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K REACTOR INLET ASSEMBLY CAVITATION STUDY
HEADER VENTURI VERSUS NOZZLE VENTURI

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K REACTOR INLET ASSEMBLY CAVITATION STUDY
HEADER VENTURI VERSUS NOZZLE VENTURI

By

L. R. Kelley

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Process Component Development
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K REACTOR INLET ASSEMBLY CAVITATION STUDY
HEADER VENTURI VERSUS NOZZLE VENTURI

I. INTRODUCTION

A. Purpose

This document describes the development and test of a short nozzle-mounted venturi. The development's purpose was to permit the elimination of cavitation collapse in a reactor inlet pigtail during flush discharge.

B. Objectives and Scope

The objectives of this report are:

1. Discuss the development of a short, nozzle-mounted venturi.
2. Present and discuss flow test data.
3. Present and discuss cavitation data taken from a laboratory mockup.
4. Show that cavitation is eliminated from the inlet pigtail and can be tolerated in the inlet assembly.

C. Background

Cavitation damage to the inlet pigtail occurs as a result of critical flows through the venturi which is mounted upstream on the supply header. Critical flows occur during flush discharging, a common method of discharging fuel elements by letting the coolant push them out of the tube. Flush discharging is an accepted part of operational fueling. Here, critical flow occurs as a result of lowered back pressure in the process tube for approximately 10-15 minutes. This period covers the time needed to flush-discharge the ripe metal and to recharge the downstream perfs and about nine pieces of green metal. At this point, back pressure in the tube is high enough that flow has dropped below the critical flow rate in the venturi.

II. SUMMARY

A new, shortened, nozzle-mounted venturi has been developed and tested on KE Reactor and in the laboratory. The venturi is mounted directly into the inlet nozzle and relocated to the downstream end of the pigtail.

The pressure drop and flow characteristics of the new design closely parallel the standard K venturi.

Cavitation damage tests have been made both on-reactor and in the laboratory. After cavitation times in excess of 1000 hours, no pigtail damage has been noted in a sectioned pigtail. Nozzle and venturi erosion from this extended test are not critical. The test periods are equivalent to hundreds of years of service with flush discharging.

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III. DISCUSSIONA. Need for Change

During the initial startup period of the K Reactors, flow trials were run with empty tubes. The front pigtails were made from aluminum tubing then and many failed as a result of cavitation induced at the venturi. Subsequently, the pigtails were changed to stainless steel woven wire, with a teflon lining. In laboratory tests the woven wire pigtails also failed under conditions of cavitation and the resultant vapor bubble collapse. One of these pigtails failed in as little as five days with 150 per cent of normal header pressure.

A Process Standard which has been in use for years requires that any pigtail used under cavitation conditions must be replaced and the old one destroyed. Further, engineering opinion¹ was crystallized recently to state that pigtail cavitation cannot be allowed on a routine basis, since (a) any method for accounting for the number of hours of cavitation would be cumbersome and subject to possible failure, and (b) no adequate method is known for predicting pigtail deterioration or failure on the basis of history or inspection data. All test work performed over the past years involving pigtail cavitation or flush discharging has been done within the exacting limitations of Production Tests. All pigtails exposed in this fashion have been (or are being) replaced and destroyed. The development of a feasible operational fueling facility, which utilizes flush discharging, has focused attention on this problem again. Following any flush discharging, bubbles are formed at the venturi vena contracta. Since the collapse of these bubbles cannot be tolerated in the pigtail, development of hardware was begun and has now been completed to avoid the problem.

B. Method of Attack

If the flow restriction which induces cavitation could be moved downstream from the pigtail, the damage to the pigtail by bubble collapse and vibration could be eliminated. Since the cause of the cavitation was critical flow in the venturi, it was decided that moving the venturi downstream to the nozzle would protect the pigtail.

Relocation of the standard venturi to the nozzle inlet was not feasible without venturi changes for three reasons:

1. The standard venturi is too long to allow an O.F.F. Charge Monitor to fit on the nozzle barrel (see Figures 1 and 7).
2. The standard venturi would extend the pigtail out past the end of the nozzle barrel, putting the pigtail in a more exposed and vulnerable position.
3. An extension would be required on the header to replace the standard venturi. By making the new venturi much shorter, a short extension from the header could be used. This would limit the possibility of break-off damage to the whole assembly.

(1) Cavitation in Inlet Connectors, letter from O. H. Greager to R. T. Jessen, August 8, 1961.

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For these reasons a redesign of the venturi was undertaken. The design criteria for the nozzle venturi are as follows:

1. The flow characteristics must be nearly the same as those of the standard venturi. That is, at normal conditions of 60-65 gpm, the permanent losses must not exceed 60 psi, and the Panellit pressure must be approximately 200 to 235 psi.
2. All damages from cavitation collapse must be entirely eliminated from the pigtail.
3. The cavitation damage must be confined to an area where surface erosion is not critical. Failure cannot be allowed to occur suddenly and must be capable of extrapolation, inspection, and anticipation.
4. No new problems must be induced as a result of the change in inlet configuration.

The first attempt at redesign is shown in Figure 2-a. This venturi was shortened by decreasing the length of the inlet and throat sections.

It was recognized that a much shorter design could be made if a flow nozzle entrance were used. The designs shown in Figures 2-b and 3 are typical of work done in this area. The designs were tested with three different recovery section angles. These venturis were much shorter than standard and had favorable flow characteristics, but were difficult to fabricate.

Venturi #6 is the final design. The inlet section extends into the pigtail elbow and the recovery section fits against the chamfer in the nozzle base. This design is much like the one with the flow nozzle entry, except that design #6 is made in one piece and has a straight inlet section. This design is shown in Figures 1 and 8 and is detailed in Drawing SK-1-23168.

With the new venturi installed in the nozzle, the lower end of the pigtail is held away from the nozzle 1-3/16 inches beyond the current location as determined by the existing Parker fitting. This extension requires an extension adapter on the upper end of the pigtail, at the header. To meet this need, a standard orifice cage was used with a 1-3/16 inch extension added. As an extender only, the standard venturi could have been left in its original place, but prohibitive pressure losses would have resulted.

C. Flow Characteristics

The calibration curves shown in Figure 5 are for the final design. In comparing these curves with the standard venturi curves shown in Figure 4, there is no significant difference in permanent head loss, and the venturi throat pressure or Panellit pressure is about 5 psi less for the new design.

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The new design has a throat diameter of 0.425 inches whereas the standard venturi has a throat diameter of only 0.419 inches. The venturi throat pressures remained almost the same. At first glance, the throat pressure should be higher for the larger throat, i.e., the pressure drop from header to venturi throat would be less. The throat pressure is nearly the same for the new venturi, since it is downstream from the pigtail and adapter. This means that the pressure at the entrance of the venturi is the header pressure minus the head loss in the pigtail and adapter. The pressure drop from the front header to the new venturi throat is really greater than the venturi pressure drop alone. For this reason the throat diameter was made larger in order to keep the Panellit pressure approximately the same.

The difference in header pressure and front nozzle pressure is the permanent head loss for the inlet assembly. The two assemblies have equal permanent losses. This means that if header and nozzle pressures before and after the change in hardware are equal, the tube flow will be unchanged as a result of the hardware change.

D. Pigtail Damage

One of the design criteria was the elimination of the cavitation damage in the front pigtail. Two things contribute to pigtail damage. These are: (1) collapse of the vapor bubbles originating at the venturi throat, and (2) vibration.

Bubble collapse results in erosion of the upper elbow and teflon lining. The vibration, whether caused by the bubble collapse or by sympathetic response to flow disturbances, causes the layers of wire to rub on each other and erode. Wire breaking results in loss of support for the teflon and a leak develops.

Since the venturi was moved from the header to the nozzle, the source of cavitation was eliminated from the upstream end of the pigtail. Any upstream bubble formation occurring must now be induced by something other than the venturi. The inside radius of the elbows was such a possibility. Pressure taps were put in the elbows and the pressure was measured to be well above 300 psi. There are no other flow restrictions in the pigtail that could lower the static pressure due to a venturi effect, or small radii where separation of the flow from the wall could occur. All cavitation bubble collapse has been eliminated from the pigtail.

During the earlier pigtail tests with the standard upstream venturi, some of the pigtails actually became warm from the vibration. No such temperature rise has been noted with the new configuration.

A pigtail, which was used for approximately forty days under cavitation conditions with a standard venturi, was sectioned. It had developed a leak in the teflon due to erosion caused by bubble collapse. The top elbow was also eroded. Worn spots on the wire braids between the inner and outer layers of wire were clearly visible.

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A pigtail was used under cavitation conditions for thirty-three days on-reactor with the new venturi at the nozzle. No wear at all was visible after sectioning, either to the lining or the steel braid. Details of this test are reported in HW-73184.¹

Another pigtail and downstream venturi has run in the laboratory in excess of 1100 hours. No pigtail leaks have developed and no broken wires are visible to indicate damage.

It is concluded that pigtail damage as a result of cavitation has been eliminated. Vibration data have been taken but the instruments are too insensitive to measure the minute effects noted, and are therefore inconclusive at the present time. Further vibration testing is planned for the future to ensure that other hardware is not damaged.

E. Nozzle and Venturi Damage

The objective of eliminating the pigtail damage was satisfied. The next concern was about the criticality of the new location and design with respect to erosion of metal in the nozzle inlet and venturi exit.

In consideration of the cavitation collapse part of the problem, it was desired to attain a fairly even distribution of the surface erosion in the nozzle and the venturi. For example, if the damage were to occur at the junction between the two parts, easy visual inspection would be assured. To make the collapse of the bubbles occur near the end of the venturi, the included angle in the recovery section was set at 7 degrees. A recovery section angle of 7 degrees is also the recommended handbook value² for small head losses in the recovery of static pressure.

With this configuration the bubble collapse occurs about equally in the venturi exit and the nozzle inlet.

1. Venturi Damage

The damage to the venturi exit is shown for comparison in Figures 8, 9, and 10. This amount of erosion is considered negligible for the time involved. As shown in Figure 9 it is really little more than surface roughening with an approximate 0.003 inch change in radius at the end. The amount of wall thickness available at this point is 0.068 inch. After 730 hours of cavitation only 4.4 per cent of the wall has been eroded. Even if the erosion progresses completely through the venturi wall, the flow is still inside the nozzle base and flow loss could not result.

(1) Final Report, Venturi at Front Nozzle Production Test IP-473-AE, P. B. McCarthy, P. A. Carlson, April 1, 1962.

(2) Mechanical Engineering Handbook, Marks, Lionel S.

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2. Nozzle Damage

The damage in the nozzle entry is shown for comparison in Figures 12 and 13. The nozzle has clearly become the critical member of the inlet assembly. The soft aluminum is much more amenable to erosion than is the venturi. Although the areas of collapse in the venturi and the nozzle are approximately equal, the severity of the damage is not equally distributed. The damage is mainly concentrated on one side of the nozzle entry and is maximized at one point only, where erosion of 5/32 inch has occurred.

The minimum wall thickness of the casting is 35/64 inch. If the eroded section had chosen this part of the nozzle wall, 38 per cent of the wall would have been eroded. This amount of damage is a result of thirty days of continuous cavitation. Assuming that a process tube operated at cavitating conditions for not 10 minutes but one-half hour during operational refueling, and that six charges are scheduled per year; the cavitation time is three hours per year. The 730 hours of cavitation damage shown in Figure 13 is equivalent to 250 years on-reactor for O.F.F. conditions.

The new venturi is considered acceptable for current reactor use under operational fueling conditions. It should be noted that a cavitating tube with the new venturi is much quieter under operation than it was before. This points out the possibility of unintentionally leaving a tube empty for several hours or even an operating period. Any such extreme of service should still require nozzle and venturi inspection and perhaps replacement, depending on the degree of damage found. A test nozzle has run in excess of 1200 hours at the time of writing. With approximately 30 per cent of the metal eroded one can estimate that the nozzle should be good for three or four months of empty tube operation if the erosion concentrates on the shortest dimension. However, it appears that the erosion is not concentrating on the shortest dimension to the outside. Three or four months is a conservative estimate and it appears that eight to ten months of continuous cavitation collapse may be sustained before leakage occurs. Further tests are in progress to determine the ultimate failure time for a nozzle.

F. New Problems Encountered

Shocks from the bubble collapse in the nozzle are felt to a limited degree by the exit assembly as a result of energy transmission down the tube. Some evidence has been observed of erosion in the rear nozzle Parker fitting, of exit pigtail vibration, and of leaking flapper caps. These problems may not be significant but will be observed closely in all future tests.

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FIGURE 1-b

STANDARD VENTURI ASSEMBLY

FIGURE 1-a

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FIGURE 2-a

VENTURI NO. 2

FIGURE 2-b

VENTURI NO. 3

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FIGURE 3-a

VENTURI NO. 4

FIGURE 3-b

VENTURI NO. 5

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FIGURE 4

FLOW CHARACTERISTICS OF STANDARD K VENTURI

FIGURE 5

FLOW CHARACTERISTICS OF SHORTENED NOZZLE-MOUNTED VENTURI

FIGURE 6
INLET ASSEMBLY WITH SHORT NOZZLE VENTURI

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FIG. 7 - INLET ASSEMBLY WITH SHORTENED NOZZLE VENTURI

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FIG. 8 - SHORTENED NOZZLE VENTURI

FIG. 9 - SHORTENED NOZZLE VENTURI
RECOVERY SECTION BEFORE CAVITATION DAMAGE

FIG. 10 - SHORTENED VENTURI RECOVERY
SECTION SHOWING DAMAGE AFTER 160 HOURS

FIG. 11 - SHORTENED VENTURI RECOVERY
SECTION SHOWING DAMAGE AFTER 730 HOURS

FIG. 12 - STANDARD K NOZZLE SHOWING DAMAGE AFTER 160 HOURS

FIG. 13 - STANDARD K NOZZLE SHOWING DAMAGE AFTER 730 HOURS

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