal and hot subchannel tests were performed for each mixer to determine reproducibility of experimental measurements and to simulate various temperature disparities. In all experimental tests, temperature measurements were reproducible within five percent.

Single phase pressure losses were measured by means of a differential mercury manometer across a 10.25 in. length of process tube which included a mixer spool plus 8.25 in. of an 03N I&E fuel slug. Experimental pressure measurements were obtained over this short section of process tube in order to obtain accurate values of mixer pressure losses. The same test assembly was used to obtain pressure drop-flow curves for each mixer type simply by interchanging mixers.

DISCUSSION OF RESULTS

Mixer Effectiveness

Mixing effectiveness data are presented for "hot hole," "hot rib," and "hot hole-hot rib" upstream temperature disparities in Figures (1), (2), and (3), respectively. In these figures, the dimensionless mixing effectiveness factor is plotted versus upstream and downstream temperature measurement locations for each type of mixer spool. In this manner, one can see the effectiveness of a mixer spool in reducing a given upstream temperature disparity. The mixing effectiveness factor is defined as $(T - T_M) / (T_{UHC} - T_M)$ where T_M is the mixed mean temperature of all upstream or downstream subchannels and T_{UHC} is the upstream hot channel temperature causing the disparity. This factor represents the deviation of a local subchannel temperature from the mean mixed temperature and thus indicates the degree of subchannel enthalpic mixing.

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For the upstream hot hole case presented in Figure (1), the new mixer and the standard mixer each reduced the initial temperature difference as far as the downstream hole is concerned. The standard mixer was about 12 percent more effective in balancing the temperatures about a mixed mean temperature at the various downstream locations. For the upstream hot rib case presented in Figure (2), each mixer cooled the rib, and the new mixer provided 12 percent better overall enthalpic mixing. Finally, for the hot hole-hot rib case presented in Figure (3), the new mixer cooled the hole and rib subchannels somewhat better than the standard mixer; however, the standard mixer provided approximately 14 percent better overall downstream mixing.

In summary, the standard mixer was more effective in balancing the downstream temperatures about a mixed mean temperature of all fluid subchannels. It should be noted that although the new mixer was capable of reducing the temperature disparities of the hole and the annular rib subchannels, it tended to divert fluid from the hot upstream subchannel to a location downstream without mixing this fluid to a great extent with fluid from other subchannels. These results can be explained by the lesser degree of mixing or turbulence created by the new mixer in comparison to the standard mixer. However, the higher degree of overall enthalpic mixing of the standard mixer was also accompanied by higher pressure losses which will be discussed shortly.

Pressure Losses

Single-phase pressure-flow curves for the standard and new mixer spools are presented in Figure (4). Experimental data for each of the mixers was obtained across a 10.25 in. length of process tube which included a mixer spool plus 8.25 in. of a 03N I&E uranium fuel slug. However, the pressure drop due to the 8.25 in. portion of uranium slug was analytically subtracted from the measured pressure drop so that the pressure-flow curve of the mixer alone is presented in Figure (4). Pressure drop values of the portion of uranium slug were obtained by scaling data of a 32 piece fuel column. For comparison, the pressure-flow curve of a single (8.75 in. long) 03N I&E fuel slug is also presented in Figure (4).

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Results in Figure (4) show that pressure losses caused by the standard mixer were greater than those of the new mixer. At a typical flow of 50 gpm, the difference amounted to about 2.4 psi. The slope of the ΔP -flow curve of the old mixer was greater than that of the new mixer. As a result, the pressure loss difference between the two mixers is greater at high flow rates than at low flow rates. For example, the pressure drop of the standard mixer was 5.3 psi greater than the new mixer at 70 gpm but only 0.6 psi at 30 gpm. These results are explicable due to the increased turbulence caused by the old mixer. Also, the cross-sectional area of flow of the old mixer was much less than the new mixer causing increased pressure losses.

A comparison of the pressure-flow curves of the mixers and that of a single uranium fuel slug is also presented in Figure (4). The slope of the ΔP -flow curve of the fuel slug was less than that of either mixer spool because of the lesser degree of turbulent drag created by the fuel slug. At a typical flow of 50 gpm, the pressure loss due to the single slug was equivalent to that of the new mixer but is 2.4 psi less than the standard mixer.

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FIGURE (1)

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7 X 10 INCHES
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FIGURE (2)

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FIGURE (3)

FIGURE (4)

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