27
6-2-77 to NTL
25 cip.

ORNL/TM-5733

Fabrication of an Improved Tube-to-Pipe Header Heat Exchanger for the Fuel Failure Mockup (FFM) Facility

J. J. Prislinger
R. H. Jones

MASTER

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

REPRODUCTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy \$4.00; Microfiche \$3.00

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Energy Research and Development Administration/United States Nuclear Regulatory Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Contract No. W-7405-eng-26

PLANT AND EQUIPMENT DIVISION

FABRICATION OF AN IMPROVED TUBE-TO-PIPE HEADER HEAT EXCHANGER
FOR THE FUEL FAILURE MOCKUP (FFM) FACILITY

J. J. Prislinger and R. H. Jones

Date Published: May 1977

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

MASTER

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *eb*

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

CONTENTS

	Page
Abstract	1
Introduction	1
Fabrication Procedure	2
Description of Extrusion Punch and Die Set	4
Bending of Heat Exchanger Tubing and Assembly of Component Parts	4
Fig. 1	6
Fig. 2	7
Fig. 3	8
Fig. 4	9
Fig. 5	10
Fig. 6	11
Fig. 7	12
Fig. 8	13
Fig. 9	14
Fig. 10	15
Summary	16
Acknowledgements	16
Distribution	17

FABRICATION OF AN IMPROVED TUBE-TO-PIPE HEADER HEAT EXCHANGER FOR THE FUEL FAILURE MOCKUP (FFM) FACILITY

J. J. Prisliger and R. H. Jones

ABSTRACT

The procedure used in fabricating an improved tube-to-pipe header heat exchanger for the Fuel Failure Mockup (FFM) Facility is described. Superior performance is accomplished at reduced cost with adherence to the *ASME Boiler and Pressure Vessel Code*. The techniques used and the method of fabrication are described in detail.

INTRODUCTION

As part of the Laboratory's Liquid Metal Fast Breeder Reactor Program to study the hydraulic behavior of LMFBR fuel assemblies, the Fabrication Department of the Plant and Equipment Division has fabricated a 2000-kW stainless steel heat exchanger for the Fuel Failure Mockup (FFM) Facility, an experimental rig operated by the Reactor Division (now Engineering Technology Division).

The construction of the heat exchanger is part of a program to improve the testing capacity of the facility. The heat exchanger cools molten sodium after it has been heated electrically to simulate a portion of the type fuel assembly to be used in the Clinch River Breeder Reactor at Oak Ridge and the Fast Flux Test Facility Reactor at Hanford, Washington. The heat exchanger will remove heat from molten sodium at various flow rates up to $0.0379 \text{ m}^3/\text{s}$ (600 gpm) and at a maximum temperature of 704°C (1300°F).

The heat exchanger was code stamped in accordance with the rules of the *ASME Boiler and Pressure Vessel Code*, Section III, Class 3, for nuclear components. The purpose of this report is to describe the procedure used in fabricating the heat exchanger, with a description of the method used to extrude the header outlets, thus eliminating a machined adapter and an additional weld for each

tube-to-header joint of a preliminary design. A novel solution for a tube bending problem is also described.

FABRICATION PROCEDURE

The fabrication procedure consisted of extruding the header, bending the tubes, assembling the component parts, welding, and inspection. The extrusion punch and die set is shown in Fig. 1.

We developed a three-step cold extrusion process to extrude the header outlets. The three stages of the extrusion are shown in Fig. 2. This method eliminated fabricating 80 nozzles and halved the number of welds and radiographs while providing good structural integrity. Also, the extruded header improved the flow properties of molten sodium in the smoother transition joint as shown in Figs. 3 and 4, reducing turbulence and vibration. The pipe material used in the header was type 304H stainless steel, which is used for high-temperature service.

The procedure for making the two headers was as follows:

1. Two fully-annealed, 4-in. (0.1-m) schedule 40 IPS pipes, 2.03 m (80 in.) long, were cut longitudinally into two halves with a milling cutter. The edges were then beveled as shown in Fig. 4 in preparation for welding the halves together after the header outlets were extruded.
2. One of the pipe halves was placed in a milling machine, and forty 3.2-mm (1/8-in.) holes were drilled 44 mm (1 3/4 in.) apart, with care to maintain good perpendicularity.
3. A 60° countersink was used to taper the holes from the convex side of the pipe, leaving a 3.2-mm (1/8-in.) land adjacent to the inside of the pipe.
4. The annealed headers were cold extruded in three steps with two intermediate annealing cycles. The first step involved the use of a tapered extrusion punch with pilot pin, as shown in Fig. 1. After the pipe half was properly

aligned by use of the pilot pin, the punch was pressed in 11 mm (7/16-in.). Tests had determined previously that penetration exceeding 11 mm (7/16 in.) caused edge cracking as a result of excessive work hardening. Extruding the outlet at room temperature produced a hardness of R_C 30 at the edge or thinnest portion of the outlet. Fig. 3 is a macrograph of a sample longitudinal section of a header outlet purposely over-etched to show the cold work flow lines.

5. Annealing the header restored ductility. The pipe half outlets were extruded an additional 11 mm (7/16 in.) and reannealed.
6. In the third stage of the extrusion, the punch major diameter penetrated the header to form the finished extrusion as shown in Fig. 4. The header outlet half was annealed again before the two halves were welded together. After welding, the header was again annealed, and the tubes were welded to the extruded outlets.

The annealing cycle consisted of placing the headers in a can, filling with a protective atmosphere of argon, heating to 1038°C (1900°F), and holding at temperature for one hour. The can was then removed from the furnace and fan-cooled to room temperature before opening.

Hot extruding was considered but was rejected for two reasons:

- (1) the difficulty of maintaining constant forging temperature and uniformity of grain size, which could affect corrosion resistance; and
- (2) possible danger of soaking too long below 957°C (1775°F), which might produce sigma phase and brittleness.

Cold extrusion of annealed type 304H stainless steel appeared more attractive because it offered greater uniformity in thermal and mechanical history, and it eliminated the above uncertainties.

DESCRIPTION OF EXTRUSION PUNCH AND DIE SET

The punch and die set used in extruding the header outlets consisted of an upper and a lower die. This set held the pipe half in place during extrusion, as shown in Fig. 1. The die material was AISI-SAE D-2 tool steel, hardened and tempered to R_c 58 to 60. The lower die was a block 0.15 x 0.15 x 0.20 m (6 x 6 x 8 in.) with a 57.2-mm-radius (2.25-in.) concave cylindrical surface to properly support the pipe half. The lower section also contained a 28.58-mm (1.125-in.) hole in the center of the block with a 3.2-mm (1/8-in.) radius at the concave surface where the pipe half made contact. The upper section of the punch and die set was also a 0.15 x 0.15 x 0.20-m (6 x 6 x 8-in.) block with a 51-mm (2-in.) radius convex surface to fit snugly inside the 0.1-m (4-in.) pipe half. A 19.05-mm-diam (0.750 in.) hole was bored into the upper die to locate the extrusion punch.

The inside diameter of the extruded outlets was 19.05 mm (0.750 in.), i.e., the same as the inside of the tubing and the major diameter of the punch. The extrusion punch was tapered, having a 60° included angle, a 4.8-mm (3/16-in.) radius, and a 3.2-mm (1/8-in.) pilot pin. The pilot pin assured alignment during the first stage of the extrusion.

BENDING OF HEAT EXCHANGER TUBING AND ASSEMBLY OF COMPONENT PARTS

The tubing used in the heat exchanger was type 304H stainless steel, having an inside diameter of 19.05 mm (0.750 in.), and a wall thickness of 1.65 mm (0.065 in.). Tube lengths of 9.1 m (30 ft) were bent into a serpentine tube 25.9 m (85 ft) in length and welded as shown in Fig. 5. The 180° bends were made with a center-to-center dimension of four times the outside diameter of the tube, or less than half the normal practice bending radius.

When made with a conventional automatic bending machine, the 180° bends flattened 10 to 12%, exceeding the maximum 8% ASME Code requirement (NB4223-2). The tubes were then pressurized continuously

during bending to 16.5 MPa (2400 psi) with demineralized water. This resulted in acceptable flattening of only 5.5 to 6% in the bends. Sections of the bends were removed, and inspection revealed that the wall thickness of the outside of the bend had been reduced by only 0.05 mm (0.002 in.). Fig. 6 shows several sections of tubes after bending under pressure.

After the 40 serpentine tubes were bent, the component parts were assembled, welded, and inspected. Fig. 7 shows the first set of tubes after being welded to the header. Fig. 8 is a photo taken after about 80% of the tubes have been welded to the header. The unwelded outlets are closed off to facilitate purging of the header. Fig. 9 shows the heat exchanger after all the tube sections have been welded to the header. Fig. 10 shows the completed tube-to-header assembly installed in the housing.

Fig. 1. Extrusion Punch and Die Set.

Fig. 2. Three Stages of Extruded Pipe Header Outlets.

Fig. 3. Longitudinal Section of Type 304H Stainless Steel Pipe Header over-etched to show cold work flow lines. Pitting was due to over-etching. Etched with HCl + cupric ammonium chloride.

PHOTO 1861-75

Fig. 4 Header Halves - Upper part of photo shows smooth flow lines of outlets along inside of header. Lower part photo shows header jiggged up ready for closure weld.

Fig. 5. Positioning Unit used for ease of purging and welding of single pass tube-to-tube welds.

Fig. 6. Tubes after bending at 16.5 MPa (2400 psi) with demineralized water. Flattening was only 5.5 to 6.0% using this method as compared to 10 to 12% using a conventional automatic bending machine.

Fig. 7. Installation of first set of tubes. Tubes have not been welded to header.

Fig. 8. About 80% of tube-to-header welds completed. Unwelded outlets are closed off so header can be purged.

Fig. 9. Completed Tube-to-Header Assembly.

Fig. 10. Completed 2-Megawatt Heat Exchanger.

SUMMARY

Innovative shop practices were applied to produce an economical and satisfactory product. Both the extruded-nozzle, split header procedure and the internally-pressurized tube bending method should be applicable to other similar fabrication requirements.

ACKNOWLEDGEMENTS

The authors wish to thank R. M. Farnham for his personal interest and many suggestions, and C. H. Wodtke and Sigfred Peterson for editing the report.

The authors also wish to recognize critical contributions to this heat exchanger fabrication from W. O. Wilson and R. L. Laughlin in extrusion punch and die development; H. C. Cox in tube bending technique improvement; C. E. Shubert in a reliable and repeatable heat treatment cycle; and C. J. Ward with W. G. Hylton in innovating the assembly and welding sequence.

INTERNAL DISTRIBUTION

1. W. A. Blevins	30. C. R. Rickard
2-7. C. W. Collins	31-32. H. E. Seagren
8. J. E. Cunningham	33. C. E. Shubert
9. R. M. Farnham	34. J. R. Weir
10. M. Fontana	35. C. H. Wodtke
11. D. R. Frizzell	36-37. Central Research Library
12. P. A. Gnadt	38. Document Reference Section
13-22. R. H. Jones	39-40. Laboratory Records Department
23. R. E. MacPherson, Jr.	41. Laboratory Records, ORNL R.C.
24-28. J. J. Prislinger	42. ORNL Patent Office
29. M. E. Ramsey	

EXTERNAL DISTRIBUTION

43. Research and Technical Support Division, ERDA, ORO
44-70. Technical Information Center, ERDA