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TECHNICAL MEMORANDUM

ANL-CT-80-3

MASTER

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA BANK

by

H. Halle, J. M. Chenoweth, and M. W. Wambsganss

Components Technology Division

ARGONNE NATIONAL LABORATORY

February 1980

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ANL-CT-80-3
Engineering and
Equipment (UC-38)

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February 1980

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*Assistant Technical Director, Heat Transfer Research, Inc., Alhambra, CA

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DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA BANK

by

H. Halle, J. M. Chenoweth, and M. W. Wambsganss

ABSTRACT

Development of a new heat exchanger tube vibration data bank at Argonne National Laboratory is described. The objective is to accumulate comprehensive case histories on heat exchangers that have experienced tube-vibration problems and units that have been trouble-free, and render this information available for evaluation, improvement, and development of vibration-prediction methods and design guidelines. Discussions include difficulties in generating a data bank, data form development, and solicitation efforts. Also included are 15 case histories upon which the data bank will be built. As new case histories are received, they will be assembled and published as addenda to this report.

I. INTRODUCTION

Flow-induced vibration has become a vital factor in the design of heat exchangers along with the more traditional thermal, hydraulic, and mechanical considerations. There have been many cases of shell-and-tube heat exchangers experiencing vibration problems, often leading to tube failures, and, in some cases, costly plant shutdowns. These vibration problems have motivated theoretical and experimental studies which have resulted in the development of prediction methods and design guidelines to avoid detrimental tube vibration. However, most of these studies involved single tubes or tube banks subjected to idealized uniform crossflow or parallel flow conditions. Although these conditions can occur locally, they are not typical of the changing flow patterns throughout an actual shell-and-tube exchanger: Flow passages, and thus flow conditions, are much more complex than simulated by either mathematical models or experimental equivalents. Consequently, extrapolation of these methods for predicting flow-induced vibration problems to heat exchanger tube bundles has been seriously challenged. Available prediction methods provide useful guidance but are considered unreliable to the extent that their application to heat exchanger design evaluation is uncertain thus requiring the use of large factors of safety.

To examine the ability of these methods to correctly predict the absence or presence of flow-induced tube vibrations, field data must be collected from case histories of individual heat exchangers and stored in a manner that can be input into these methods.

Efforts in support of such a data bank are being carried out at Argonne National Laboratory (ANL), and funded by the U.S. Department of Energy, Office of Fossil Energy, Division of Fossil Fuel Utilization. The activity is also a part of a U.S. contribution to an International Energy Agency (IEA) program of Research and Development on Heat Transfer and Heat Exchangers.

Solicitation and collection of case histories for the data bank has been assigned by ANL to Heat Transfer Research, Inc. (HTRI), a nonprofit cooperative of heat transfer equipment manufacturers, engineering contractors, and processing companies to promote application-oriented research in heat transfer. ANL is working with HTRI to take advantage of their experience with data banks, their established contacts with manufacturers and users throughout the world, and to ensure anonymity of contributors to the bank.

This report describes the DOE/ANL/HTRI Heat Exchanger Tube Vibration Data Bank, including background information, objectives, assessment of difficulties involved, data form development, solicitation efforts, and, as an appendix, fifteen case histories of heat exchanger tube vibration. These histories were purchased from HTRI with program funds and represent cases in which acoustic vibration, damaging tube vibration, and no vibration were present. They constitute the initial entries and the base upon which the new data bank will be built. As additional case histories are received, the data will be collated and published annually as addenda to this report.

II. BACKGROUND

The need for a bank of field data for shell-and-tube heat exchangers that have experienced flow-induced tube vibration problems was recognized by the Tubular Exchanger Manufacturers Association (TEMA) in 1969. Data collected from its members represented observations of gross effects that were considered significant parameters concerning tube vibrations. These proprietary data were made available to HTRI in 1971. Since that time, a new understanding of vibration phenomena has shown that the data are inadequate to evaluate critically current prediction methods.

In 1972, HTRI started collecting case histories for a heat exchanger tube vibration data bank. A form was designed that requested more data than found in the TEMA Data Bank. More specifically, case histories also were requested for heat exchangers which had not experienced vibration problems.

The data obtained ranged from very complete to sparse. In some instances, data gaps could be filled either by contacting the organization submitting the case, by making back-calculations, or by using "good engineering judgment." Although the HTRI data bank is proprietary to HTRI members, gross comparisons of predictions by known methods with field observations have been published.† Of the more than 60 cases submitted, only 25 were sufficiently documented to

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† J. M. Chenoweth, "Flow-Induced Tube Vibrations in Shell and Tube Heat Exchangers," ERDA Report SAN/1273-1 (February 1977).

be included in the data bank. However, only six of these cases deal with liquid shellside flow. Additionally, the data are heavily biased toward cases for which vibration problems have been experienced; there is a lack of cases for which no vibration problems occurred.

In England, Heat Transfer and Fluid Flow Service (HTFS) also has collected, analyzed, and prepared a report on tube-vibration data. However, the report is proprietary to HTFS members.

In 1976, HTRI conducted a study on flow-induced tube vibration in shell-and-tube heat exchangers for the Division of Conservation Research and Technology of the Energy Research and Development Administration (ERDA). This study included a Heat Exchanger Tube Vibration Workshop to identify the most promising areas of needed research in flow-induced vibration in industrial shell-and-tube heat exchangers. An international panel of 14 vibration experts, representing ongoing research, was invited to present their evaluation of the current state-of-the-art, and to participate with other attendees in discussions and formulation of research recommendations. The results of the presentations and discussions were published by Chenoweth.

During the workshop, the panelists stressed the importance of obtaining and using field data to establish the validity of any prediction method. The difficulty of obtaining reliable field data was recognized, and the development of improved methods (i.e., data banks) to acquire such data was recommended.

Based, in part, on the results and recommendations from this workshop, development of a bank of field data was selected as one of two program activities to be assigned to ANL. The second activity involves obtaining tube-vibration data under controlled conditions from testing of a specially built, industrial size, segmentally baffled shell-and-tube heat exchanger.

III. OBJECTIVES

The DOE/ANL/HTRI Heat Exchanger Tube Vibration Data Bank has as its immediate objective the collection of sufficient, reliable, well-documented field data to (1) demonstrate confidence in the application of available prediction methods to the design of equipment; (2) provide a basis for improving these methods; or (3) provide the researcher with information for developing new methods. The ultimate goal, in addition to reducing the number of heat exchangers that experience detrimental vibrations, is to minimize the number of heat exchangers that are unnecessarily overdesigned to avoid flow-induced vibration problems.

IV. ASSESSMENT OF DIFFICULTIES

Following are some of the reasons why it may be difficult to obtain comprehensive field data on flow-induced vibration in shell-and-tube heat exchangers.

(1) Plant managers and field service engineers are, understandably, more interested in getting a plant back into production than investigating the source of vibration-induced failure of a heat exchanger.

(2) Before a vibration problem develops, there is no incentive to make observations that could identify the source of the problem. Thus, although a long-term phenomenon may have caused the failure, recent operational changes are usually suspected.

(3) Actual operating conditions often do not agree with conditions assumed in the design of a heat exchanger, particularly during startup, shutdown, and plant upsets. It is reasonable to suspect many vibration problems are initiated during these phases of operation.

(4) Flow velocity profiles within a tube bundle and tube damping, both important parameters in any prediction method, are difficult to measure and to calculate.

(5) Records are seldom kept of "as built" heat exchangers. Deviations during initial construction and subsequent field changes are not always noted on drawings.

(6) Before organizations will release the desired amount of data, they must be assured that its source will be protected and that its use will be restricted to evaluation of prediction methods.

The last item was a contributing factor in the decision to assign an independent, non-government organization (i.e., HTRI) the task of collecting, storing, and coding the data forwarded to ANL.

V. DATA FORM

It is important that the data be collected in a systematic way, be as complete as possible, and as accurate as practical. Toward this end, a standard questionnaire is required which lists the desired information that may be available but may not be considered significant by each contributor.

The questionnaire should provide entries for sufficient primary data to enable an investigator (1) to calculate important derived data such as flow velocity fractions and natural frequencies (if not measured); (2) to input the data in various predition methods; (3) to compare the calculated results with actual performance; and (4) to request additional information that may be made available by the source.

The DOE/ANL/HTRI Heat Exchanger Tube Vibration Data Form and Instruction Sheet developed to satisfy these requirements are reproduced in Appendix 1. The 4-page data form is based on a Heat Exchanger Vibration Data Sheet developed and used by HTRI to accumulate their data bank. In consultation with HTRI, the format of their data sheet has been rearranged and enlarged to motivate and accommodate more input, particularly with respect to vibration damage description, analysis of two-phase flow, and evaluation of the influence of axial forces on tubes.

As the case histories are received by HTRI, they will be coded. Page 1 of the Data Form will be retained in a confidential file. Pages 2, 3, and 4, which contain the pertinent technical information will be sent to ANL for inclusion in the DOE/ANL/HTRI Heat Exchanger Tube Vibration Bank.

VI. SOLICITATION

As discussed above, the task of soliciting case histories has been assigned to HTRI. The letter of solicitation that accompanies the data form is included in Appendix 1.

A direct solicitation for case histories has been made to HTRI member organizations (> 150) located through the world. Additionally, non-HTRI member organizations will be solicited.

The vibration problem is sufficiently complex, that a follow-up procedure will be implemented to ensure complete documentation of each case history. In addition, the quality of the information will be evaluated; poor data with inadequate documentation will only be misleading. It is better to have fewer reliable data in a data bank than a larger amount of questionable data.

VII. INITIAL CASE HISTORIES

Fifteen of the most representative of well-documented case histories have been purchased from the HTRI Data Bank, and the information transferred to the new data forms. These forms are reproduced as Appendix 2, and represent the initial case histories of the DOE/ANL/HTRI Heat Exchanger Tube Vibration Data Bank. Owing to the enlarged format and increased number of entries, there are areas where the data are incomplete.

Also included in Appendix 2 is a summary tabulation of the geometries and various process fluids of the heat exchangers.

VIII. DISCUSSION

Successful development of a data bank of heat exchanger tube vibration case histories cannot be guaranteed a priori because of the many difficulties in obtaining data that are sufficiently detailed and reliable. For the most part, these difficulties are beyond the control of the data bank developer. In fact, some investigators who have attempted to assemble a similar bank for evaluation of prediction methods have concluded that such an effort, while initially appealing, is difficult to accomplish in practice because of inherent uncertainties in the data.

Nevertheless, development of the DOE/ANL/HTRI Heat Exchanger Tube Vibration Data Bank is deemed a significant effort toward a better understanding of the phenomena involved, and marked improvement in formulation and application of prediction methods.

More specifically: Although information in the data bank will be predominantly of a qualitative nature, it will aid researchers and design engineers in (1) identifying regions within a tube bundle (such as the first row after the baffle cut) that are most susceptible to vibration and whether the mode of failure is tube wear at the baffle or intertube impacting; and (2) determining the relative effectiveness of various design features (e.g., impingement plates) in reducing the potential for tube vibration.

As a source of practical information, the data bank will be particularly beneficial to researchers who have no direct experience in design or operation of heat exchangers, but are involved in development of design guidelines and corresponding performance-prediction methods.

For the effort to be successful will require the cooperation of the contributors to the bank to ensure that complete and accurate data are provided. Also, it will be necessary to collect case histories from heat exchangers that have as well as those that have not experienced vibration problems, and from units with liquids, gases, and two-phase mixtures as the shellside fluid. As the number of respective case histories increases, trends in the dynamic behavior will become apparent, as will any anomalies that should be disregarded because of inaccurate or uncertain data. As necessary, selected case histories will be followed up with personal contacts and/or on-site visits for purposes of obtaining clarification or additional information.

It is not unreasonable to expect that it will take several years to collect a sufficient number of well-documented cases for the data bank to become a useful tool in the evaluation of prediction methods. However, during this time period the available data will provide useful guidance of research efforts. For example, new methods to calculate flow velocities may be derived which will increase the potential usefulness of the data over what it would be today.

APPENDIX 1

HTRI Solicitation Letter for Tube Vibration Case Histories

and

DOE/ANL/HTRI Heat Exchanger Tube Vibration Data Form

HTRI
HEAT TRANSFER RESEARCH, INC.

Research Facilities
1000 South Fremont Avenue Alhambra, California 91802 Telephone (213) 570-3950
Telex 67-4888 (CFBRAUN) TWX 910-589-3377

Subject: Tube Vibration Data Bank on Shell-and-Tube Heat Exchangers

The importance of correctly predicting, and thus eliminating, the danger of possible tube vibration in shell-and-tube heat exchangers hardly needs to be emphasized. There are many known cases where tube vibration resulted in destruction of tubes with very dangerous and costly consequences. HTRI has been active in tube vibration research for the past eight years.

In October 1976 HTRI organized under contract to ERDA (presently US Department of Energy, DOE) a Tube Vibration Workshop with a panel discussion on the state of the art by selected international experts. (Reference ERDA Report No. SAN/1273-1.) One of the principal conclusions was the urgent need for a tube vibration data bank. To test the various predictive methods developed from theory or laboratory studies, field data on large-scale industrial shell-and-tube heat exchangers are necessary. Our subsequent contract with DOE resulted in

- HTRI consulting on a research program involving a large-scale test exchanger for vibration study at the Argonne National Laboratory. This test is currently under way and is producing most important data. The results will eventually be published as a report from Argonne National Laboratory and will also be made available to the International Energy Agency.
- HTRI, acting on behalf of DOE/Argonne, soliciting and collecting data for a new DOE/ANL/HTRI Heat Exchanger Tube Vibration Data Bank.

The reason Argonne National Laboratory has given the task of establishing the Tube Vibration Data Bank to HTRI is (a) our previous experience in the proper assembly of tube vibration data, and (b) to assure anonymity of the data sources.

By this letter I am requesting support from your company to supply field data on shell-and-tube heat exchangers that experienced vibration problems as well as data on similar exchangers that did not experience vibration problems. Such cases to be useful need to be reasonably well documented. A new Data Form (attached) was developed to assist in collecting the data. It reflects our experience and anticipates items that are significant but might be overlooked. The identity of the data source will be confidential to HTRI Staff as only pages 2, 3, and 4 of the Data Form will be included in the Data Bank. Your cooperation will assure that badly needed data will be available for a well-organized international cooperative project on flow-induced vibration and ultimately the formulation of improved methods for tube vibration prediction.

Sincerely yours,

Jerry Taborek
Technical Director

JT:pth
Attachment

Administrative Office
1499 Huntington Drive, Suite 309 South Pasadena, California 91030
Telephone (213) 570-3980 Telex 67-5355 (HTRI)

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Name of Person Submitting Case ______________________ (Confidential)

Phone Number ______________________

Address ______________________
____
____
____

Item No. ______________________ (Confidential)

Reference No. ______________________ (Confidential)

Assigned Case No. ________

Date Submitted ________

INSTRUCTIONS

HTRI is collecting data on vibration and vibration damage in shell-and-tube heat exchangers which will be incorporated into a Vibration Data Bank sponsored by the U. S. Department of Energy (DOE). Some years ago, TEMA and HTRI collected case studies of vibration which have become the initial entries in the data bank. Recognizing that more comprehensive data are needed, this data collection form has been prepared. The case studies will be used to test and to aid in the improvement of proposed correlations for predicting the occurrence of vibration and possible damage which might result. Until a sufficiently broad data bank can be assembled and used to test possible prediction methods, it will be impossible to make predictions with any degree of confidence.

Any predictive method must not only indicate when vibration problems are probable, but must also predict accurately when they will be absent. Consequently, we are interested in also receiving a number of cases of heat exchangers which did not experience vibration and yet were similar to ones which had vibration problems. Much of the requested information may be available from drawings and/or specification sheets for the exchangers. If these are supplied, only the flow conditions and observed descriptions of damage, vibration frequencies, etc. need be filled in on the data sheets. The company submitting the data and any Item and Reference Numbers used to identify the exchanger will be confidential. HTRI will assign a case number and forward the data to Argonne National Laboratory (ANL) for publication for DOE.

Please fill in the forms as completely as possible. Supplement with photographs, sketches, drawings, and descriptions if available. Indicate known deviation from construction drawings. Add anything you feel would assist in understanding flow-induced vibration. For the benefit of all, please contribute as many cases as possible. Mail the completed forms with attachments to:

Heat Transfer Research, Inc.
1000 S. Fremont Avenue
Alhambra, CA 91802

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 2

Assigned
Case No. ____________

Type ☐ TEMA Exchanger Designation ____________
☐ Special Exchanger (Describe) ____________

Shell Orientation ☐ Horizontal
☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

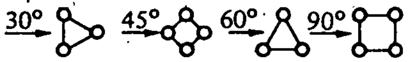
Inside Diameter, mm (in.) ____________
Wall Thickness, mm (in.) ________ Material ____________
Inlet Nozzle ID, mm (in.) ____________
Outlet Nozzle ID, mm (in.) ____________
Impingement Protection ☐ No ☐ Yes
(Describe) ____________
Annular Distributor ☐ No ☐ Yes
Open Cut Area mm² (in.²) ____________
Nozzle-to-First Tube Row Distance, mm (in.) ____________

CROSS BAFFLE GEOMETRY

Type ☐ Segmental; ☐ Double-Segmental ☐ Disc/Doughnut
☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter ____________
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☐ Perpendicular ☐ Parallel ☐ 45°
Central Baffles ☐ Perpendicular ☐ Parallel ☐ 45°
Baffle Thickness, mm (in.) ________ Material ____________
Diametral Clearances Shell-to-baffle, mm (in.) ____________
Tube-to-baffle mm (in.) ____________
Bundle-to-shell, mm (in.) ____________
Number of Baffles Along Length of Shell ____________
Baffle Spacing, mm (in.) ________ Central ____________
Inlet ________ Outlet ____________
Unsupported Tube Span Lengths, mm (in.) ____________
Longest ________ Inlet ________ Outlet ____________

TUBE GEOMETRY

Outside Diameter, mm (in.) ____________
Wall Thickness, mm (in.) ________ Material ____________
Tube Lengths
Straight Tube, Inside Tubesheets, mm (in.) ____________
U-Tube, Tubesheet to Bend Tangent, mm (in.) ____________
Tube Pitch, mm (in.) ____________
Layout (Please Circle)

Flow 

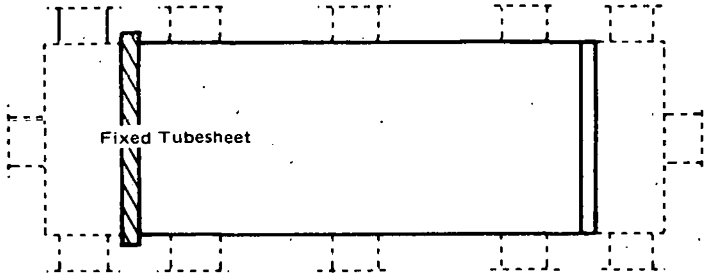
No. of Tubes ________ No. of Tubepasses ____________
First Tubepass ☐ Countercurrent ☐ Cocurrent
Tube-to-Tubesheet Joint
☐ Welded ☐ Roller Expanded ☐ Other ____________
If U-Tube
Maximum Bend Radius, mm (in.) ____________
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel
If Bend Supported, Describe in Comments Below
If Finned Tubes
Fins/m (Fins/in.) ________ Fin Material ____________
Diameter, mm (in.), Root ______ Over Fins ____________
If Enhanced Surface Tubes ____________
(Describe) ____________

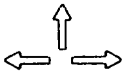
DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

COMMENTS AND SKETCH

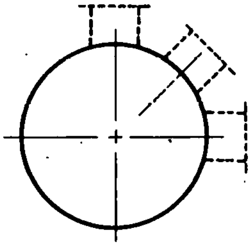
Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.





Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned
Case No. ____________

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	**Shellside**	**Tubeside**	**Shellside**
Flow Rate, kg/s (10^3lb/hr)				
Inlet Temperature, C (F)				
Outlet Temperature, C (F)				
Inlet Pressure, kPa (psia) Absolute				
Measured ΔP, kPa (psi)				
Inlet Weight Fraction Vapor				
Outlet Weight Fraction Vapor				
Vibration Observed	☐ No ☐ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	**Tubeside**		**Shellside**	
Fluid Name				
Reference Temperature, C (F)				
Liquid Properties at Reference Temperatures				
Density, kg/m^3 (lb/ft^3)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/m ft F)				
Heat Capacity, kJ/kg·C (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, kg/m^3 (lb/ft^3)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/hr ft F)				
Heat Capacity, kJ/kg·C (Btu/lb F)				
Fluid Molecular Weight, kg/mol (lb/mole)				
If Boiling or Condensing				
Latent Heat, kJ/kg (Btu/lb)				

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned
Case No. ____________

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, kg/s (10^3 lb/hr)				
If Known, Crossflow Velocity at baffle tip, m/s (ft/sec)*				
Crossflow Velocity at centerline, m/s (ft/sec)*				
Velocity Through Window in Baffle, m/s (ft/sec)*				
Inlet Nozzle Velocity, m/s (ft/sec)*				
Outlet Nozzle Velocity, m/s (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☐ No ☐ Yes

Source Frequency, Hz ________ rpm ____________

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☐ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☐ Cutting at Baffle ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

☐ Corrosion Evident ☐ Fouling Evident

☐ General Description of Damage ____________________________

____

Exchanger Operation History

- How Long on Stream Before Damage Occurred? ____________________
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of

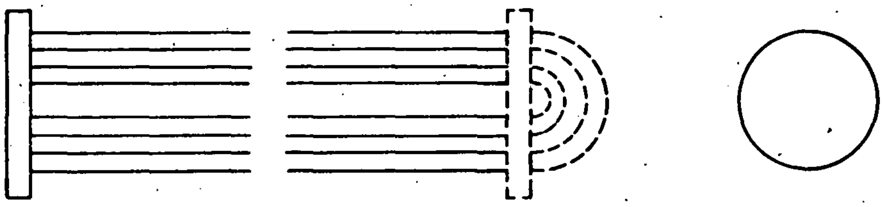
  ☐ Start-up ☐ Plant-Upset ☐ Shutdown

  Describe ____________________________
- If Vibration Remedy Applied, Describe and Indicate Results: ____________________

  ____

  ____

TUBE BUNDLE DAMAGE SKETCH



APPENDIX 2

Case Histories 101-115 of the DOE/ANL/HTRI Tube Vibration Data Bank

Summary of Heat Exchanger Case Histories in Appendix 2

Case No.	Shell Type*	Baffle Type*	Bundle Type	Tube OD in.	Tube Pitch Ratio	Layout Angle deg.	Tubeside Fluid	Shellside Fluid	Shell Diameter in.	Damage Reported
101	BEM	Seg.	FXTS	0.750	1.33	30	City Gas	City Gas	47.2	Noise
102	BJM	Seg.	FXTS	0.750	1.25	60	Water	Refrig.	44.0	Baffle
103	AEP	2-Seg.	OPFH	0.625	1.20	30	Water	Water	19.3	Collision
104	AES	Seg.	SRFH	0.625	1.20	30	Water	Air	10.1	Baffle
105	AET	Seg.	PTFH	0.984	1.28	60	Water	City Gas	57.7	——
106	AET	Seg.	PTFH	0.984	1.28	60	Water	C_2H_4	57.7	Near Tubesheet
107	CEM	2-Seg.	FXTS	0.750	1.25	60	Nat'l Gas	Nat'l Gas	37.0	Baffle
108	CEM	3-Seg.	FXTS	0.750	1.25	60	Nat'l Gas	Nat'l Gas	44.0	Tubejoint
109	CEM	2-Seg.	FXTS	0.750	1.33	60	Nat'l Gas	Nat'l Gas	53.0	——
110	CEN	2-Seg.	FXTS	1.000	1.25	45	Water	Olefin	45.0	Baffle
111	CEN	2-Seg.	FXTS	1.000	1.25	45	Water	Olefin	45.0	——
112	AJS	Seg.	PTFH	0.750	1.33	90	Water	Air	43.0	Tubejoint
113	AEU	Seg.	U-tube	0.750	1.33	90	Water	H.C.	17.3	Baffle
114	AEL	2-Seg.	FXTS	0.750	1.25	60	Rich Gas	Lean Gas	56.0	Near Inlet
115	BJS	Seg.	PTFH	0.750	1.67	90	Water	Proc. Gas	69.0	Noise

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*For definitions, see Standards of Tubular Exchanger Manufacturers Association, Sixth Edition, 1978.

To protect the identity of the organization submitting this case, HTRI has assigned a case number. Additionally the data on pages 2, 3, and 4 have been reviewed to ensure that they do not include any propietary information. This is a replacement for the original page 1 that provides space for additional comments, drawings, photographs, etc.

Assigned Case No. 101

Summary

This 48-in. diameter by 13-ft long BEM TEMA style heat exchanger with segmental baffles had "city gas" in both the shell side and the tube side. Although no direct damage to the tubes was noted, there was a loud noise during operation. The noise was assumed to have been the result of flow-induced acoustic vibration. Information is limited to that presented on data form.

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 2

Assigned Case No. 101

Type ☒ TEMA Exchanger Designation BEM
☐ Special Exchanger (Describe)

Shell Orientation ☒ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 47.2
Wall Thickness, mm (in.) Material
Inlet Nozzle ID, ~~mm~~ (in.) 20
Outlet Nozzle ID, ~~mm~~ (in.) 20
Impingement Protection ☒ No ☐ Yes
(Describe)
Annular Distributor ☒ No ☐ Yes
Open Cut Area mm^2 (in.^{2})
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.) 3.55

CROSS BAFFLE GEOMETRY

Type ☒ Segmental; ☐ Double-Segmental ☐ Disc/Doughnut
☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 25
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☒ Perpendicular ☐ Parallel ☐ 45°
Central Baffles ☒ Perpendicular ☐ Parallel ☐ 45°
Baffle Thickness, ~~mm~~ (in.) 0.437 Material ?
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.118
Tube-to-baffle ~~mm~~ (in.) 0.01
Bundle-to-shell, ~~mm~~ (in.) 4
Number of Baffles Along Length of Shell 3
Baffle Spacing, ~~mm~~ (in.) Central 29.6
Inlet 47.7 Outlet 47.7
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 77.3 Inlet 77.3 Outlet 77.3

TUBE GEOMETRY

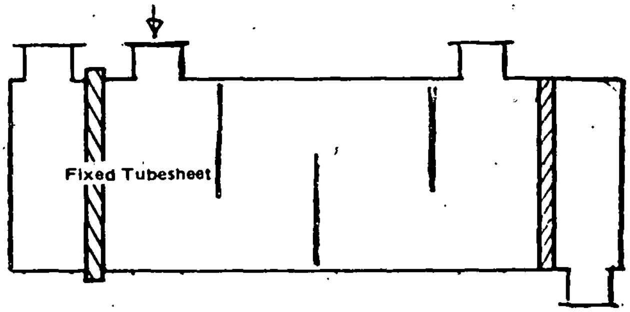
Outside Diameter, ~~mm~~ (in.) 0.750
Wall Thickness, ~~mm~~ (in.) 0.0787 Material 304 SS
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 153
U-Tube, Tubesheet to Bend Tangent, mm (in.) —
Tube Pitch, ~~mm~~ (in.) 1.00
Layout (Please Circle)
Flow [✓ 30°] 45° 60° 90°
No. of Tubes No. of Tubepasses
First Tubepass ☐ Countercurrent ☐ Cocurrent
Tube-to-Tubesheet Joint
☒ Welded ☐ Roller Expanded ☐ Other
If U-Tube
Maximum Bend Radius, mm (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel
If Bend Supported, Describe in Comments Below
If Finned Tubes
Fins/m (Fins/in.) — Fin Material —
Diameter, mm (in.), Root — Over Fins —
If Enhanced Surface Tubes —
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

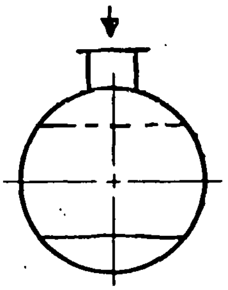
COMMENTS AND SKETCH

Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



Assigned Case No. 101

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)	?	184		
Inlet Temperature, ~~C~~ (F)	69.8	37.4		
Outlet Temperature, ~~C~~ (F)	53.6	54.5		
Inlet Pressure, ~~kPa~~ (psia) Absolute	370	370		
Measured ΔP, ~~kPa~~ (psi) CALCULATED	0.34	0.9		
Inlet Weight Fraction Vapor	1.0	1.0		
Outlet Weight Fraction Vapor	1.0	1.0		
Vibration Observed	☐ No ☒ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	"CITY GAS"		"CITY GAS"	
Reference Temperature ~~C~~ (F)	69.8	53.6	37.4	54.5
Liquid Properties at Reference Temperatures				
Density, kg/m^3 (lb/ft^3)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/m ft F)				
Heat Capacity, kJ/kg·C (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)	0.82	0.82	0.825	0.825
Viscosity, ~~mPa·s~~ (cP)			0.0146	0.0146
Thermal Conductivity, ~~W/m·C~~ (Btu/hr ft F)				
Heat Capacity, ~~kJ/kg·C~~ (Btu/lb F)				
Fluid Molecular Weight, ~~kg/mol~~ (lb/mole)				
If Boiling or Condensing				
Latent Heat, ~~kJ/kg~~ (Btu/lb)	—		—	

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 101

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, ~~kg/s~~ (10^3 lb/hr)	184			
If Known, Crossflow Velocity at baffle tip, ~~m/s~~ (ft/sec)*				
Crossflow Velocity at centerline, ~~m/s~~ (ft/sec)*				
Velocity Through Window in Baffle, ~~m/s~~ (ft/sec)*				
Inlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Outlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz	NOISE NOTED			
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated. HTRI ST-4 COMPUTER PROGRAM

Vibration Caused by External Sources ☒ No ☐ Yes

Source Frequency, Hz ______ rpm ______

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☒ No

☐ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☐ Cutting at Baffle ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

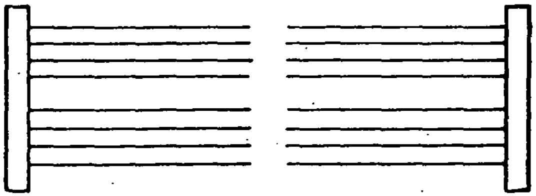
☐ Corrosion Evident ☐ Fouling Evident

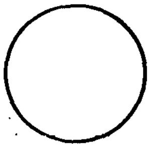
☐ General Description of Damage ______

Exchanger Operation History

- How Long on Stream Before Damage Occurred? ______
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of
  ☐ Start-up ☐ Plant-Upset ☐ Shutdown
  Describe ______
- If Vibration Remedy Applied, Describe and Indicate Results: ______

TUBE BUNDLE DAMAGE SKETCH





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Assigned Case No. 102

Summary

This 44-in. diameter by 12-ft long BEJ TEMA style heat exchanger with segmental baffles had propylene vapor on the shell side and cooling water on the tube side. The vapor entered the shell through the double nozzles. The vapor was cooled but not condensed. Tube damage was noted as cutting at the baffles; however, the specific location in the bundle was not noted. Information is limited to that presented on data form.

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 102

Type ☒ TEMA Exchanger Designation BJM
☐ Special Exchanger (Describe)

Shell Orientation ☒ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 44
Wall Thickness, ~~mm~~ (in.) Material
Inlet Nozzle ID, ~~mm~~ (in.) 20 (TWO)
Outlet Nozzle ID, ~~mm~~ (in.) 24
Impingement Protection ☒ No ☐ Yes
(Describe) —
Annular Distributor ☒ No ☐ Yes
Open Cut Area ~~mm²~~ (in.²) —
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.)

CROSS BAFFLE GEOMETRY

Type ☒ Segmental; ☐ Double-Segmental ☐ Disc/Doughnut
☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 46
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☐ Perpendicular ☒ Parallel ☐ 45°
Central Baffles ☐ Perpendicular ☒ Parallel ☐ 45°
Baffle Thickness, ~~mm~~ (in.) 0.625 Material
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.225
Tube-to-baffle ~~mm~~ (in.) 0.015625
Bundle-to-shell, ~~mm~~ (in.) 0.50
Number of Baffles Along Length of Shell 4
Baffle Spacing, ~~mm~~ (in.) Central 26.375
Inlet 29.75 Outlet 25.375
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 56.75 Inlet 56.75 Outlet 52.375

TUBE GEOMETRY

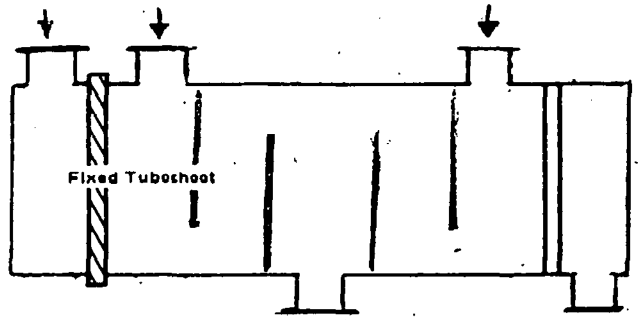
Outside Diameter, ~~mm~~ (in.) 0.750
Wall Thickness, ~~mm~~ (in.) 0.065 Material ADMIRALTY BRASS
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 140.25
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —
Tube Pitch, ~~mm~~ (in.) 0,9375
Layout (Please Circle)
Flow 30° 45° [✓ 60°] 90°
No. of Tubes No. of Tubepasses
First Tubepass ☒ Countercurrent ☒ Cocurrent
Tube-to-Tubesheet Joint
☐ Welded ☒ Roller Expanded ☐ Other
If U-Tube
Maximum Bend Radius, mm (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel
If Bend Supported, Describe in Comments Below
If Finned Tubes
Fins/m (Fins/in.) — Fin Material —
Diameter, mm (in.), Root — Over Fins —
If Enhanced Surface Tubes —
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

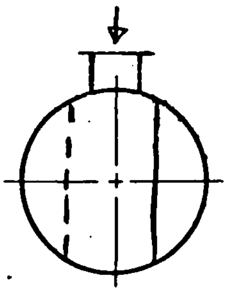
COMMENTS AND SKETCH

Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 3

Assigned
Case No. 102

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)	?	676		
Inlet Temperature, ~~C~~ (F)	75	182		
Outlet Temperature, ~~C~~ (F)	120	100		
Inlet Pressure, ~~kPa~~ (psia) Absolute	69.7	236		
Measured ΔP, ~~kPa~~ (psi)	12.4	4.0		
Inlet Weight Fraction Vapor	0	1.0		
Outlet Weight Fraction Vapor	0	1.0		
Vibration Observed	☐ No ☒ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	COOLING WATER		PROPYLENE	
Reference Temperature, ~~C~~ (F)			100	182
Liquid Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)				
Viscosity, ~~mPa·s~~ (cP)				
Thermal Conductivity, ~~W/m·C~~ (Btu/m ft F)				
Heat Capacity, ~~kJ/kg·C~~ (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)			1.62	1.44
Viscosity, ~~mPa·s~~ (cP)			0.0087	0.0095
Thermal Conductivity, ~~W/m·C~~ (Btu/hr ft F)				
Heat Capacity, ~~kJ/kg·C~~ (Btu/lb F)				
Fluid Molecular Weight, ~~kg/mol~~ (lb/mole)				
If Boiling or Condensing				
Latent Heat, ~~kJ/kg~~ (Btu/lb)	—		—	

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 4

Assigned Case No. 102

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, ~~kg/s~~ (10^3 lb/hr)	676			
If Known, Crossflow Velocity at baffle tip, ~~m/s~~ (ft/sec)*	27.8			
Crossflow Velocity at centerline, ~~m/s~~ (ft/sec)*	26.4			
Velocity Through Window in Baffle, ~~m/s~~ (ft/sec)*	23.8			
Inlet Nozzle Velocity, ~~m/s~~ (ft/sec)*	33.4			
Outlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources. ☐ No ☐ Yes

Source Frequency, Hz ______ rpm ______

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☒ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☒ Cutting at Baffle ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

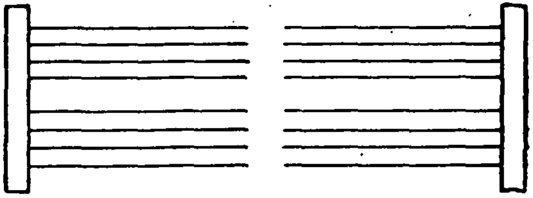
☐ Corrosion Evident ☐ Fouling Evident

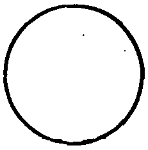
☐ General Description of Damage ______

Exchanger Operation History

- How Long on Stream Before Damage Occurred? ______
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of
  ☐ Start-up ☐ Plant-Upset ☐ Shutdown
  Describe ______
- If Vibration Remedy Applied, Describe and Indicate Results: ______

TUBE BUNDLE DAMAGE SKETCH





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Assigned Case No. 103

Summary

This 20-in. diameter by 7-ft long AEP TEMA style heat exchanger with segmental baffles had water on both the shell side and the tube side. The inlet nozzle orientation was such that its centerline intersected the baffle cut at 45°. The baffle cut was 45 percent of the shell inside diameter which results in little crossflow. The tube damage reported tube-to-tube impact resulting in splitting of the tube material until leaks developed. Information is limited to that presented on data form.

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 2

Assigned Case No. 103

Type ☒ TEMA Exchanger Designation AEP
☐ Special Exchanger (Describe)

Shell Orientation ☒ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 19.25
Wall Thickness, ~~mm~~ (in.) ____ Material ____
Inlet Nozzle ID, ~~mm~~ (in.) 12
Outlet Nozzle ID, ~~mm~~ (in.) 12
Impingement Protection ☒ No ☐ Yes
(Describe) —
Annular Distributor ☒ No ☐ Yes
Open Cut Area ~~mm²~~ (in.²) —
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.) 1.4

CROSS BAFFLE GEOMETRY

Type ☒ Segmental; ☐ Double-Segmental ☐ Disc/Doughnut
☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 45
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☐ Perpendicular ☐ Parallel ☒ 45°
Central Baffles ☐ Perpendicular ☐ Parallel ☒ 45°
Baffle Thickness, ~~mm~~ (in.) 0.375 Material ____
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.141
Tube-to-baffle ~~mm~~ (in.) 0.019
Bundle-to-shell, ~~mm~~ (in.) 2.812
Number of Baffles Along Length of Shell 3
Baffle Spacing, ~~mm~~ (in.) Central 21
Inlet 21 Outlet 21
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 42 Inlet ____ Outlet ____

TUBE GEOMETRY

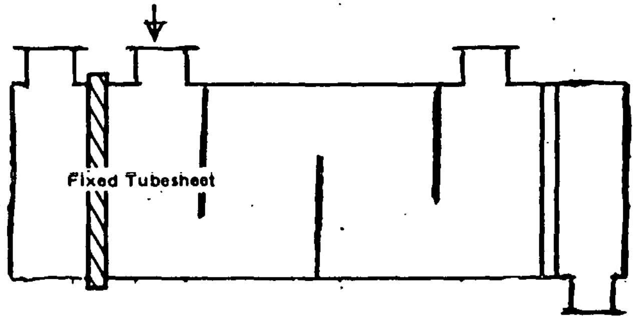
Outside Diameter, ~~mm~~ (in.) 0.625
Wall Thickness, ~~mm~~ (in.) 0.049 Material 90/10 CuNi
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 84
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —
Tube Pitch, ~~mm~~ (in.) 0.750
Layout (Please Circle)
Flow [✓ 30°] 45° 60° 90°
No. of Tubes 407 No. of Tubepasses 1
First Tubepass ☐ Countercurrent ☐ Cocurrent
Tube-to-Tubesheet Joint
☐ Welded ☒ Roller Expanded ☐ Other ____
If U-Tube
Maximum Bend Radius, mm (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel
If Bend Supported, Describe in Comments Below
If Finned Tubes
Fins/m (Fins/in.) — Fin Material —
Diameter, mm (in.), Root — Over Fins —
If Enhanced Surface Tubes —
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

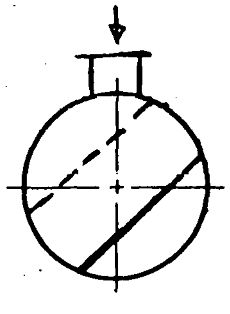
COMMENTS AND SKETCH

Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



⇦ ⬆ ⇨ Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



PAIR OF SEAL STRIPS

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 3

Assigned
Case No. 103

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)		800		
Inlet Temperature, ~~C~~ (F)		140		
Outlet Temperature, ~~C~~ (F)		134		
Inlet Pressure, ~~kPa~~ (psia) Absolute		~30		
Measured ΔP, ~~kPa~~ (psi)				
Inlet Weight Fraction Vapor		0		
Outlet Weight Fraction Vapor		0		
Vibration Observed	☐ No ☒ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	WATER		WATER	
Reference Temperature, C (F)				
Liquid Properties at Reference Temperatures				
Density, kg/m^3 (lb/ft^3)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/m ft F)				
Heat Capacity, kJ/kg·C (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, kg/m^3 (lb/ft^3)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/hr ft F)				
Heat Capacity, kJ/kg·C (Btu/lb F)				
Fluid Molecular Weight, kg/mol (lb/mole)				
If Boiling or Condensing				
Latent Heat, kJ/kg (Btu/lb)				

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 103

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, ~~kg/s~~ (10^3 lb/hr)	800			
If Known, Crossflow Velocity at baffle tip, m/s (ft/sec)*				
Crossflow Velocity at centerline, m/s (ft/sec)*				
Velocity Through Window in Baffle, m/s (ft/sec)*				
Inlet Nozzle Velocity, m/s (ft/sec)*				
Outlet Nozzle Velocity, m/s (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☐ No ☐ Yes

Source Frequency, Hz ______ rpm ______

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☒ Yes Complete sketch at bottom of page indicating location in bundle

Type ☒ Tube-to-Tube Impact ☐ Cutting at Baffle ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

☐ Corrosion Evident ☐ Fouling Evident

☐ General Description of Damage TUBES SPLIT AND LEAKING

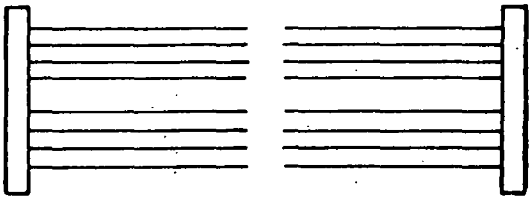
Exchanger Operation History

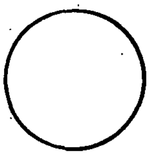
- How Long on Stream Before Damage Occurred? ______
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of

  ☐ Start-up ☐ Plant-Upset ☐ Shutdown

  Describe ______
- If Vibration Remedy Applied, Describe and Indicate Results: ______

TUBE BUNDLE DAMAGE SKETCH





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Assigned Case No. 104

Summary

This 10-in. diameter by 6-ft long AES TEMA style heat exchanger with segmental baffles had air on the shell side and water on the tube side. The inlet nozzle orientation was such that its centerline intersected the baffle cut at 45°. The baffle cut was 45 percent of the shell inside diameter which results in little crossflow. All tubes showed evidence of cutting at each baffle. It was noted that there was a possibility that the vibration might have been induced by outside sources. Information is limited to that presented on data form.

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 2

Assigned Case No. 104

Type ☒ TEMA Exchanger Designation AES
☐ Special Exchanger (Describe)

Shell Orientation ☐ Horizontal ☐ Vertical
NOT GIVEN

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 10.136
Wall Thickness, ~~mm~~ (in.) Material
Inlet Nozzle ID, ~~mm~~ (in.) 5
Outlet Nozzle ID, ~~mm~~ (in.) 5
Impingement Protection ☒ No ☐ Yes
(Describe) —
Annular Distributor ☒ No ☐ Yes
Open Cut Area ~~mm²~~ (in.²) —
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.)

CROSS BAFFLE GEOMETRY

Type ☒ Segmental; ☐ Double-Segmental ☐ Disc/Doughnut ☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 45
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☐ Perpendicular ☐ Parallel ☒ 45°
Central Baffles ☐ Perpendicular ☐ Parallel ☒ 45°
Baffle Thickness, ~~mm~~ (in.) 0.375 Material
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.090
Tube-to-baffle ~~mm~~ (in.) 0.019
Bundle-to-shell, ~~mm~~ (in.) 2.636
Number of Baffles Along Length of Shell 6
Baffle Spacing, ~~mm~~ (in.) Central 10
Inlet 10 Outlet 10
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 20 Inlet 20 Outlet 20

TUBE GEOMETRY

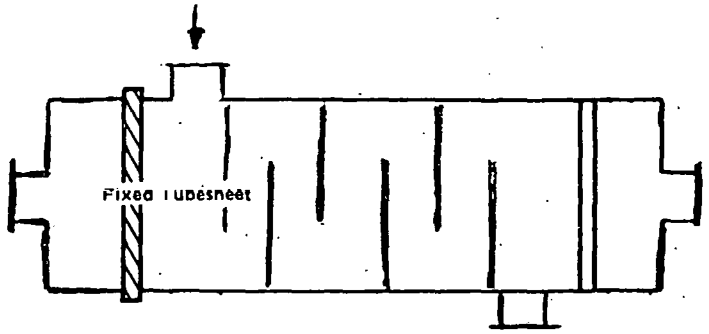
Outside Diameter, ~~mm~~ (in.) 0.625
Wall Thickness, ~~mm~~ (in.) 0.065 Material 90/10 CuNi
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 70
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —
Tube Pitch, ~~mm~~ (in.) 0.750
Layout (Please Circle)
Flow [✓ 30°] 45° 60° 90°
No. of Tubes 78 No. of Tubepasses 1
First Tubepass ☐ Countercurrent ☐ Cocurrent
Tube-to-Tubesheet Joint
☐ Welded ☐ Roller Expanded ☐ Other NOT GIVEN
If U-Tube
Maximum Bend Radius, mm (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel
If Bend Supported, Describe in Comments Below
If Finned Tubes
Fins/m (Fins/in.) — Fin Material —
Diameter, mm (in.), Root — Over Fins —
If Enhanced Surface Tubes —
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

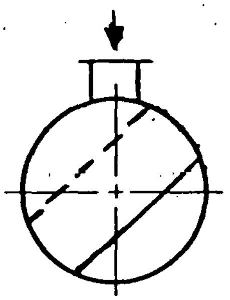
COMMENTS AND SKETCH

Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



⇦ ⇧ ⇨ Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



TWO PAIRS OF SEAL STRIPS

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 3

Assigned
Case No. 104

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	**Shellside**	**Tubeside**	**Shellside**
Flow Rate, ~~kg/s~~ (10^3lb/hr)		10.476		
Inlet Temperature, ~~C~~ (F)	163.7	530		
Outlet Temperature, ~~C~~ (F)	170.6	250		
Inlet Pressure, ~~kPa~~ (psia) Absolute		113		
Measured ΔP, ~~kPa~~ (psi)				
Inlet Weight Fraction Vapor		1.0		
Outlet Weight Fraction Vapor		1.0		
Vibration Observed	☐ No ☒ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	**Tubeside**		**Shellside**	
Fluid Name	WATER		AIR	
Reference Temperature C (F)				
Liquid Properties at Reference Temperatures				
Density, kg/m³ (lb/ft³)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/m ft F)				
Heat Capacity, kJ/kg·C (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, kg/m³ (lb/ft³)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/hr ft F)				
Heat Capacity, kJ/kg·C (Btu/lb F)				
Fluid Molecular Weight, kg/mol (lb/mole)				
if Boiling or Condensing				
Latent Heat, kJ/kg (Btu/lb)				

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 104

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, ~~kg/s~~ (10^3 lb/hr)	10.476			
If Known, Crossflow Velocity at baffle tip, ~~m/s~~ (ft/sec)*				
Crossflow Velocity at centerline, ~~m/s~~ (ft/sec)*	62.9			
Velocity Through Window in Baffle, ~~m/s~~ (ft/sec)*	22			
Inlet Nozzle Velocity, ~~m/s~~ (ft/sec)*	69			
Outlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, ~~db~~	NOISE NOTED			

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☐ No ☐ Yes ☒ POSSIBLE

Source Frequency, Hz ______ rpm ______

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☒ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☒ Cutting at Baffle ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

☐ Corrosion Evident ☐ Fouling Evident

☐ General Description of Damage ALL TUBES SHOWED EVIDENCE OF CUTTING AT EACH BAFFLE

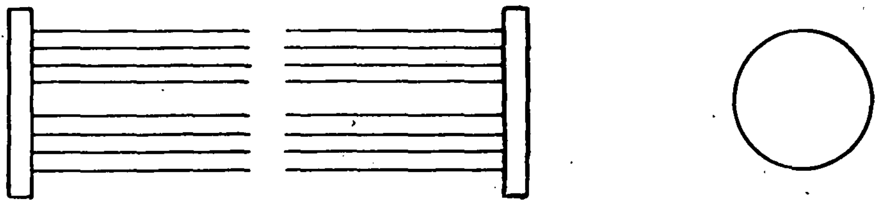
Exchanger Operation History

- How Long on Stream Before Damage Occurred? ______
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of

  ☐ Start-up ☐ Plant-Upset ☐ Shutdown

  Describe ______
- If Vibration Remedy Applied, Describe and Indicate Results: ______

TUBE BUNDLE DAMAGE SKETCH



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Assigned Case No. **105**

Summary

This 57-in. diameter by 12-ft long AET TEMA style heat exchanger with segmental baffles had acetylene on the shellside and water on the tubeside. The tube span for baffle window tubes at the inlet and the outlet greatly exceeded the TEMA Standards for maximum spans for 1-in. carbon steel tubes. However, for this case no vibration was noted for the given flow rates. Information is limited to that presented on data form.

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 2

Assigned Case No. 105

Type ☒ TEMA Exchanger Designation AET
☐ Special Exchanger (Describe)

Shell Orientation ☒ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

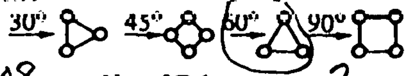
Inside Diameter, ~~mm~~ (in.) 57.3
Wall Thickness, ~~mm~~ (in.) Material
Inlet Nozzle ID, ~~mm~~ (in.) 22.8
Outlet Nozzle ID, ~~mm~~ (in.) 22.8
Impingement Protection ☒ No ☐ Yes
(Describe) —
Annular Distributor ☒ No ☐ Yes
Open Cut Area ~~mm²~~ (in.²) —
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.) 4.41

CROSS BAFFLE GEOMETRY

Type ☒ Segmental; ☐ Double-Segmental ☐ Disc/Doughnut
☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 44
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☐ Perpendicular ☒ Parallel ☐ 45°
Central Baffles ☐ Perpendicular ☒ Parallel ☐ 45°
Baffle Thickness, ~~mm~~ (in.) 0.625 Material
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.27
Tube-to-baffle ~~mm~~ (in.) 0.02
Bundle-to-shell, ~~mm~~ (in.) 3.74
Number of Baffles Along Length of Shell 6
Baffle Spacing, ~~mm~~ (in.) Central 34.65
Inlet 55.5 Outlet 40.56
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 90.15 Inlet 90.15 Outlet 75.21

TUBE GEOMETRY

Outside Diameter, ~~mm~~ (in.) 0.988
Wall Thickness, ~~mm~~ (in.) 0.079 Material CS
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 234.65
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —
Tube Pitch, ~~mm~~ (in.) 1.26
Layout (Please Circle)



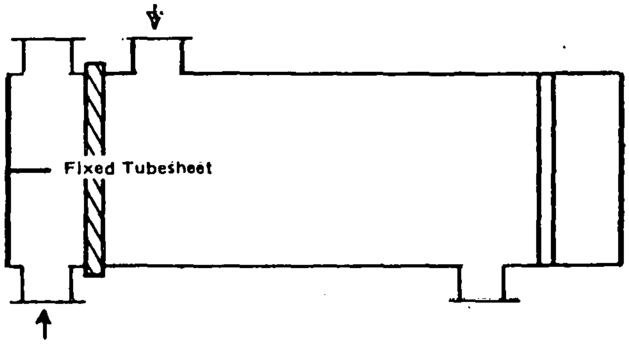
No. of Tubes 1508 No. of Tubepasses 2
First Tubepass ☒ Countercurrent ☐ Cocurrent
Tube-to-Tubesheet Joint
☒ Welded ☐ Roller Expanded ☐ Other
If U-Tube
Maximum Bend Radius, ~~mm~~ (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel —
If Bend Supported, Describe in Comments Below
If Finned Tubes
~~Fins/m~~ (Fins/in.) — Fin Material —
Diameter, ~~mm~~ (in.), Root — Over Fins —
If Enhanced Surface Tubes —
(Describe) —

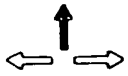
DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

COMMENTS AND SKETCH

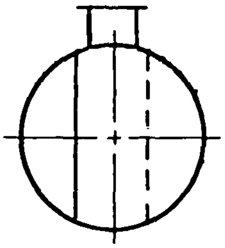
Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.





Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 3

Assigned Case No. 105

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)		351		
Inlet Temperature, ~~C~~ (F)	74.7	201		
Outlet Temperature, ~~C~~ (F)	10.4	86		
Inlet Pressure, ~~kPa~~ (psia) Absolute	65.4	277		
Measured ΔP, ~~kPa~~ (psi)				
Inlet Weight Fraction Vapor	0	1.0		
Outlet Weight Fraction Vapor	0	1.0		
Vibration Observed	☒ No ☐ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	WATER		C_2H_2	
Reference Temperature ~~C~~ (F)			201	86
Liquid Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)				
Viscosity, ~~mPa·s~~ (cP)				
Thermal Conductivity, ~~W/m-C~~ (Btu/m ft F)				
Heat Capacity, ~~kJ/kg-C~~ (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)			1.16	1.52
Viscosity, mPa·s (cP)			0.127	
Thermal Conductivity, ~~W/m-C~~ (Btu/hr ft F)				
Heat Capacity, ~~kJ/kg-C~~ (Btu/lb F)				
Fluid Molecular Weight, ~~kg/mol~~ (lb/mole)				
If Boiling or Condensing				
Latent Heat, ~~kJ/kg~~ (Btu/lb)			—	

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 105

VIBRATION AND DAMAGE DESCRIPTION NO VIBRATION NOTED

When Vibration Present, Shellside Flow Rate, kg/s (10^3 lb/hr)				
If Known, Crossflow Velocity at baffle tip, m/s (ft/sec)*				
Crossflow Velocity at centerline, m/s (ft/sec)*				
Velocity Through Window in Baffle, m/s (ft/sec)*				
Inlet Nozzle Velocity, m/s (ft/sec)*				
Outlet Nozzle Velocity, m/s (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☐ No ☐ Yes

Source Frequency, Hz ________ rpm ________

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☐ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☐ Cutting at Baffle ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

☐ Corrosion Evident ☐ Fouling Evident

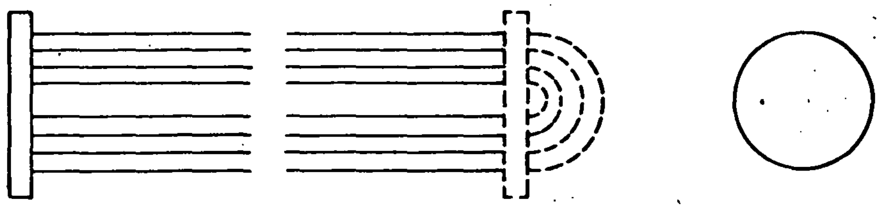
☐ General Description of Damage ________

Exchanger Operation History

- How Long on Stream Before Damage Occurred? ________
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of
  ☐ Start-up ☐ Plant-Upset ☐ Shutdown

  Describe ________
- If Vibration Remedy Applied, Describe and Indicate Results: ________

TUBE BUNDLE DAMAGE SKETCH



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Assigned Case No. 106

Summary

This 57-in. diameter by 12-ft long AET TEMA style heat exchanger with segmental baffles had acetylene on the shellside and water on the tubeside. The tubespan for the baffle window tubes at the inlet and outlet were nearly the limit specified in the TEMA Standards for 1-in. carbon steel tubes. Flow-induced tube vibration is indicated as the cause for tube damage near the tubesheet. Information is limited to that presented on the data form.

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 2

Assigned Case No. 106

Type ☒ TEMA Exchanger Designation A E T
☐ Special Exchanger (Describe)

Shell Orientation ☒ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 57.3
Wall Thickness, ~~mm~~ (in.) ______ Material ______
Inlet Nozzle ID, ~~mm~~ (in.) 22.8
Outlet Nozzle ID, ~~mm~~ (in.) 22.8
Impingement Protection ☒ No ☐ Yes
(Describe) —
Annular Distributor ☒ No ☐ Yes
Open Cut Area ~~mm~~² (in.²) —
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.) 1.87

CROSS BAFFLE GEOMETRY

Type ☒ Segmental; ☐ Double-Segmental ☐ Disc/Doughnut
☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 44
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☒ Perpendicular ☐ Parallel ☐ 45°
Central Baffles ☒ Perpendicular ☐ Parallel ☐ 45°
Baffle Thickness, ~~mm~~ (in.) 0.63 Material ______
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.27
Tube-to-baffle ~~mm~~ (in.) 0.02
Bundle-to-shell, ~~mm~~ (in.) 3.74
Number of Baffles Along Length of Shell 3
Baffle Spacing, ~~mm~~ (in.) Central 34.49
Inlet 40.1 Outlet 34.34
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 74.6 Inlet 74.6 Outlet 68.82

TUBE GEOMETRY

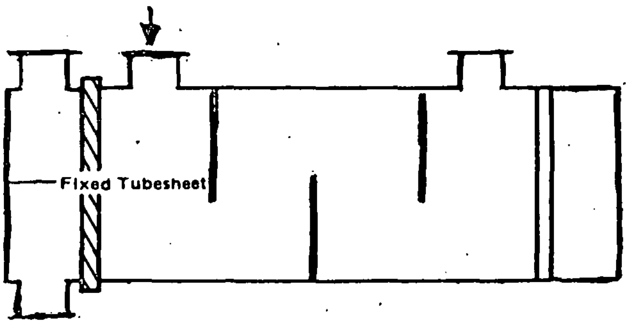
Outside Diameter, ~~mm~~ (in.) 0.988
Wall Thickness, ~~mm~~ (in.) 0.07874 Material CS
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 143.48
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —
Tube Pitch, ~~mm~~ (in.) 1.26
Layout (Please Circle)
Flow 30° 45° [✓ 60°] 90°
No. of Tubes 1508 No. of Tubepasses 4
First Tubepass ☐ Countercurrent ☐ Cocurrent
Tube-to-Tubesheet Joint
☒ Welded ☐ Roller Expanded ☐ Other ______
If U-Tube
Maximum Bend Radius, ~~mm~~ (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel
If Bend Supported, Describe in Comments Below
If Finned Tubes
~~Fins/m~~ (Fins/in.) — Fin Material —
Diameter, ~~mm~~ (in.), Root ____ Over Fins —
If Enhanced Surface Tubes —
(Describe) —

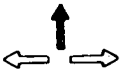
DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

COMMENTS AND SKETCH

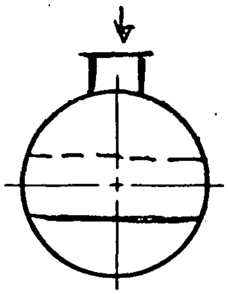
Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.





Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 3

Assigned Case No. 106

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)		405		
Inlet Temperature, ~~C~~ (F)	71.6	201		
Outlet Temperature, ~~C~~ (F)	97.3	86		
Inlet Pressure, ~~kPa~~ (psia) Absolute		277		
Measured ΔP, ~~kPa~~ (psi)				
Inlet Weight Fraction Vapor	0	1.0		
Outlet Weight Fraction Vapor	0	1.0		
Vibration Observed	☐ No ☒ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	WATER		C_2H_4	
Reference Temperature ~~C~~ (F)			201	
Liquid Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)				
Viscosity, ~~mPa-s~~ (cP)				
Thermal Conductivity, ~~W/m-C~~ (Btu/m ft F)				
Heat Capacity, ~~kJ/kg-C~~ (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)				
Viscosity, ~~mPa-s~~ (cP)			0.0127	
Thermal Conductivity, ~~W/m-C~~ (Btu/hr ft F)				
Heat Capacity, ~~kJ/kg-C~~ (Btu/lb F)				
Fluid Molecular Weight, ~~kg/mol~~ (lb/mole)				
If Boiling or Condensing				
Latent Heat, ~~kJ/kg~~ (Btu/lb)				

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 106

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, ~~kg/s~~ (10^3 lb/hr)	405			
If Known, Crossflow Velocity at baffle tip, ~~m/s~~ (ft/sec)*				
Crossflow Velocity at centerline, ~~m/s~~ (ft/sec)*				
Velocity Through Window in Baffle, ~~m/s~~ (ft/sec)*				
Inlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Outlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☐ No ☐ Yes

Source Frequency, Hz ______ rpm ______

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☒ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☐ Cutting at Baffle ☒ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

☐ Corrosion Evident ☐ Fouling Evident

☐ General Description of Damage ______

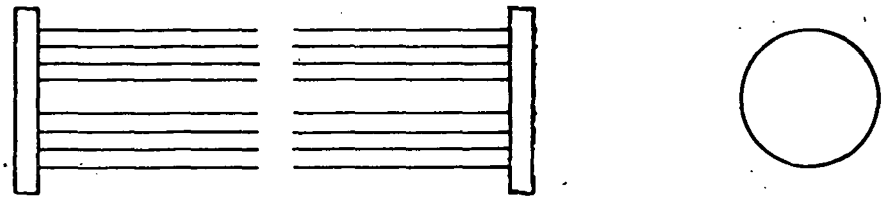
Exchanger Operation History

- How Long on Stream Before Damage Occurred? ______
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of

  ☐ Start-up ☐ Plant-Upset ☐ Shutdown

  Describe ______
- If Vibration Remedy Applied, Describe and Indicate Results: ______

TUBE BUNDLE DAMAGE SKETCH



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Assigned Case No. 107

Summary

This 37-in. diameter by 40-ft long CEM TEMA style heat exchanger is one of two in series joined by welding their shells together. The tubeside fluid, natural gas with ethylene glycol to prevent hydration, passes from the one exchanger to the next without external piping. The shellside fluid, natural gas, flows counter current and between shells through external piping. Both exchangers were identical on the shell side and both experienced similar tube damage in the same locations of the exchanger. Most of the damage was noted after operating the plant at more than 40 percent higher than the designed shellside flow. Leaking tubes were plugged. During a subsequent overhaul of the bundles, the leaking tubes were found to be "broken on side near the nozzles." It is interesting to note that the damaged tubes were not those with the longest span at the inlet end zone.

For this case, there are construction drawings and a field report describing the operation history and the repairs made to the exchanger.

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 2

Assigned Case No. 107

Type ☒ TEMA Exchanger Designation CEM FIXED TUBESHEET
☐ Special Exchanger (Describe)

Shell Orientation ☒ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 37
Wall Thickness, ~~mm~~ (in.) 1.5 Material CS
Inlet Nozzle ID, ~~mm~~ (in.) 16
Outlet Nozzle ID, ~~mm~~ (in.) 16
Impingement Protection ☐ No ☒ Yes
(Describe) CIRCULAR PLATE 16.5" OD
Annular Distributor ☒ No ☐ Yes
Open Cut Area ~~mm²~~ (in.²) —
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.) 6.125

CROSS BAFFLE GEOMETRY

Type ☐ Segmental; ☒ Double-Segmental ☐ Disc/Doughnut
☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 30.3 (1 TUBE OVERLAP)
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☐ Perpendicular ☒ Parallel ☐ 45°
Central Baffles ☐ Perpendicular ☒ Parallel ☐ 45°
Baffle Thickness, ~~mm~~ (in.) 0.625 Material CS
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.1875
Tube-to-baffle ~~mm~~ (in.) 0.0156
Bundle-to-shell, ~~mm~~ (in.) 1.500
Number of Baffles Along Length of Shell 16
Baffle Spacing, ~~mm~~ (in.) Central 27.3
Inlet 30.6 Outlet 30.6
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 57.9 Inlet 57.9 Outlet 57.9

TUBE GEOMETRY

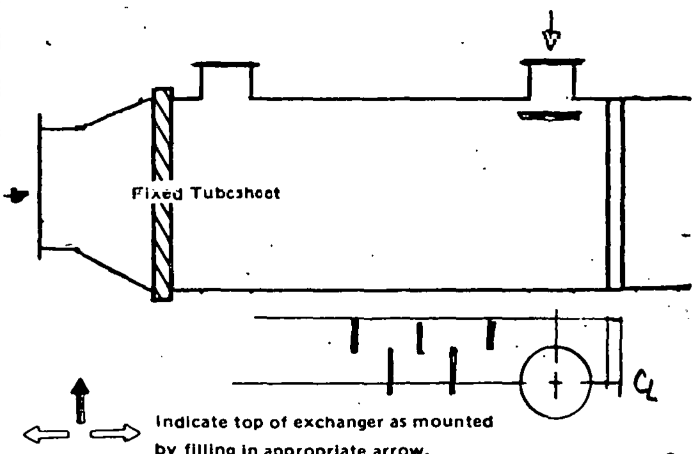
Outside Diameter, ~~mm~~ (in.) 0.750
Wall Thickness, ~~mm~~ (in.) 0.065 Material CS
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 467.1
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —
Tube Pitch, mm (in.) 0.9375
Layout (Please Circle)
Flow 30° 45° [✓ 60°] 90°
No. of Tubes 1170 No. of Tubepasses 1
First Tubepass ☒ Countercurrent ☐ Cocurrent
Tube-to-Tubesheet Joint NOT GIVEN
☐ Welded ☐ Roller Expanded ☐ Other
If U-Tube
Maximum Bend Radius, mm (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel
If Bend Supported, Describe in Comments Below
If Finned Tubes
~~Fins/m~~ (Fins/in.) — Fin Material —
Diameter, ~~mm~~ (in.), Root — Over Fins —
If Enhanced Surface Tubes —
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

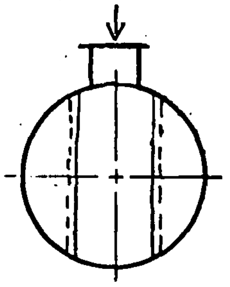
COMMENTS AND SKETCH

Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned
Case No. 107

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)		341.5		210
Inlet Temperature, ~~C~~ (F)	69	-23	86	-29
Outlet Temperature, ~~C~~ (F)	25	57	26	80
Inlet Pressure, ~~kPa~~ (psia) Absolute	1055	1045	10·50	1040
Measured ΔP, ~~kPa~~ (psi)	10	20	5	8
Inlet Weight Fraction Vapor	1.0	1.0	1.0	1.0
Outlet Weight Fraction Vapor	1.0	1.0	1.0	1.0
Vibration Observed	☐ No ☒ Yes		☒ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	NATURAL GAS + GLYCOL		NATURAL GAS	
Reference Temperature, C (F)				
Liquid Properties at Reference Temperatures				
Density, kg/m^3 (lb/ft^3)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/m ft F)				
Heat Capacity, kJ/kg·C (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, kg/m^3 (lb/ft^3)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/hr ft F)				
Heat Capacity, kJ/kg·C (Btu/lb F)				
Fluid Molecular Weight, kg/mol (lb/mole)				
If Boiling or Condensing				
Latent Heat, kJ/kg (Btu/lb)	—		—	

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 107

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, ~~kg/s~~ (10^3 lb/hr)	341.5			
If Known, Crossflow Velocity at baffle tip, ~~m/s~~ (ft/sec)*				
Crossflow Velocity at centerline, ~~m/s~~ (ft/sec)*				
Velocity Through Window in Baffle, ~~m/s~~ (ft/sec)*				
Inlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Outlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☒ No ☐ Yes

Source Frequency, Hz ______ rpm ______

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☒ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☐ Cutting at Baffle ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

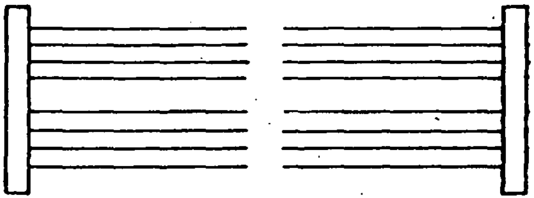
☐ Corrosion Evident ☐ Fouling Evident

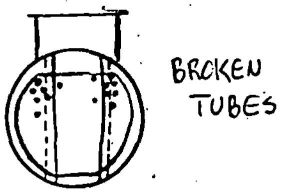
☒ General Description of Damage "BROKEN TUBES" ON SIDE OF BUNDLE NEAR NOZZLES.

Exchanger Operation History

- How Long on Stream Before Damage Occurred? ______
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of
  ☐ Start-up ☐ Plant-Upset ☐ Shutdown
  Describe ______
- If Vibration Remedy Applied, Describe and Indicate Results: ______

TUBE BUNDLE DAMAGE SKETCH





DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

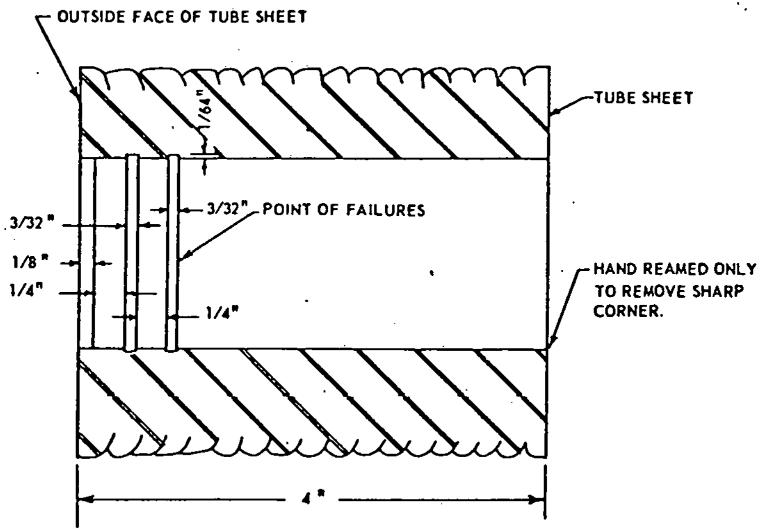
To protect the identity of the organization submitting this case, HTRI has assigned a case number. Additionally the data on pages 2, 3, and 4 have been reviewed to ensure that they do not include any propietary information. This is a replacement for the original page 1 that provides space for additional comments, drawings, photographs, etc.

Assigned Case No. 108

Summary

This 44-in. diameter by 40-ft long CEM TEMA style heat exchanger is one of three that are joined tubesheet to tubesheet so that in effect the tubes are 120 ft long. The tubeside flow is natural gas with glycol to prevent hydration while the shellside flow is counter current and passes between shells through external piping. The bundle uses triple-segmental baffles so the shellside flow is primarily axial. The tube spans are longer than TEMA Standards maximum spans for 3/4-in. carbon steel. The heat exchanger operated successfully for one and a half years at the design conditions. However, tubes began leaking where they were joined to the tubesheet in all three exchangers when the shellside flow rate was substantially increased beyond that used for design. The sketch below indicates the location of these failures. The failed tubes were characterized by particularly long spans in the outlet end zones. Minor cutting of the tubes at the baffles was also reported.

For this case, there are construction drawings and a field report describing the operating history, the damage noted, and the repairs made to the exchanger.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 2

Assigned Case No. 108

Type ☒ TEMA Exchanger Designation CEM (FIXED TUBESHEET)
☐ Special Exchanger (Describe)

Shell Orientation ☒ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 44
Wall Thickness, ~~mm~~ (in.) Material CS
Inlet Nozzle ID, ~~mm~~ (in.) 17.9
Outlet Nozzle ID, ~~mm~~ (in.) 17.9 (21.6 SHELL C)
Impingement Protection ☒ No ☐ Yes
(Describe) —
Annular Distributor ☒ No ☐ Yes
Open Cut Area ~~mm²~~ (in.²) —
Nozzle-to-First Tube Row Distance, mm (in.) 8.4

CROSS BAFFLE GEOMETRY

Type ☐ Segmental; ☐ Double-Segmental ☐ Disc/Doughnut
☒ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 35
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☐ Perpendicular ☒ Parallel ☐ 45°
Central Baffles ☐ Perpendicular ☒ Parallel ☐ 45°
Baffle Thickness, ~~mm~~ (in.) 0.625 Material CS
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.239
Tube-to-baffle ~~mm~~ (in.) 0.0194
Bundle-to-shell, ~~mm~~ (in.) 0.632
Number of Baffles Along Length of Shell 22
Baffle Spacing, ~~mm~~ (in.) Central 18.5
Inlet 40.62 Outlet 40.63
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 77.63 Inlet 77.62 Outlet 77.63

TUBE GEOMETRY

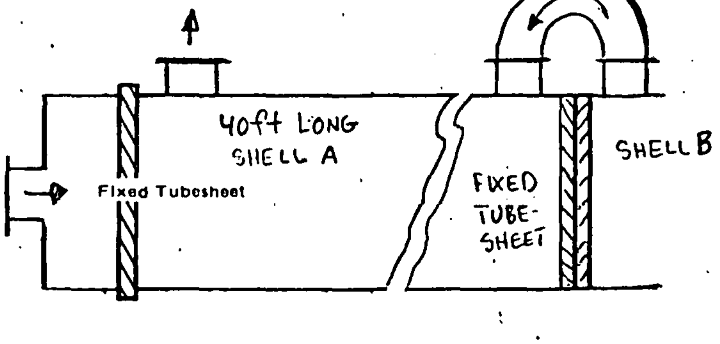
Outside Diameter, ~~mm~~ (in.) 0.750
Wall Thickness, ~~mm~~ (in.) 0.060 Material CS
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 469.75
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —
Tube Pitch, ~~mm~~ (in.) 0.9375
Layout (Please Circle)
Flow 30° 45° [✓ 60°] 90°
No. of Tubes 2160 No. of Tubepasses 1
First Tubepass ☒ Countercurrent ☐ Cocurrent
Tube-to-Tubesheet Joint
☐ Welded ☒ Roller Expanded ☐ Other
If U-Tube
Maximum Bend Radius, ~~mm~~ (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel
If Bend Supported, Describe in Comments Below
If Finned Tubes
~~Fins/m~~ (Fins/in.) — Fin Material —
Diameter, ~~mm~~ (in.), Root — Over Fins —
If Enhanced Surface Tubes —
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

COMMENTS AND SKETCH

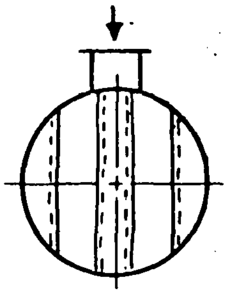
Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



Indicate top of exchanger as mounted by filling in appropriate arrow.

3 SHELLS IN SERIES
120 ft long tubes

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 3

Assigned
Case No. 108

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^{3}lb/hr)		320		
Inlet Temperature, ~~C~~ (F) (TRAIN OF)	84/54/23	-28/14/48		
Outlet Temperature, ~~C~~ (F) (3 IN SERIES)	54/23/-11	14/48/75		
Inlet Pressure, ~~kPa~~ (psia) Absolute	835	825		
Measured ΔP, kPa (psi)				
Inlet Weight Fraction Vapor	1.0	1.0		
Outlet Weight Fraction Vapor	1.0	1.0		
Vibration Observed	☐ No ☒ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	NAT'L GAS + GLYCOL		NAT'L GAS	
Reference Temperature ~~C~~ (F)	84	-11	-28	75
Liquid Properties at Reference Temperatures				
Density, kg/m^3 (lb/ft^3)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/m ft F)				
Heat Capacity, kJ/kg·C (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)	2.79	3.86	3.82	2.62
Viscosity, ~~mPa·s~~ (cP)				
Thermal Conductivity, ~~W/m·C~~ (Btu/hr ft F)				
Heat Capacity, ~~kJ/kg·C~~ (Btu/lb F)				
Fluid Molecular Weight, ~~kg/mol~~ (lb/mole)				
If Boiling or Condensing				
Latent Heat, ~~kJ/kg~~ (Btu/lb)	—		—	

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 108

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, ~~kg/s~~ (10^3 lb/hr)	320			
If Known, Crossflow Velocity at baffle tip, ~~m/s~~ (ft/sec)*				
Crossflow Velocity at centerline, ~~m/s~~ (ft/sec)*				
Velocity Through Window in Baffle, ~~m/s~~ (ft/sec)*				
Inlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Outlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☒ No ☐ Yes

Source Frequency, Hz ________ rpm ________

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☒ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☒ Cutting at Baffle (MINOR) ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☒ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

☒ Corrosion Evident ☐ Fouling Evident

☐ General Description of Damage TUBES LEAKING WHERE ROLLED INTO TUBESHEETS

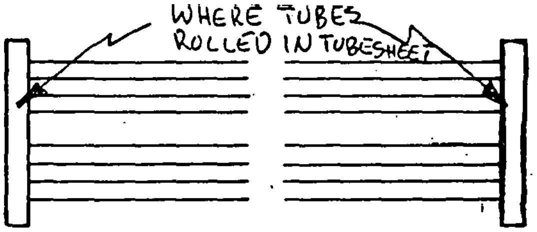
Exchanger Operation History

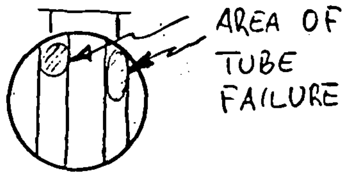
- How Long on Stream Before Damage Occurred? 1½ YEARS
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of

  ☐ Start-up ☐ Plant-Upset ☐ Shutdown

  Describe INCREASED FLOWRATE BEYOND DESIGN
- If Vibration Remedy Applied, Describe and Indicate Results: ________

TUBE BUNDLE DAMAGE SKETCH





MOST FAILURES IN SHELLS A AND B

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Assigned Case No. 109

Summary

This 53-in. diameter by 40-ft long CEM TEMA style heat exchanger is one of two in series that share a common shell. There is natural gas with glycol to prevent hydration on the tube side. Between exchangers the tubeside flow passes through an open shell section about 4 ft long before entering the tubes of the downstream exchanger. The shellside fluid is natural gas flowing counter current and piped externally between shells. The bundle has double-segmented baffles and is flat on top to a depth of 8-1/2 in. A round impingement plate the same diameter as the inlet nozzle ID is 8-1/2 in. below the nozzle. A unique feature is a flat plate seal welded to the shell to block shell-side flow bypassing at the top of the bundle. The maximum span lengths are less than the TEMA Standards maximum lengths for 3/4-in. carbon steel tubes.

No tube vibration has been noted in this unit even when operated at greater than 20 percent over the designed shellside flow rate. For this case, there are construction drawings and a short field report of the operating history of the exchanger train.

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 109

Type ☒ TEMA Exchanger Designation CEM
☐ Special Exchanger (Describe)

Shell Orientation ☒ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 53
Wall Thickness, ~~mm~~ (in.) 1.75 Material CS
Inlet Nozzle ID, ~~mm~~ (in.) 20
Outlet Nozzle ID, ~~mm~~ (in.) 20
Impingement Protection ☐ No ☒ Yes
(Describe) 20 in. OD BY 3/8 in.
Annular Distributor ☒ No ☐ Yes
Open Cut Area ~~mm²~~ (in.^{2}) —
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.) 8.125

CROSS BAFFLE GEOMETRY

Type ☐ Segmental; ☒ Double-Segmental ☐ Disc/Doughnut ☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 30.7
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☐ Perpendicular ☒ Parallel ☐ 45°
Central Baffles ☐ Perpendicular ☒ Parallel ☐ 45°
Baffle Thickness, ~~mm~~ (in.) 0.625 Material CS
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.225
Tube-to-baffle ~~mm~~ (in.) 0.0156
Bundle-to-shell, ~~mm~~ (in.) 0.625
Number of Baffles Along Length of Shell 15
Baffle Spacing, ~~mm~~ (in.) Central 29.5
Inlet 32.75 Outlet 32.75
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 62.25 Inlet 62.25 Outlet 62.25

TUBE GEOMETRY

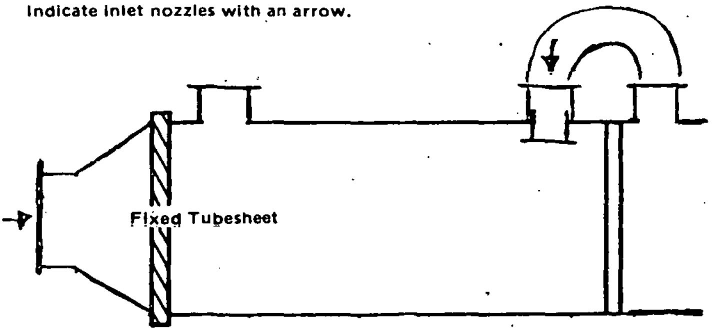
Outside Diameter, ~~mm~~ (in.) 0.750
Wall Thickness, ~~mm~~ (in.) 0.065 Material CS
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 478.5
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —
Tube Pitch, ~~mm~~ (in.) 1.00
Layout (Please Circle)
Flow 30° 45° [✓ 60°] 90°
No. of Tubes 2220 No. of Tubepasses 1
First Tubepass ☒ Countercurrent ☐ Cocurrent
Tube-to-Tubesheet Joint
☐ Welded ☐ Roller Expanded ☐ Other NOT GIVEN
If U-Tube
Maximum Bend Radius, ~~mm~~ (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel
If Bend Supported, Describe in Comments Below
If Finned Tubes
~~Fins/m~~ (Fins/in.) — Fin Material —
Diameter, ~~mm~~ (in.), Root — Over Fins —
If Enhanced Surface Tubes —
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

COMMENTS AND SKETCH

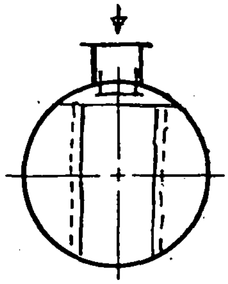
Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



TRAIN OF TWO SHELLS IN PARALLEL
TWO PARALLEL TRAINS

⇦ ⬆ ⇨ Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned
Case No. 109

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)		554		
Inlet Temperature, ~~C~~ (F)	65	-30		
Outlet Temperature, ~~C~~ (F)	-5	46		
Inlet Pressure, ~~kPa~~ (psia) Absolute	698	690		
Measured ΔP, ~~kPa~~ (psi)	3	11		
Inlet Weight Fraction Vapor	1.0	1,0		
Outlet Weight Fraction Vapor	1.0	1,0		
Vibration Observed	☒ No ☐ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	NATURAL GAS + GLYCOL		NATURAL GAS	
Reference Temperature ~~C~~ (F)	-5	65	-30	46
Liquid Properties at Reference Temperatures				
Density, kg/m^3 (lb/ft^3)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/m ft F)				
Heat Capacity, kJ/kg·C (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)				
Viscosity, ~~mPa·s~~ (cP)	3.10	2.40	3.15	2.35
Thermal Conductivity, ~~W/m·C~~ (Btu/hr ft F)				
Heat Capacity, ~~kJ/kg·C~~ (Btu/lb F)				
Fluid Molecular Weight, ~~kg/mol~~ (lb/mole)				
If Boiling or Condensing				
Latent Heat, ~~kJ/kg~~ (Btu/lb)	—		—	

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned
Case No. 109

NO VIBRATION OBSERVED

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, kg/s (10^3 lb/hr)				
If Known, Crossflow Velocity at baffle tip, m/s (ft/sec)*				
Crossflow Velocity at centerline, m/s (ft/sec)*				
Velocity Through Window in Baffle, m/s (ft/sec)*				
Inlet Nozzle Velocity, m/s (ft/sec)*				
Outlet Nozzle Velocity, m/s (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☐ No ☐ Yes
Source Frequency, Hz ______ rpm ______
☐ Machinery ☐ Piping
☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No
☐ Yes Complete sketch at bottom of page indicating location in bundle

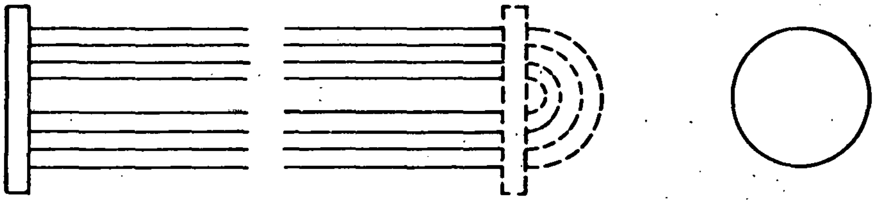
Type ☐ Tube-to-Tube Impact ☐ Cutting at Baffle ☐ Near Tubesheet
☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow
☐ All Around Tube Circumference
☐ Corrosion Evident ☐ Fouling Evident
☐ General Description of Damage ______

Exchanger Operation History

- How Long on Stream Before Damage Occurred? ______
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of
  ☐ Start-up ☐ Plant-Upset ☐ Shutdown
  Describe ______
- If Vibration Remedy Applied, Describe and Indicate Results: ______

TUBE BUNDLE DAMAGE SKETCH



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Assigned Case No. 110

Summary

This 45-in. diameter by 40-ft long CEM TEMA style heat exchanger is in refinery service. The tubeside fluid is cooling tower water while the shellside fluid is an olefin-isooctane mixture with hydrofluoric acid. Indications are that there was a loud noise coming from the exchanger at start-up before the tubeside fluid was brought on stream. Tubes that failed were those within a few rows of the baffle tips of the double-segmental baffles. The breaks were at baffles near the center of the tube length. Metallurgical analysis indicates corrosion fatigue that was probably initiated by flow-induced vibration. The exchanger bundle was replaced with a new one with 18 instead of 12 baffles and no further vibration was noted (See Case 111).

For this case, there are partial construction drawings, an indication of the specific tubes that failed, and a metallurgical report on the failed tubes.

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 110

Type ☒ TEMA Exchanger Designation CEN
☐ Special Exchanger (Describe)

Shell Orientation ☒ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 45
Wall Thickness, ~~mm~~ (in.) Material
Inlet Nozzle ID, ~~mm~~ (in.) 24
Outlet Nozzle ID, ~~mm~~ (in.) 24
Impingement Protection ☒ No ☐ Yes
(Describe) —
Annular Distributor ☒ No ☐ Yes
Open Cut Area ~~mm²~~ (in.²) —
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.) 1.5

CROSS BAFFLE GEOMETRY

Type ☐ Segmental; ☒ Double-Segmental ☐ Disc/Doughnut
☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 26.5
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☐ Perpendicular ☒ Parallel ☐ 45°
Central Baffles ☐ Perpendicular ☒ Parallel ☐ 45°
Baffle Thickness, ~~mm~~ (in.) 0.625 Material CS
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.25
Tube-to-baffle ~~mm~~ (in.) 0.0156
Bundle-to-shell, ~~mm~~ (in.) 1.125
Number of Baffles Along Length of Shell 12
Baffle Spacing, ~~mm~~ (in.) Central 36.5
Inlet 35.9 Outlet 35.9
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 70.4 Inlet 70.4 Outlet 70.4

TUBE GEOMETRY

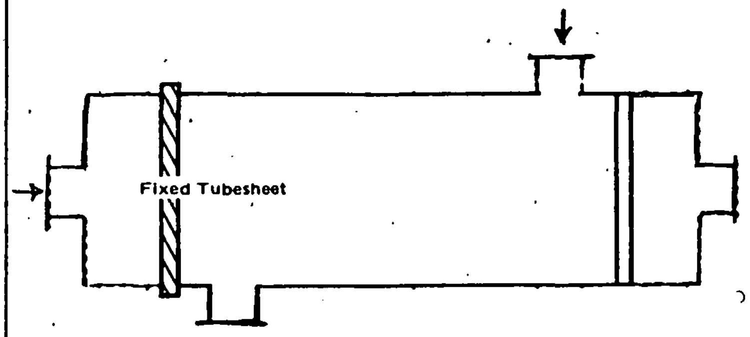
Outside Diameter, ~~mm~~ (in.) 1.0
Wall Thickness, ~~mm~~ (in.) 0.134 Material CS
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 473.25
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —
Tube Pitch, ~~mm~~ (in.) 1.25
Layout (Please Circle)
Flow 30° [✓ 45°] 60° 90°
No. of Tubes 930 No. of Tubepasses 1
First Tubepass ☒ Countercurrent ☐ Cocurrent
Tube-to-Tubesheet Joint
☒ Welded ☒ Roller Expanded ☐ Other
If U-Tube
Maximum Bend Radius, ~~mm~~ (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel —
If Bend Supported, Describe in Comments Below
If Finned Tubes
~~Fins/m~~ (Fins/in.) — Fin Material —
Diameter, mm ~~(in.)~~, Root Over Fins —
If Enhanced Surface Tubes —
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

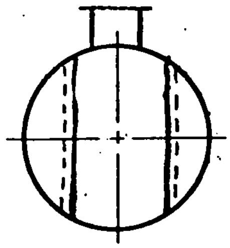
COMMENTS AND SKETCH

Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



⇦ ⬆ ⇨ Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 3

Assigned
Case No. 110

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)		3300		
Inlet Temperature, ~~C~~ (F)		95		
Outlet Temperature, ~~C~~ (F)		90		
Inlet Pressure, ~~kPa~~ (psia) Absolute		200		
Measured ΔP, ~~kPa~~ (psi)		—		
Inlet Weight Fraction Vapor	0	0		
Outlet Weight Fraction Vapor	0	0		
Vibration Observed	☐ No ☒ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

ISOBUTANE

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	WATER		HYDROCARBON AND HYDROFLUORIC ACID	
Reference Temperature ~~C~~ (F)			93	
Liquid Properties at Reference Temperatures				
Density, ~~kg/m³~~ (lb/ft³)			44.5	
Viscosity, ~~mPa·s~~ (cP)			0.65	
Thermal Conductivity, ~~W/m-C~~ (Btu/m ft F)				
Heat Capacity, ~~kJ/kg-C~~ (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, kg/m³ (lb/ft³)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/hr ft F)				
Heat Capacity, kJ/kg·C (Btu/lb F)				
Fluid Molecular Weight, kg/mol (lb/mole)				
If Boiling or Condensing				
Latent Heat, kJ/kg (Btu/lb)				

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 110

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, ~~kg/s~~ (10^3 lb/hr)	3300			
If Known, Crossflow Velocity at baffle tip, ~~m/s~~ (ft/sec)*				
Crossflow Velocity at centerline, ~~m/s~~ (ft/sec)*				
Velocity Through Window in Baffle, ~~m/s~~ (ft/sec)*				
Inlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Outlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☒ No ☐ Yes

Source Frequency, Hz ______ rpm ______

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☒ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☒ Cutting at Baffle ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

☒ Corrosion Evident ☐ Fouling Evident

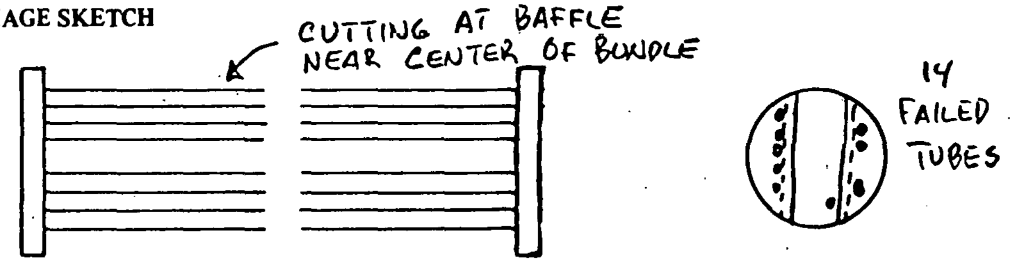
☐ General Description of Damage 14 TUBES NEAR BAFFLE TIPS AND IN CENTRAL SPANS

Exchanger Operation History

- How Long on Stream Before Damage Occurred? ______
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of
  ☐ Start-up ☐ Plant-Upset ☐ Shutdown

  Describe ______
- If Vibration Remedy Applied, Describe and Indicate Results: REBUILT BUNDLE WITH 18 BAFFLES. NO FURTHER PROBLEMS

TUBE BUNDLE DAMAGE SKETCH



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Assigned Case No. 111

Summary

This 45-in. diameter by 40-ft long CEM TEMA style heat exchanger is the same shell as for Case 110 with a replacement bundle. These are 18 double-segmental baffles instead of the original 12. The service and the fluids are the same. This exchanger resulted in a higher shellside pressure drop; however, added pump capacity was available. The exchanger has operated for several years without any vibration problems.

The information is limited to that included on the data form.

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 2

Assigned Case No. 111

Type ☒ TEMA Exchanger Designation CEN
☐ Special Exchanger (Describe)

Shell Orientation ☒ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 45
Wall Thickness, ~~mm~~ (in.) ______ Material ______
Inlet Nozzle ID, ~~mm~~ (in.) 24
Outlet Nozzle ID, ~~mm~~ (in.) 24
Impingement Protection ☒ No ☐ Yes
(Describe) —
Annular Distributor ☒ No ☐ Yes
Open Cut Area ~~mm~~^{2} (in.^{2}) —
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.) 1.5

CROSS BAFFLE GEOMETRY

Type ☐ Segmental; ☒ Double-Segmental ☐ Disc/Doughnut ☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 26.5
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☐ Perpendicular ☒ Parallel ☐ 45°
Central Baffles ☐ Perpendicular ☒ Parallel ☐ 45°
Baffle Thickness, ~~mm~~ (in.) 0.625 Material CS
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.25
Tube-to-baffle ~~mm~~ (in.) 0.0156
Bundle-to-shell, ~~mm~~ (in.) 1.125
Number of Baffles Along Length of Shell 18
Baffle Spacing, ~~mm~~ (in.) ______ Central 25
Inlet 24.13 Outlet 24.13
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 50 Inlet 49.13 Outlet 49.13

TUBE GEOMETRY

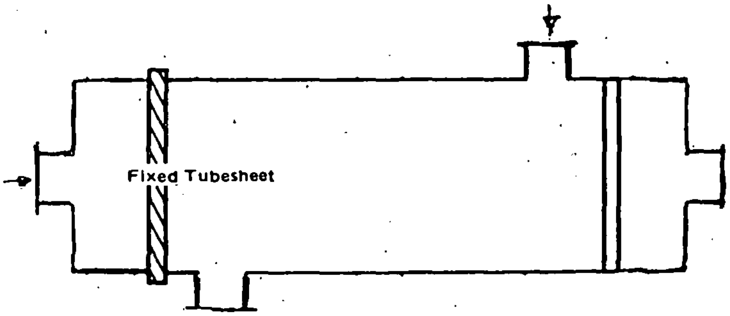
Outside Diameter, ~~mm~~ (in.) 1.0
Wall Thickness, ~~mm~~ (in.) 0.134 Material ______
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 473.25
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —
Tube Pitch, ~~mm~~ (in.) 1.25
Layout (Please Circle)
Flow 30° [✓ 45°] 60° 90°
No. of Tubes 930 No. of Tubepasses 1
First Tubepass ☒ Countercurrent ☐ Cocurrent
Tube-to-Tubesheet Joint
☒ Welded ☒ Roller Expanded ☐ Other ______
If U-Tube
Maximum Bend Radius, ~~mm~~ (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel —
If Bend Supported, Describe in Comments Below
If Finned Tubes
~~Fins/m~~ (Fins/in.) — Fin Material —
Diameter, ~~mm~~ (in.), Root ______ Over Fins —
If Enhanced Surface Tubes —
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

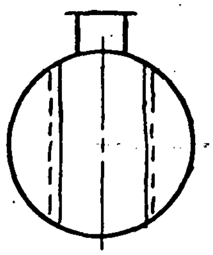
COMMENTS AND SKETCH

Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 3

Assigned Case No. 111

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)		3300		
Inlet Temperature, ~~C~~ (F)		95		
Outlet Temperature, ~~C~~ (F)		90		
Inlet Pressure, ~~kPa~~ (psia) Absolute		200		
Measured ΔP, ~~kPa~~ (psi)		—		
Inlet Weight Fraction Vapor	0	0		
Outlet Weight Fraction Vapor	0	0		
Vibration Observed	☒ No ☐ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

ISOBUTANE

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	WATER		HYDROCARBON PLUS HYDROFLUORIC ACID	
Reference Temperature ~~C~~ (F)			93	
Liquid Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)			44.5	
Viscosity, ~~mPa·s~~ (cP)			0.65	
Thermal Conductivity, ~~W/m·C~~ (Btu/m ft F)				
Heat Capacity, ~~kJ/kg·C~~ (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, kg/m^3 (lb/ft^3)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/hr ft F)				
Heat Capacity, kJ/kg·C (Btu/lb F)				
Fluid Molecular Weight, kg/mol (lb/mole)				
If Boiling or Condensing				
Latent Heat, kJ/kg (Btu/lb)				

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 111

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, kg/s (10^3 lb/hr)				
If Known, Crossflow Velocity at baffle tip, m/s (ft/sec)*				
Crossflow Velocity at centerline, m/s (ft/sec)*				
Velocity Through Window in Baffle, m/s (ft/sec)*				
Inlet Nozzle Velocity, m/s (ft/sec)*				
Outlet Nozzle Velocity, m/s (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☐ No ☐ Yes

Source Frequency, Hz ________ rpm ________

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☐ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☐ Cutting at Baffle ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

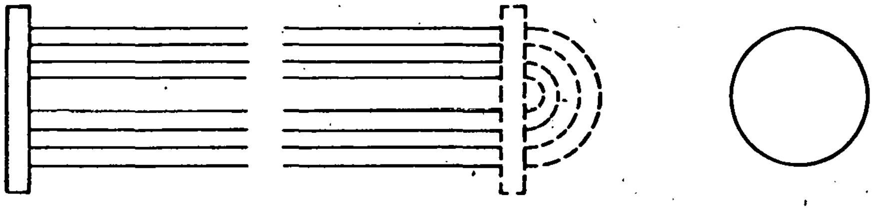
☐ Corrosion Evident ☐ Fouling Evident

☐ General Description of Damage ________

Exchanger Operation History

- How Long on Stream Before Damage Occurred? ________
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of
  ☐ Start-up ☐ Plant-Upset ☐ Shutdown
  Describe ________
- If Vibration Remedy Applied, Describe and Indicate Results: ________

TUBE BUNDLE DAMAGE SKETCH



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Assigned Case No. 112

Summary

This 43-in. diameter by 19-ft long AJS TEMA style heat exchanger has an annular distribution at the center inlet with a series of slots to direct half of the shellside flow of air to each of the two ends of the exchanger. Cooling tower water flowed in the tube side. The bundle has segmental baffles with relatively short unsupported span lengths for 3/4-in. admiralty tubes. The tube field is arranged in an inline layout with a pitch-to-diameter ratio of 1.33. The indication is that this exchanger had "frequent tube leaks." Unfortunately, there is no indication as to where the leaks occurred. Tube vibration is given as the probable cause.

For this case, there are partial construction drawings, a field inspection report, and the exchanger specification sheet.

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 112

Type ☒ TEMA Exchanger Designation AJS
☐ Special Exchanger (Describe)

Shell Orientation ☐ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 43
Wall Thickness, ~~mm~~ (in.) Material
Inlet Nozzle ID, ~~mm~~ (in.) 16
Outlet Nozzle ID, ~~mm~~ (in.) 12
Impingement Protection ☒ No ☐ Yes
(Describe) —
Annular Distributor ☐ No ☒ Yes
Open Cut Area ~~mm²~~ (in.²) 912
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.) 1.625

CROSS BAFFLE GEOMETRY

Type ☒ Segmental; ☐ Double-Segmental ☐ Disc/Doughnut
☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 33
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☐ Perpendicular ☒ Parallel ☐ 45°
Central Baffles ☐ Perpendicular ☒ Parallel ☐ 45°
Baffle Thickness, ~~mm~~ (in.) 0.5 Material CS
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.25
Tube-to-baffle ~~mm~~ (in.) 0.0156
Bundle-to-shell, ~~mm~~ (in.) 1.25
Number of Baffles Along Length of Shell 8 + DIVIDER
Baffle Spacing, ~~mm~~ (in.) Central 23
Inlet 23 Outlet 21.75
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 46 Inlet 46 Outlet 44.75

TUBE GEOMETRY

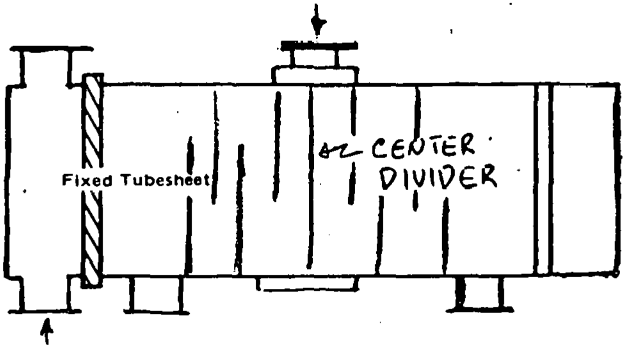
Outside Diameter, ~~mm~~ (in.) 0.750
Wall Thickness, ~~mm~~ (in.) 0.065 Material ADMIRALTY
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 227.5
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —
Tube Pitch, ~~mm~~ (in.) 1.00
Layout (Please Circle)
Flow 30° 45° 60° [✓ 90°]
No. of Tubes 1814 No. of Tubepasses 6
First Tubepass ☒ Countercurrent ☒ Cocurrent
Tube-to-Tubesheet Joint
☐ Welded ☒ Roller Expanded ☐ Other
If U-Tube
Maximum Bend Radius, ~~mm~~ (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel
If Bend Supported, Describe in Comments Below
If Finned Tubes
~~Fins/m~~ (Fins/in.) — Fin Material —
Diameter, ~~mm~~ (in.), Root — Over Fins —
If Enhanced Surface Tubes —
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

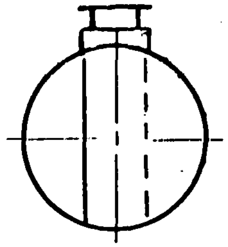
COMMENTS AND SKETCH

Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 112

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)	378	168		
Inlet Temperature, ~~C~~ (F)	90	225		
Outlet Temperature, ~~C~~ (F)	105	105		
Inlet Pressure, ~~kPa~~ (psia) Absolute	65	118		
Measured ΔP, ~~kPa~~ (psi)	.6	1.5		
Inlet Weight Fraction Vapor	0	1.0		
Outlet Weight Fraction Vapor	0	1.0		
Vibration Observed	☐ No ☒ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	WATER		AIR	
Reference Temperature ~~C~~ (F)				
Liquid Properties at Reference Temperatures				
Density, kg/m³ (lb/ft³)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/m ft F)				
Heat Capacity, kJ/kg·C (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, kg/m³ (lb/ft³)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/hr ft F)				
Heat Capacity, kJ/kg·C (Btu/lb F)				
Fluid Molecular Weight, kg/mol (lb/mole)				
If Boiling or Condensing				
Latent Heat, kJ/kg (Btu/lb)			—	

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 112

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, ~~kg/s~~ (10^3 lb/hr)	168			
If Known, Crossflow Velocity at baffle tip, ~~m/s~~ (ft/sec)*				
Crossflow Velocity at centerline, ~~m/s~~ (ft/sec)*				
Velocity Through Window in Baffle, ~~m/s~~ (ft/sec)*				
Inlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Outlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☒ No ☐ Yes

Source Frequency, Hz ______ rpm ______

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☒ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☐ Cutting at Baffle ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

☐ Corrosion Evident ☐ Fouling Evident

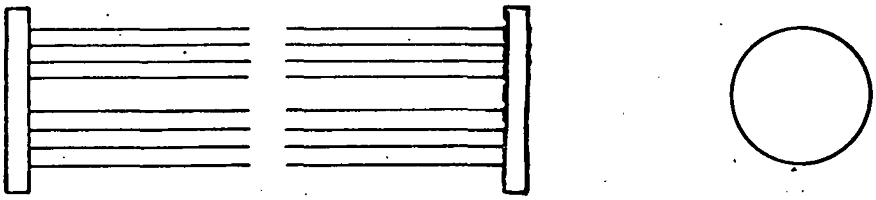
☐ General Description of Damage "FREQUENT TUBE LEAKS"

Exchanger Operation History

- How Long on Stream Before Damage Occurred? ______
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of
  ☐ Start-up ☐ Plant-Upset ☐ Shutdown

  Describe ______
- If Vibration Remedy Applied, Describe and Indicate Results: ______

TUBE BUNDLE DAMAGE SKETCH



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Assigned Case No. 113

Summary

This 17-in. diameter by 16-ft long AEU TEMA style heat exchanger has cooling water flowing inside the two tube passes formed by the U-tubes. On the shell side a hydrocarbon designated "Atmospheric Top Pumparound" flows through a bundle with segmental baffles with very little overlap so the flow is mostly parallel to the tubes. Originally admiralty tubes were used and these suffered damage. The inspection report indicates evidence of "fretting corrosion with numerous penetrations under baffles." The indication is that there was a combined effect of vibration and corrosion. The tubes that failed were near the longitudinal baffle passlane and at the baffle plates. The cutting action resulted in the tubes being worn through on one side, but the specific orientation is not noted.

For this case, there are in addition to the data form, an inspection report, transmittal letter, and an indication of the remedial action taken. The bundle was retubed with 430 alloy stainless steel except for the bottom row of fin tubes which were with titanium. No further problems have been indicated.

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 2

Assigned Case No. 113

Type ☒ TEMA Exchanger Designation AEU
☐ Special Exchanger (Describe)

Shell Orientation ☒ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 17.25
Wall Thickness, ~~mm~~ (in.) 0.375 Material CS
Inlet Nozzle ID, ~~mm~~ (in.) 7.625
Outlet Nozzle ID, ~~mm~~ (in.) 7.625
Impingement Protection ☒ No ☐ Yes
(Describe) —
Annular Distributor ☒ No ☐ Yes
Open Cut Area ~~mm²~~ (in.²) —
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.) 2.4375

CROSS BAFFLE GEOMETRY

Type ☒ Segmental; ☐ Double-Segmental ☐ Disc/Doughnut
☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 43.5
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☐ Perpendicular ☒ Parallel ☐ 45°
Central Baffles ☐ Perpendicular ☒ Parallel ☐ 45°
Baffle Thickness, ~~mm~~ (in.) 0.375 Material CS
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.123
Tube-to-baffle ~~mm~~ (in.) 0.0156
Bundle-to-shell, ~~mm~~ (in.) 2.0
Number of Baffles Along Length of Shell 6
Baffle Spacing, ~~mm~~ (in.) Central 27
Inlet 27 Outlet 27
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 54 Inlet 54 Outlet 54

TUBE GEOMETRY

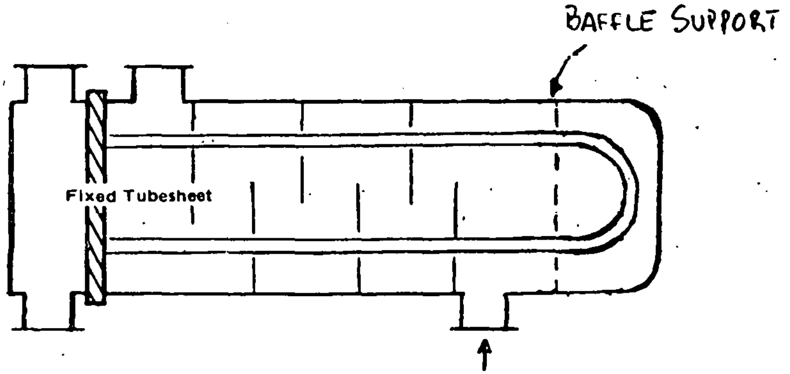
Outside Diameter, ~~mm~~ (in.) 7.50
Wall Thickness, ~~mm~~ (in.) 0.065 Material ADMIRALTY BRASS
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) —
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) 189
Tube Pitch, ~~mm~~ (in.) 1.00
Layout (Please Circle)
Flow 30° 45° 60° [✓ 90°]
No. of Tubes 116 No. of Tubepasses 2
First Tubepass ☐ Countercurrent ☐ Cocurrent ?
Tube-to-Tubesheet Joint
☐ Welded ☒ Roller Expanded ☐ Other
If U-Tube
Maximum Bend Radius, ~~mm~~ (in.) 7.25
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☒ Parallel
If Bend Supported, Describe in Comments Below
If Finned Tubes
~~Fins/m~~ (Fins/in.) — Fin Material —
Diameter, ~~mm~~ (in.), Root — Over Fins —
If Enhanced Surface Tubes —
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

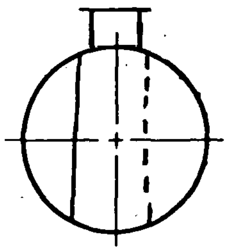
COMMENTS AND SKETCH

Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



⇦ ⇧ ⇨ Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 3

Assigned
Case No. 113

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)		372.4		
Inlet Temperature, ~~C~~ (F)	70	234		
Outlet Temperature, ~~C~~ (F)	100	176		
Inlet Pressure, ~~kPa~~ (psia) Absolute				
Measured ΔP, ~~kPa~~ (psi)				
Inlet Weight Fraction Vapor	0	0		
Outlet Weight Fraction Vapor	0	0		
Vibration Observed	☐ No ☒ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	WATER		"TOPS PUMPAROUND"	
Reference Temperature ~~C~~ (F)			234	176
Liquid Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)			43.14	44.84
Viscosity, ~~mPa·s~~ (cP)			0.21	0.22
Thermal Conductivity, ~~W/m·C~~ (Btu/m ft F)				
Heat Capacity, ~~kJ/kg·C~~ (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, kg/m^3 (lb/ft^3)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/hr ft F)				
Heat Capacity, kJ/kg·C (Btu/lb F)				
Fluid Molecular Weight, kg/mol (lb/mole)				
If Boiling or Condensing				
Latent Heat, kJ/kg (Btu/lb)				

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 4

Assigned Case No. 113

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, ~~kg/s~~ (10^3 lb/hr)	372.4			
If Known, Crossflow Velocity at baffle tip, ~~m/s~~ (ft/sec)*				
Crossflow Velocity at centerline, ~~m/s~~ (ft/sec)*				
Velocity Through Window in Baffle, ~~m/s~~ (ft/sec)*				
Inlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Outlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☒ No ☐ Yes

Source Frequency, Hz ________ rpm ________

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☒ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☒ Cutting at Baffle ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☒ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

☐ Corrosion Evident ☐ Fouling Evident

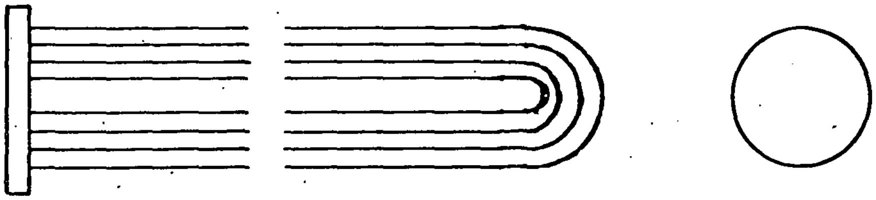
☐ General Description of Damage TWO TUBES WORN THROUGH ON ONE SIDE AT BAFFLE SUPPORTS

Exchanger Operation History

- How Long on Stream Before Damage Occurred? ________
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of
  ☐ Start-up ☐ Plant-Upset ☐ Shutdown

  Describe ________
- If Vibration Remedy Applied, Describe and Indicate Results. ________

TUBE BUNDLE DAMAGE SKETCH



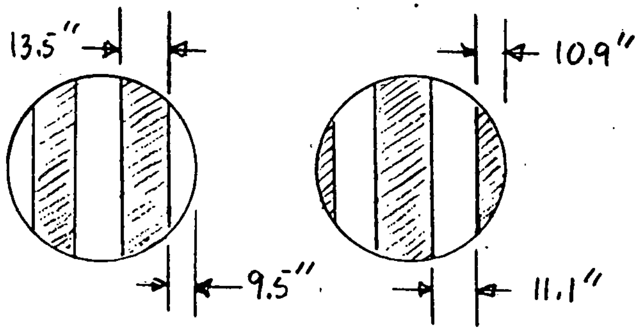
To protect the identity of the organization submitting this case, HTRI has assigned a case number. Additionally the data on pages 2, 3, and 4 have been reviewed to ensure that they do not include any propietary information. This is a replacement for the original page 1 that provides space for additional comments, drawings, photographs, etc.

Assigned Case No.	114

Summary

This 56-in. diameter by 50-ft long AEL TEMA style heat exchanger has a hydrocarbon gas stream on both the shell side and the tube side. The "lean gas" is heated on the shell side where the bundle has 19 "double double-segmental" baffles. See sketch below. The "rich gas" is cooled on the tube side in a single tube pass. There was no impingement device under the shellside inlet nozzle. Tubes failed in "top three rows under shell inlet nozzle."

For this case, in addition to the data form is a description of the process conditions and geometry including the sketch reproduced below.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 2

Assigned Case No. 114

Type ☒ TEMA Exchanger Designation AEL

☐ Special Exchanger (Describe)

Shell Orientation ☐ Horizontal ☐ Vertical NOT GIVEN

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 56

Wall Thickness, ~~mm~~ (in.) Material

Inlet Nozzle ID, ~~mm~~ (in.) 20

Outlet Nozzle ID, ~~mm~~ (in.) 24

Impingement Protection ☒ No ☐ Yes

(Describe) —

Annular Distributor ☒ No ☐ Yes

Open Cut Area ~~mm²~~ (in.²) —

Nozzle-to-First Tube Row Distance, ~~mm~~ (in.) 4.1

CROSS BAFFLE GEOMETRY

Type ☐ Segmental; ☒ Double-Segmental (DOUBLE) ☐ Disc/Doughnut ☐ Triple-Segmental; ☐ No-Tubes-in-Window

Baffle Cut, % Shell Diameter 30

Cut Orientation Relative to Axis of Inlet Nozzle

Inlet Baffle ☐ Perpendicular ☒ Parallel ☐ 45°

Central Baffles ☐ Perpendicular ☒ Parallel ☐ 45°

Baffle Thickness, ~~mm~~ (in.) 0.625 Material

Diametral Clearances Shell-to-baffle, ~~mm~~ (in.) 0.268

Tube-to-baffle ~~mm~~ (in.) 0.0156

Bundle-to-shell, ~~mm~~ (in.) 0.653

Number of Baffles Along Length of Shell 19

Baffle Spacing, ~~mm~~ (in.) Central 30

Inlet 28 Outlet 28

Unsupported Tube Span Lengths, ~~mm~~ (in.)

Longest 60 Inlet 58 Outlet 58

TUBE GEOMETRY

Outside Diameter, ~~mm~~ (in.) 0.750

Wall Thickness, ~~mm~~ (in.) 0.083 Material CS

Tube Lengths

Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 596

U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —

Tube Pitch, ~~mm~~ (in.) 0.9375

Layout (Please Circle)

Flow 30° 45° [✓ 60°] 90°

No. of Tubes 2910 No. of Tubepasses 1

First Tubepass ☒ Countercurrent ☐ Cocurrent

Tube-to-Tubesheet Joint

☐ Welded ☐ Roller Expanded ☐ Other NOT GIVEN

If U-Tube

Maximum Bend Radius, ~~mm~~ (in.) —

Bend Orientation Relative to Axis of Shellside Inlet Nozzle

☐ Perpendicular ☐ Parallel

If Bend Supported, Describe in Comments Below

If Finned Tubes

~~Fins/m~~ (Fins/in.) — Fin Material —

Diameter, ~~mm~~ (in.), Root — Over Fins —

If Enhanced Surface Tubes —

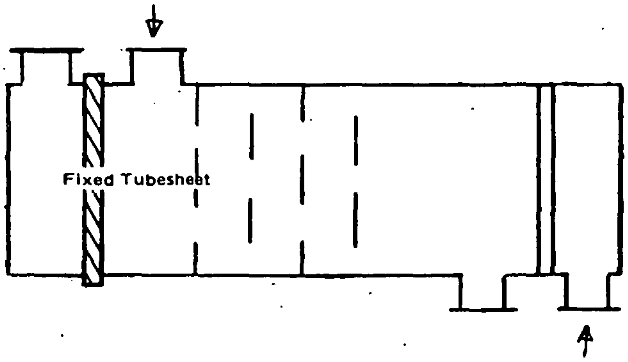
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

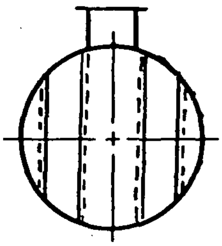
COMMENTS AND SKETCH

Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Page 3

Assigned
Case No. 114

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)	571.7	488.2		
Inlet Temperature, ~~C~~ (F)	80	-35		
Outlet Temperature, ~~C~~ (F)	-16	74		
Inlet Pressure, ~~kPa~~ (psia) Absolute	448	426		
Measured ΔP, ~~kPa~~ (psi)				
Inlet Weight Fraction Vapor	1.0	1.0		
Outlet Weight Fraction Vapor	1.0	1.0		
Vibration Observed	☐ No ☒ Yes		☐ No ☐ Yes	

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	RICH GAS		LEAN GAS	
Reference Temperature ~~C~~ (F)	19.5	74	-15.5	80
Liquid Properties at Reference Temperatures				
Density, kg/m^3 (lb/ft^3)				
Viscosity, mPa·s (cP)				
Thermal Conductivity, W/m·C (Btu/m ft F)				
Heat Capacity, kJ/kg·C (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, ~~kg/m^3~~ (lb/ft^3)				
Viscosity, ~~mPa·s~~ (cP)	0.011	0.012	0.0108	0.0120
Thermal Conductivity, ~~W/m·C~~ (Btu/hr ft F)	0.0184	0.0206	0.0172	0.0207
Heat Capacity, ~~kJ/kg·C~~ (Btu/lb F)	—	0.585	—	0.604
Fluid Molecular Weight, ~~kg/mol~~ (lb/mole)	16.62		17.41	
If Boiling or Condensing				
Latent Heat, ~~kJ/kg~~ (Btu/lb)	—		—	

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 114

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, ~~kg/s~~ (10^3 lb/hr)	448.2			
If Known, Crossflow Velocity at baffle tip, ~~m/s~~ (ft/sec)*				
Crossflow Velocity at centerline, ~~m/s~~ (ft/sec)*	11.2			
Velocity Through Window in Baffle, ~~m/s~~ (ft/sec)*	24.9			
Inlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Outlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db				

* Please describe how velocities were calculated or estimated. GIVEN

Vibration Caused by External Sources ☒ No ☐ Yes

Source Frequency, Hz ______ rpm ______

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☐ No

☒ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☐ Cutting at Baffle ☒ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

☐ Corrosion Evident ☐ Fouling Evident

☒ General Description of Damage FAILED IN TOP 3 ROWS UNDER INLET NOZZLE

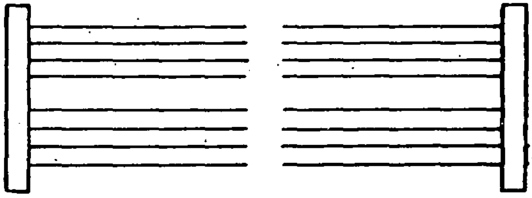
Exchanger Operation History

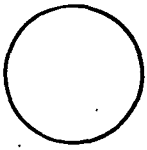
- How Long on Stream Before Damage Occurred? ______
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of

  ☐ Start-up ☐ Plant-Upset ☐ Shutdown

  Describe ______
- If Vibration Remedy Applied, Describe and Indicate Results: ______

TUBE BUNDLE DAMAGE SKETCH





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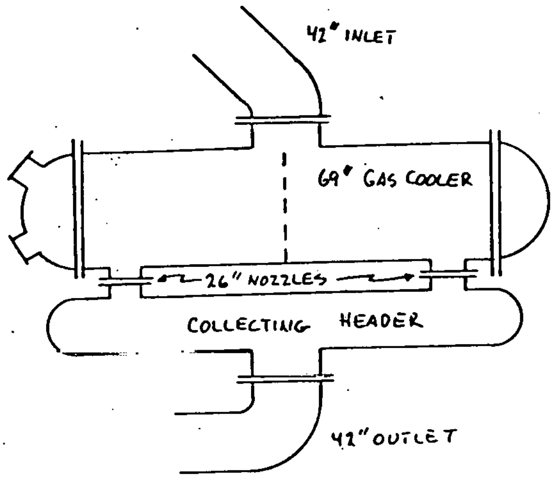
Assigned Case No. 115

Summary

This 69-in. diameter by 20-ft long BJS TEMA style heat exchanger is used as a process gas cooler. Shellside flow entered the single 42-in. nozzle at the center of the exchanger and was directed to the two ends by a solid flow divider plate. A portion of the nozzle was blanked off to prevent by passing and reduced the flow area to the equivalent of a 40.6-in. diameter nozzle. There were five crosspasses on each end with segmental baffles. The outlet nozzles were 26 in. diameter and mated matching 26-in. diameter nozzles on a vessel that acted as a collecting header to combine the flow into a 42 in. diameter outlet line. See sketch below. It should be noted that the tubefield layout was inline. There has not been any tube damage reported. However, there is an extremely loud noise. The noise was greatest at the fixed tubesheet at the top of the shell and at the bottom of the shell near the floating head. The shellside pressure drop was pulsing between 2 to 4 psi. It is not clear that the noise was flow-induced inside the shell and not being generated by an outside source.

For this case, in addition to the data form, there are complete construction drawings of the exchanger (not the collecting header), a description of noise observations, and several sketches.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 115

Type ☒ TEMA Exchanger Designation BJS
☐ Special Exchanger (Describe)

Shell Orientation ☒ Horizontal ☐ Vertical

SHELL GEOMETRY (Complete Sketch Below)

Inside Diameter, ~~mm~~ (in.) 69
Wall Thickness, ~~mm~~ (in.) 0.50 Material CS
Inlet Nozzle ID, ~~mm~~ (in.) 42 BLANKED TO 40.6
Outlet Nozzle ID, ~~mm~~ (in.) 26
Impingement Protection ☒ No ☐ Yes
(Describe) —
Annular Distributor ☒ No ☐ Yes
Open Cut Area ~~mm²~~ (in.²) —
Nozzle-to-First Tube Row Distance, ~~mm~~ (in.) 2.6875

CROSS BAFFLE GEOMETRY

Type ☒ Segmental; ☐ Double-Segmental ☐ Disc/Doughnut ☐ Triple-Segmental; ☐ No-Tubes-in-Window
Baffle Cut, % Shell Diameter 45
Cut Orientation Relative to Axis of Inlet Nozzle
Inlet Baffle ☒ Perpendicular ☐ Parallel ☐ 45°
Central Baffles ☒ Perpendicular ☐ Parallel ☐ 45°
Baffle Thickness, ~~mm~~ (in.) 0.50 Material CS
Diametral Clearances Shell-to-baffle, ~~mm~~ (in.)
Tube-to-baffle ~~mm~~ (in.)
Bundle-to-shell, ~~mm~~ (in.)
Number of Baffles Along Length of Shell 9
Baffle Spacing, ~~mm~~ (in.) Central 19
Inlet 20.75 Outlet 39.312
Unsupported Tube Span Lengths, ~~mm~~ (in.)
Longest 58.312 Inlet 38 Outlet 58.312

TUBE GEOMETRY

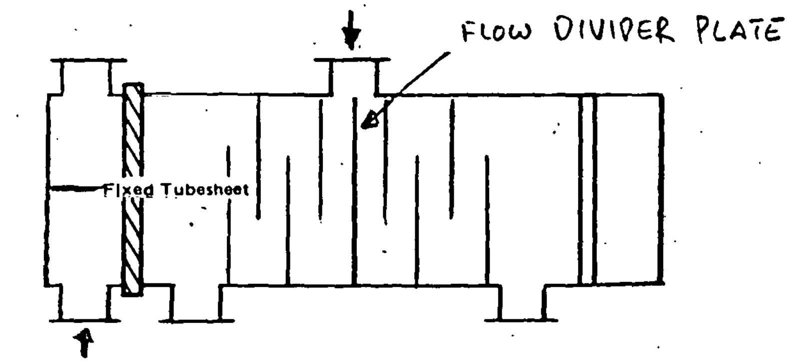
Outside Diameter, ~~mm~~ (in.) 0.750
Wall Thickness, ~~mm~~ (in.) 0.083 Material CS
Tube Lengths
Straight Tube, Inside Tubesheets, ~~mm~~ (in.) 234.9
U-Tube, Tubesheet to Bend Tangent, ~~mm~~ (in.) —
Tube Pitch, ~~mm~~ (in.) 1.25
Layout (Please Circle)
Flow 30° 45° 60° [✓ 90°]
No. of Tubes 2028 No. of Tubepasses 2
First Tubepass ☒ Countercurrent ☒ Cocurrent
Tube-to-Tubesheet Joint
☐ Welded ☒ Roller Expanded ☐ Other
If U-Tube
Maximum Bend Radius, ~~mm~~ (in.) —
Bend Orientation Relative to Axis of Shellside Inlet Nozzle
☐ Perpendicular ☐ Parallel —
If Bend Supported, Describe in Comments Below
If Finned Tubes
~~Fins/m~~ (Fins/in.) — Fin Material —
Diameter, ~~mm~~ (in.), Root — Over Fins —
If Enhanced Surface Tubes —
(Describe) —

DETUNING BAFFLE

If Detuning Baffle Used to Control Acoustic Vibration, Indicate Position on Sketch Below

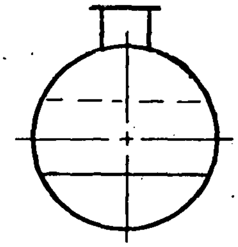
COMMENTS AND SKETCH

Complete sketches by drawing in tubeside and shellside nozzles. Indicate inlet nozzles with an arrow.



Indicate top of exchanger as mounted by filling in appropriate arrow.

Show shellside inlet nozzle location, baffle cut orientation, and impingement devices.



DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned
Case No. 115

PROCESS CONDITIONS

	Reference Condition A		Reference Condition B	
	Tubeside	Shellside	Tubeside	Shellside
Flow Rate, ~~kg/s~~ (10^3lb/hr)	1697*	372		
Inlet Temperature, ~~C~~ (F)	87	192		
Outlet Temperature, ~~C~~ (F)	96	105		
Inlet Pressure, ~~kPa~~ (psia) Absolute	50	51		
Measured ΔP, ~~kPa~~ (psi)	—	—		
Inlet Weight Fraction Vapor	0	1.0		
Outlet Weight Fraction Vapor	0	1.0		
Vibration Observed	☐ No ☒ Yes		☐ No ☐ Yes	

* CALCULATED

FLUID PHYSICAL PROPERTIES

Fill In All Applicable Entries	Tubeside		Shellside	
Fluid Name	WATER		PROCESS GAS	
Reference Temperature ~~C~~ (F)			105	192
Liquid Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)				
Viscosity, ~~mPa·s~~ (cP)				
Thermal Conductivity, ~~W/m·C~~ (Btu/m ft F)				
Heat Capacity, ~~kJ/kg·C~~ (Btu/m ft F)				
Vapor or Gas Properties at Reference Temperatures				
Density, ~~kg/m~~^{3} (lb/ft^3)				
Viscosity, ~~mPa·s~~ (cP)			0.0099	0.0115
Thermal Conductivity, ~~W/m·C~~ (Btu/hr ft F)			0.0366	0.0397
Heat Capacity, ~~kJ/kg·C~~ (Btu/lb F)			0.3330	0.6090
Fluid Molecular Weight, ~~kg/mol~~ (lb/mole)			22.59	
If Boiling or Condensing				
Latent Heat, ~~kJ/kg~~ (Btu/lb)			—	

DOE/ANL/HTRI HEAT EXCHANGER TUBE VIBRATION DATA FORM

Assigned Case No. 115

VIBRATION AND DAMAGE DESCRIPTION

When Vibration Present, Shellside Flow Rate, ~~kg/s~~ (10^3 lb/hr)	372			
If Known, Crossflow Velocity at baffle tip, ~~m/s~~ (ft/sec)*				
Crossflow Velocity at centerline, ~~m/s~~ (ft/sec)*				
Velocity Through Window in Baffle, ~~m/s~~ (ft/sec)*				
Inlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Outlet Nozzle Velocity, ~~m/s~~ (ft/sec)*				
Measured Natural Frequency, Hz				
Measured Acoustic Frequencies, Hz				
Noise Sound Level, db	VERY LOUD!			

* Please describe how velocities were calculated or estimated.

Vibration Caused by External Sources ☐ No ☐ Yes ☒ MOST PROBABLY NOT

Source Frequency, Hz ______ rpm ______

☐ Machinery ☐ Piping

☐ Cavitation ☐ Pulsating Flow

Damage Noted ☒ No

☐ Yes Complete sketch at bottom of page indicating location in bundle

Type ☐ Tube-to-Tube Impact ☐ Cutting at Baffle ☐ Near Tubesheet

☐ Tube-to-Shell Impact ☐ Tubesheet Joint Leaking ☐ Fatigue

Wear ☐ One Side of Tubes Only ☐ Parallel to Flow ☐ Normal to Flow

☐ All Around Tube Circumference

☐ Corrosion Evident ☐ Fouling Evident

☐ General Description of Damage NO DAMAGE TO DATE

ΔP TWICE DESIGN ON SHELLSIDE

Exchanger Operation History

- How Long on Stream Before Damage Occurred? ______
- Any Unusual Occurrence Observed Prior to Vibration as a Consequence of

  ☐ Start-up ☐ Plant-Upset ☐ Shutdown

  Describe ______
- If Vibration Remedy Applied, Describe and Indicate Results: ______

TUBE BUNDLE DAMAGE SKETCH