NSRP No. 0297
March 1990

THE NATIONAL SHIPBUILDING

RESEARCH PROGRAM

FLAME BENDING OF PIPE FOR ALIGNMENT CONTROL

PANEL SP-7 PROJECT REPORT

This project was performed by Puget Sound Naval Shipyard under sub-contract from Ingalls Shipbuilding, Inc. Funds were provided by the U. S. Navy and the Maritime Administration of the U. S.

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LEGAL NOTICE

FOREWORD

This project presents the results of an R&D project initiated by members of the Society of Naval Architects and Marine Engineers Ship Production Committee, Panel SP-7.

The project was conducted by Puget Sound Naval Shipyard by Steve Nelson, J. Dwight, Dale Heagy, D. Mortvedt, Bob Houghteling, Frank Gatto (SP-7 member) and D. Coglizer. SP-7 Panel Chairman was Lee Kvidahl and Program Manager was O. J. Davis, both of Ingalls Shipbuilding, Inc. The NSRP Administrator was Virgil Rinehart, Maritime Administration of the Department of Transportation.

A Word About the NSRP:

The National Shipbuilding Research Program (NSRP) has been engaged in research related to improvements in shipbuilding in the U. S. since 1973. The program is a cooperative effort involving commercial and U. S. Naval shipyards and related agencies, industries and educational institutions.

Since the inception of the program in 1973 R&D projects have been performed with significant contribution in the areas of facilities, environmental effects, outfitting and production aids, design and production integration, human resource innovatior shipbuilding standards, welding, industrial engineering, educatior and training, flexible automation and surface preparation and coatings. A library and bibliography of NSRP reports is maintained at the University of Michigan, Transportation Research Institute, Ann Arbor, Michigan.

The program is funded by cooperative agreement contracts by the U. S. Navy and the Maritime administration of the U. S. Department of Transportation.

ABSTRACT

The principles of flame straightening, long in use on plate structures in shipbuilding, have been applied to the problem of precision alignment of fluid system piping in shipbuilding and overhaul. Reduction of residual stresses by elimination of mechanically applied stresses to pipes for alignment prior to welding or bolting in place is a desirable objective.

This project is a first effort to develop techniques of heat control and patterns of heating to achieve alignment without adverse effects to base metal. Extensive testing has been performed and results documented to provide a data base for refinement of procedures to be used in ship production and overhaul. It was not possible within available time and funding to reach definitive conclusions on CRES pipes, however for carbon steel and copper-nickel alloys, the report shows positive results. No significant detrimental effects of repeated controlled heating were found and sufficient bending is produced to warrant use of flame bending of carbon steel and copper-nickel pipe in shipbuilding.

O. J. Davis
SP-7 Program Manager

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APPENDICES

1 BACKGROUND

1.1 Overview

This report describes the detail laboratory, analytical and hands-on work performed. The effects of flame bending on pipe movement are examined in detail. The effects of flame bending on metallurgical and mechanical properties are also reported.

All empirical data (derived by experimentation) has been compiled and is located in the appendix. Simple pipe movements can be calculated. A method of torch heat calibration has been developed using precision flow meters.

This detail study should form the basis of a practical shop document to be written, which allows the mechanic to perform flame bending with some assurance of a predictable result without damage to the pipe system material.

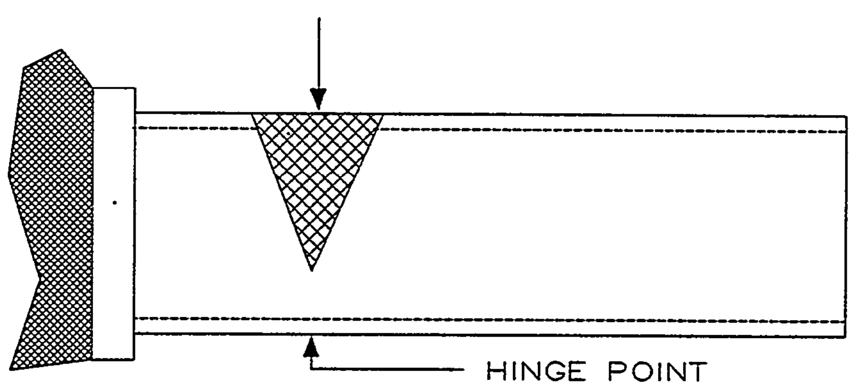
The work has been funded by the SP-7 Welding Panel.

It is anticipated that a brief practical Welding Journal Article may be written and submitted for publication during 1990.

1.1.1 Typical Flame Bent Pipe

For those panel members not familiar with flame bending pipe the following sketches show some of the fundamentals.

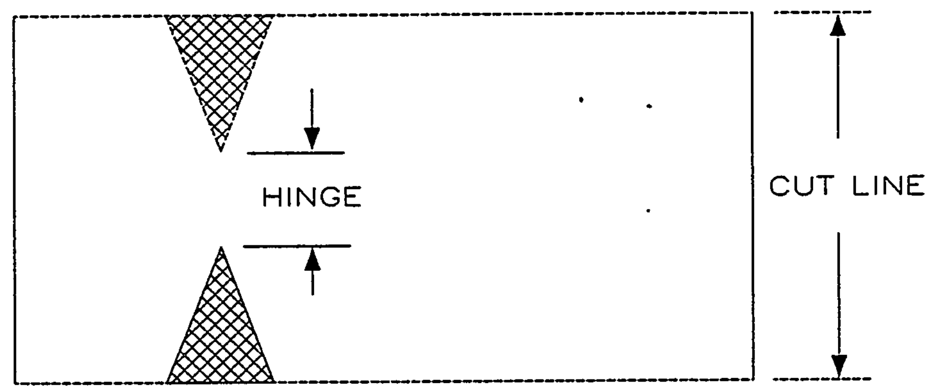
PIPE LAYED OUT FOR VEE HEAT BENDING



FILE: VEE_HT_1

The bending heat pattern shown below requires two torches be used simultaneously. The heating pattern starts at the VEE TIP HINGE and proceeds toward the wide section of the VEE PATTERN.

PIPE CUT AND SPREAD OUT SHOWING DUAL VEE HEAT PATTERN



FILE:: VEE_HT_2

1.1.1.1 Final Vee Heat Configuration

The final result is a pipe bent around a HINGE point. Figure 1.1.1.1 below can be generated using the HOLT or Line Heat method.

AFTER HEATING WITH VEE TORCH PATTERN

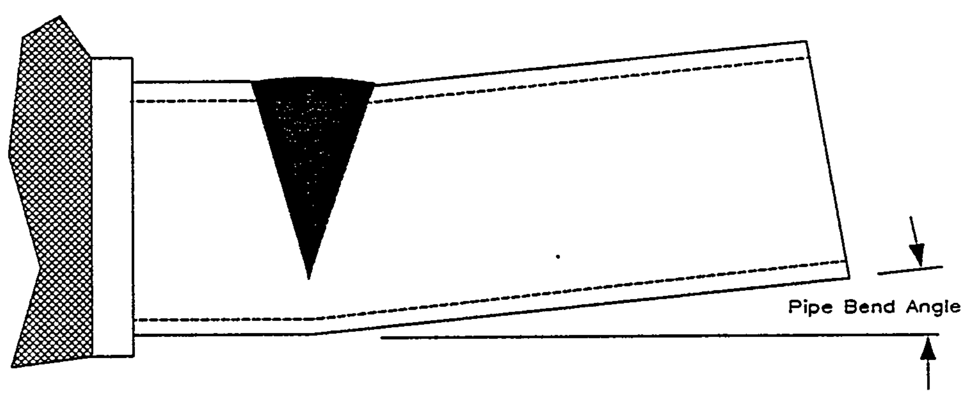


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FIGURE 1.1.1.1

1.2 Literature Review

A detailed literature survey has been completed. The survey was performed through the Edison Welding Institute by the Battelle Institute, Columbus Ohio. Dr. H. W. Mishler, Senior Research Engineer provided abstracts of 95 citations, most of which were in German. Complete copies of four (4) Ship Structure Committee reports were provided from. Dr. Mishlerts personal library. These reports deal in detail with the effects of flame straightening on ships structures.

1.2.1 Primary Concepts, Richard E HOLT [1]

Professor Richard E. Holt has written the definitive article on flame bending of structural shapes. This article explains the principals of thermal stress and strain along a single axis (perfect confinement) , along a single axis (variable confinement) and biaxial restraint.

Professor Holt identifies the spot heat as the basis of all heat patterns. "Consider a circular spot heated to an elevated temperature. The radial and tangential stresses in the hot zone will be compression equal to 0.5 $\alpha \; \Delta \; TE$. In the restraining material the radial stress will be compression with the tangential-stress tension as shown below:

$$\textit{radial} \quad \sigma_r = -0.5 \; \alpha \; \Delta \; TE\frac{a^2}{r^2}$$

$$\textit{tangential} \quad \sigma_t = -0.5 \; \alpha \; \Delta \; TE\frac{a^2}{r^2}$$

where E = modulus of elasticity; a = radius of heated zone; r = radius at which stress is calculated; AT = temperature difference between hot zone and restraining metal; a= coefficient of thermal expansion." 2

The concepts of spot heats, line heats (traveling spot) and vee heats are examined in detail as related to structural shapes such as angle, channel and I-beams.

Holt has determined that "the basic heat pattern for producing a bend in metal objects is the vee heat". 3 professor Richard E. Holt quantifies this original work by Joseph Holt into a set of general rules and simple equations.

1 Holt, R. E., "PRIMARY CONCEPTS FOR FLAME BENDING", Welding Journal, June 1971.
2 Holt, R. E., "PRIMARY CONCEPTS FOR FLAME BENDING", Welding Journal, June 1971.
3 Holt, Joseph, Contraction as a Friend in Need, Joseph Holt, 1938.

Mechanical properties of structural steels were shown to improve after flame bending. Yield strengths were slightly above the original values and Ultimate tensile strengths showed slight reductions. "Properly placed heat patterns produce a residual stress pattern tha is lower in magnitude and more uniform than as-rolled material. Tests conducted by the US Army Corps of Engineers at Clear Alaska, showed the flame straightened A36 beams were superior to the as rolled beams."

1.2.2 Flame Straightening & its Effect on Base Metal, SSC-198 [5]

This report is essentially a summary of literature and basic metallurgy associated with flame straightening on various classes of shi building plate steels. This document lists 70 references.

1.2.3 Effect of Flame[6] & Mechanical Straightening on Properties of Weldments, SSC-207

This research covered various steel plate in the range from 40,000 psi tensile to 100,000 psi tensile strength. One of the findings was;

* "Buckling-type distortion decreases drastically as the plat thickness increases, and it almost disappears when the plate thickness exceeds about 3/8"."

Fracture transition temperatures were determined for ABS-2 type pla in the as received and in the flame straightened condition. Flame straightening temperatures were very close to the experimental temperatures of the PUGET SOUND NAVAL SHIPYARD work. Their temperature were 1300 to 1400 degrees F.

As received ABS-2 plate have fracture transition temperatures of +52 F. Flame straightened plate in this study had fracture transition temperatures of +70 F.

Their conclusion was that "widespread use of flame straightening on ABS-2 steel is an acceptable procedure". The carbon steel pipe use in the Naval Shipyards are very similar to ABS-2 grade steel.

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4 Holt, R. E., "PRIMARY CONCEPTS FOR FLAME BENDING", Welding Journal, June 1971.

5 H. E. Pattee, R. M. Evans, and R. E. Monroe., "Flame Straightening and its Effect on Base Metal Properties", Ship Struct Committee Report No. 198 (August 1969)

6 H. E. Pattee, R. M. Evans, and R. E. Monroe., "Effect of Flame & Mechanical Straightening on Material Properties of Weldments", Ship Structure Committee Report No. 207 (1970)

2 OBJECTIVES

2.1 Shop or Field Calibration Method

To Develop an accurate and simple method of calibrating the heat output of the flame bending heat source.

2.2 Travel Speed and Temperature

To determine the relationship between torch travel speed and temperature gradient

2.3 Vee Heat Pattern Versus Pipe Deflection

To determine the relationship between Vee heat pattern and pipe deflection.

2.4 Multiple Heat Effects

To determine the effectiveness of multiple heats.

2.5 Experimental Process Measurements

To determine a practical method of monitoring the heat distribution, using critical process parameters such as, torch travel speed, path, spot diameter and torch heat output.

2.6 Practical Pipe Temperature Measurement

To investigate practical methods for measuring temperatures in process on the flame side, below red hot, for field applications.

2.7 Metallurgical & Mechanical Property Effects .

To determine any detrimental effects of flame bending on the mechanical properties and metallurgical structure of various alloys.

2.8 Internal Sea Water Contamination Effects

To determine any detrimental effects of flame bending on pipe with service related internal contamination.

2.9 Final Engineering Report

To write a detailed final engineering report.

2.10 Shop Working Instruction

To develop a practical shop working instruction for use on the production shop floor.

3 MATERIAL, EQUIPMENT & LABOR REQUIREMENTS

The primary purpose of this section is to describe in detail the experimental setup, material, equipment and recording devices used to achieve the final results.

3.1 Material

3.1.1 Material Type Tested .

The alloys tested were:

Alloy	Number of test heats
A. Carbon steel	57
B. Copper Nickel (70/30)	72
C. Copper Nickel (90/10)	76
D. Stainless Steel	15
E. Monel	5
TOTAL	225

3.1.2 Pipe Material Specifications (new pipe)

All pipe was purchased new from the stock system with the exception of the seawater contaminated pipe described in section 3.1.3. Pipe diameter ranged from 2" to 12", with wall thickness from 1/8" to 3/4".

The use of stock system pipe material should represent a data base line which can be translated for use by other Naval Shipyards.

3.1.3 Seawater Service Pipe Removal (12" & 4.5" Diameter)

Actual submarine main sea water (12" diameter) and auxiliary sea water (4.5" diameter) pipe represents a worst case condition for contaminated pipe.

The 4.5 and 12 inch seawater pipe was subsequently removed in lengths comparable to the new pipe lengths.

The pipe ends were sealed to preserve the internal contaminants until the actual test work was performed.

3.2 Labor

3.2.1 Code 138 Welding Engineers

All hands on lab work was performed by J. Dwight, Mr. Dale Heagy, Mr. Steve Nelson and Mr. Bob Houghteling. Mr. Derek Mortvedt assisted during certain phases of the work and was especially helpful on final review of results.

Mr. Frank Gatto was the Project Manager and provided detail technical guidance.
Mr Steve Nelson and J. Dwight shared Project Engineer responsibilities.
Mr. Douglas Coglizer provided financial and technical guidance for the entire program.

3.2.2 Shop 06 Electronics

Mr. Tony D' Andrea of Shop 67 performed all electronic support work. Mr. D'Andrea performed all installation and setup of analog to digital conversion boards and performed the initial calibrations of LVDT ' S .

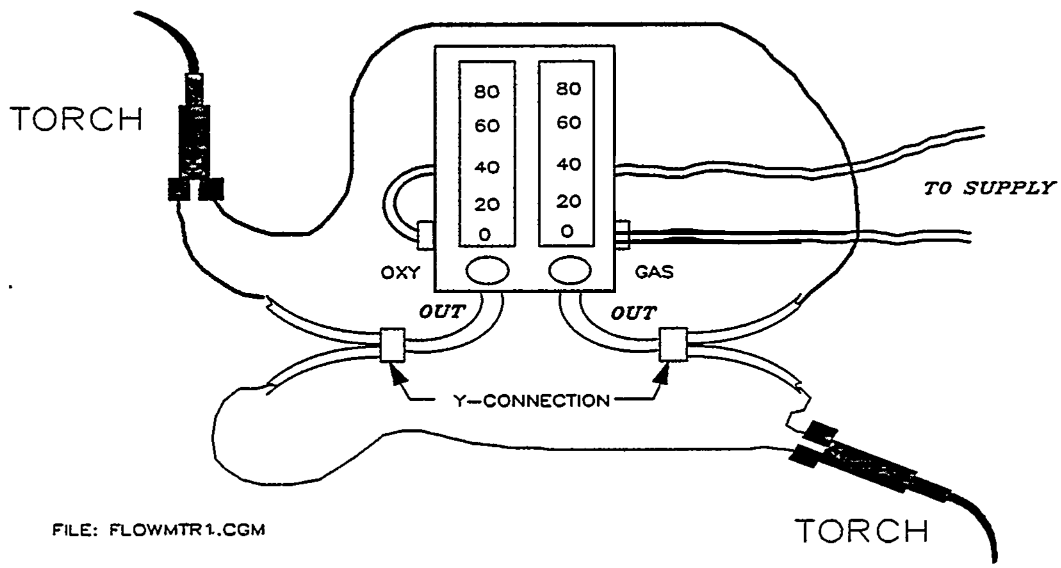
3.2.3 Code 260.2 Design Engineering Support

Code 260.2, Design Engineering, wrote a detail instruction to have 4.5 and 12 inch diameter Main Seawater Copper Nickel (70-30) pipe removed from a submarine. They selected EX-SSN618 which has been service for approximately 20 years.

Code 260.2 personnel have been helpful and maintained an interest i the flame bending study throughout the program.

3.3 Equipment

3.3.1 Heat Source



3.3.1.1 Oxy-Fuel Torch

A standard MAPP GAS + Oxygen Fuel torch was used through all tests. This gas is the standard used in the Shipyard.

3.3.1.2 OXY-Fuel Flow Meters

Flow rates are set, monitored and controlled by precision flow meters with "Y" fittings on the output side of the flow meter.

This configuration assures that each torch receives the same volume of gas.

3.3.2 Software

3.3.2.1 Lotus Freelance

Lotus "Freelance" was used to place all drawings directly into the word processing program.

3.3.2.2 CODAS Program SoftWare

Analog to digital data conversions of pipe motion was recorded in 3 axis. The data was manipulated using the CODAS software. The results of these real time records were fed into lotus 1,2,3 for graph generation.

The finish graphs are contained in -- appendix C.

3.3.3 .Electronic

3.3.3.3 Real-time Waveform Scroller Board

The CODAS WFS-200 card was used to display the data in real time .as it was gathered. This card works with the METRA BYTE EXP-16 A-D conversion card (see section 3.3.3.2)

Pipe movement was recorded as each experiment proceeded. The data was real time on the computer screen with up to 8 windows visible at one time.

The CODAS real-time waveform scroller has software that allows the user to display data at different rates. The user can also look at very small segments of the data if required.

The CODAS circuit card and software eliminates the requirement for the user to write programs. Programming is required if the METRA BYTE EXP-16 is used with out support hard/software.

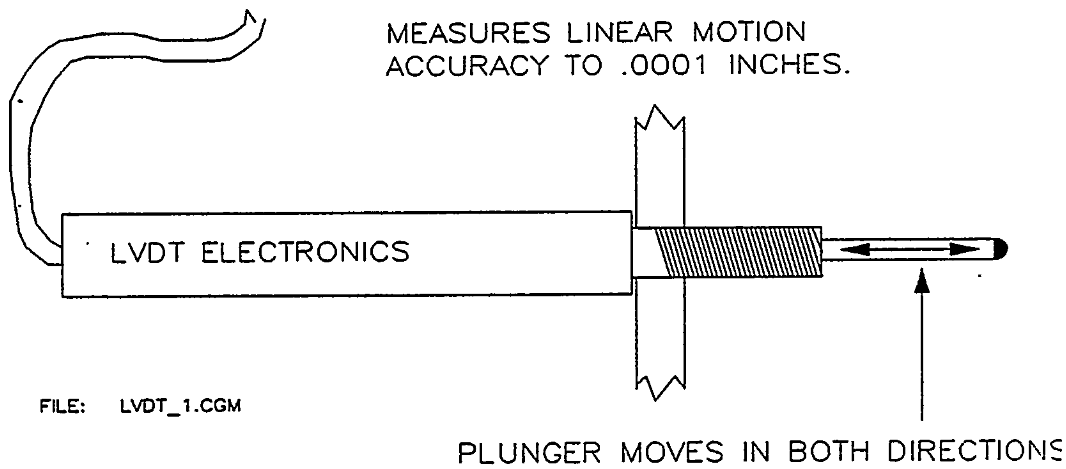
3.3.3.2 Analog to Digital Conversion Card for the Compaq Computer

The METRA BYTE EXP-16 card was installed and used in conjunction with the real time waveform scroller board.

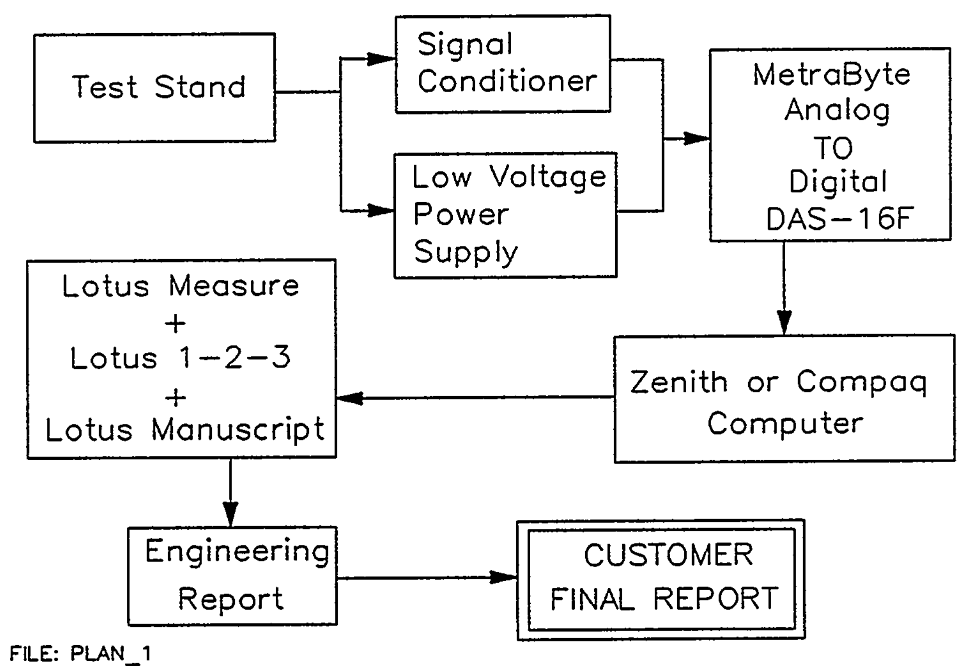
The function of this board is to convert the low voltage DC signals from various transducers such as LVDT'S and thermocouples to digital signals which the computer can process.

3.3.3.3 Linear Voltage Displacement Transducers (LVDT)

The LVDT's used in all tests for measuring deflection of pipe wer DC powered. These devices use a +/- 15VDC power supply and produc a DC output of +/- 10V. This output is subsequently reduced to +/- 5VDC for use with the CODAS BOARD.

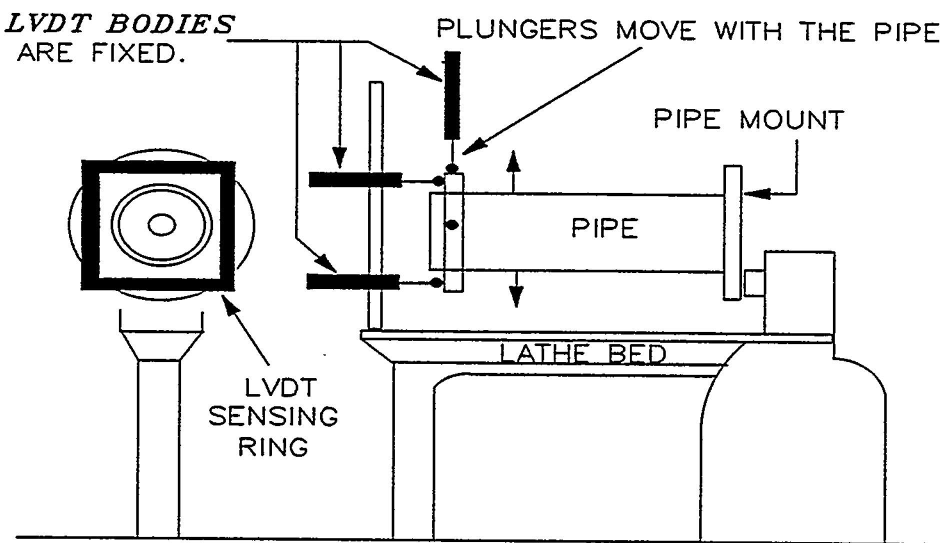


A general layout of the overall experimental gathering method car be seen in the below sketch.



3.4 Mechanical Test Setup

The overall mechanical test setup is shown below.

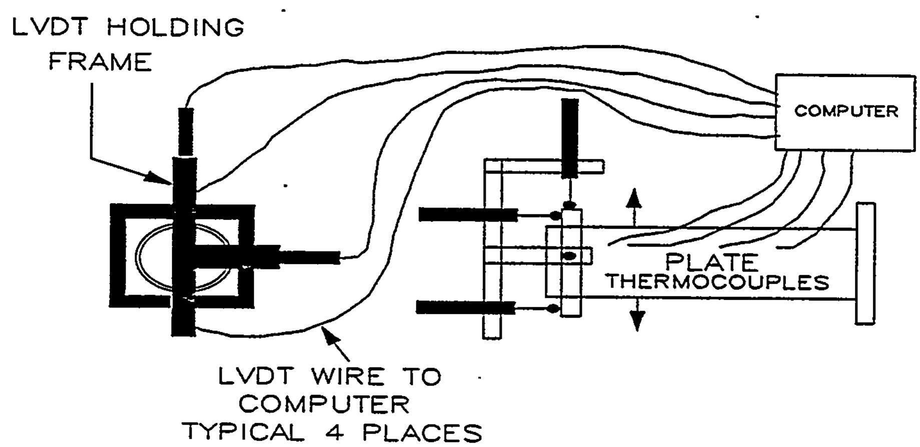


FILE: LATHE_1

3.4.1 Thermocouple Plate Test Setup

Problems were experienced with the combined LVDT + Thermocouple test setup. It was discovered that the A-D conversion card requires isolation of each channel. The thermocouple voltages are very low and were affected by the computer voltages.

Peak temperature readings were taken using a calibrated contact pyrometer during the balance of the test work.



FILE: PLATE_1

3.5 Calibration of Torch Temperature and LVDT Linear Motion

The calibration of torch temperature output and LVDT'S linear motion was performed using the following detail procedures.

3.5.1 Torch Calibration

Various methods of torch calibration were tried including thermal couples attached to pipe, plate and pipe rings. The vee heats were applied and the record of time/temperature was recorded. These results were then plotted using lotus 123.

These methods of torch calibration using automatic data gathering were too complex and the results were difficult to translate into a production procedure.

3.5.1.1 Simplified Torch Calibration

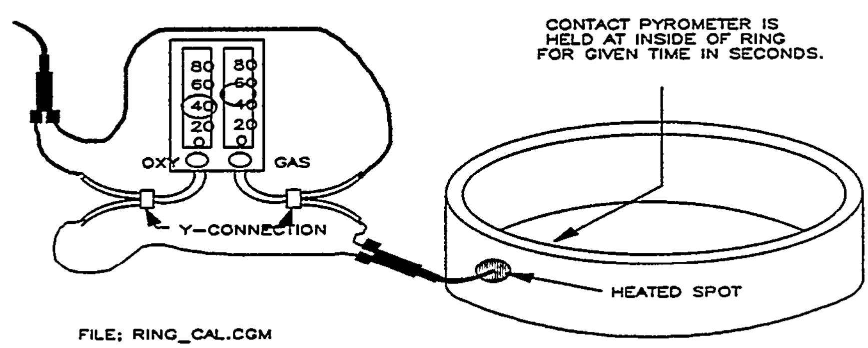
The final torch calibration method is simple, direct and easily translatable to the shop floor.

Calibration of the torch involves setting the flow meter shown in section 3.3.1 to a preset value such as: 40 Oxygen and 35 Gas.

Both torches are ignited and the flames are held next to each other for a comparison of length and color.

The final calibration is done on a ring as shown in figure 3.5.1.1 below.

TORCH CALIBRATION RING



EACH TORCH HEATS THE SAME RING AND IS ADJUSTED UNTIL THE SPOT IS HEATED TO THE SAME TEMPERATURE IN A GIVEN *NUMBER OF HEATS. THE RING IS QUENCHED TO AMBIENT BETWEEN HEATS.*

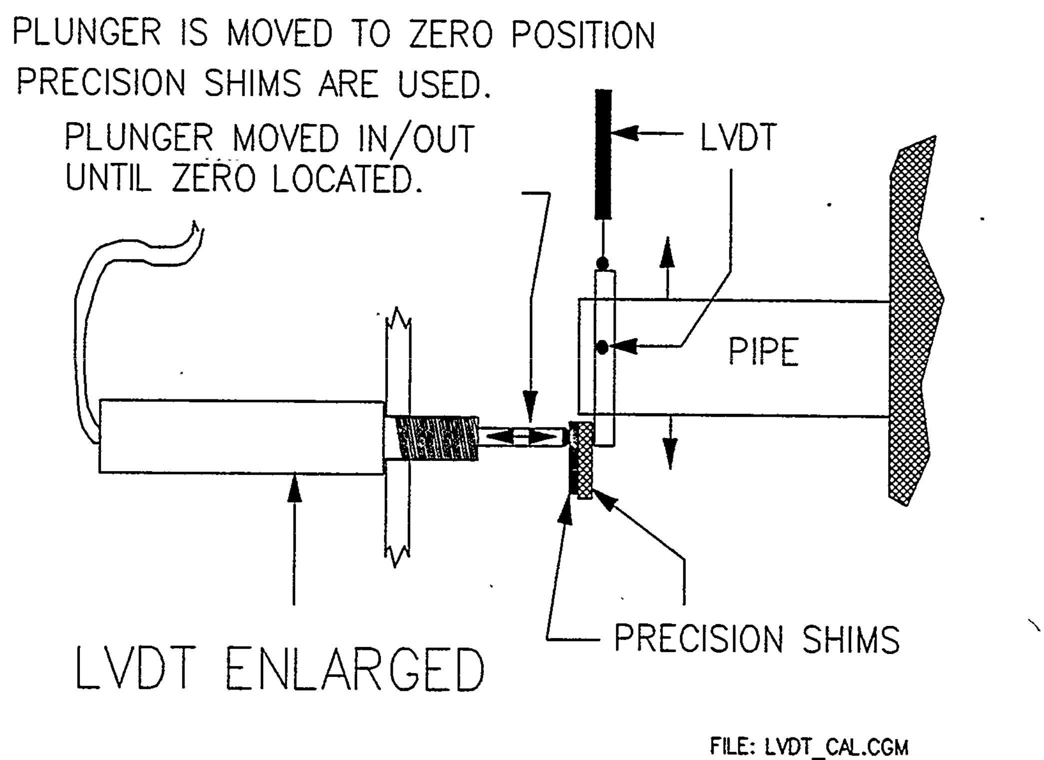
The above calibration is performed for each diameter and wall thickness. The calibration ring should be 4" to 6" in length.

3.5.2 LVDT Linear Motion Calibration

The LVDT's will measure linear motion with accuracies of +/-.0001 inches. The LVDT type selected for this project has a measurement range of 1.0 inch. This LVDT style also measures + and - movement.

If the LVDT is used in the non calibrated node then the results a values in volts. The standard output for the system is +5VDC to -5VDC .

Calibration of any LVDT involves translating this output +/- voltage into real engineering numbers. The CODAS software has a program which works with the CODAS waveform scroller board and allows the user to gather calibration data for each LVDT (or any other recording device). See the below figure for the physical setup.



Calibration is accomplished as follows.

* The LVDT (one LVDT per channel) is adjusted to zero on the computer screen.

* A small segment of voltage is recorded at Zero.

* The LVDT is repositioned to some given value. In our case a precision shim of .0925 inches thickness was used. This results in positive voltage. A small segment of voltage is recorded at this positive value.

* The LVDT is again repositioned to a negative value using the precision shims. A final small segment of voltage is recorded at this negative value.

We now have three (3) voltage readings for one LVDT channel.

* The final step is to run the program called CODAS POSTACQ which allows the voltage readings to be converted to engineering units. This small computer file is identified by a unique name such as HEAT_XX.CAL.

when data is gathered in a test the HEAT_XX.CAL file is Present and sets all test-data with the engineering units you defined. The HEAT_XX.CAL file eliminated time consuming arithmetic errors.

3.5.3 Data Gathering System Calibration

The Key Stroke instruction detailed in APPENDIX B was used throughou calibration.

APPENDIX B can be used as a detail instruction in lieu of reading th CODAS POSTACQ instruction manual.

4 LABORATORY TESTS & RESULTS

The experimental work was conducted in the Code 138 Welding Laboratory facility.

4.1 VEE Heat Testing

4.1.1 Temperature Measurement Techniques

A primary problem for flame bending is the accurate measurement of heat input and the maximum temperature reached during flame bending.

4.1.1.1 A Simple Torch Calibration Solution

The torch calibration procedure has been previously described in section 3.5.1 . A satisfactory torch calibration was considered to be when both torches heated the same spot within +/- 25° F at a given time in seconds.

The most efficient time at temperature for all 225 tests was 850° **F in 15 seconds.**

The standard time at temperature was derived by experimentation. The low temperature tested was 850° F in 10 seconds and the high temperature input tested was 1000° F in 15 seconds. The standard was selected as 850° F in 15 seconds.

Each pipe diameter, wall thickness and material type was tested using the 850° F in 25 second standard calibration.

4.1.1.2 Maximum Pipe Temperatures

Considerable concern was expressed about the effects of maximum - temperature on the chemical and physical properties of the pipe material.

Maximum pipe temperatures were measured using a contact pyrometer on the top hot spot after completion of each heat. A record of the maximum temperature was recorded on the heat work record.

4.1.2 The Test Matrix

The material which received the most testing was carbon steel. A typical series of tests were devised where only one test variable wa changed for each series. Note that this series used a 2", 4" & 6" VEE WIDTH. No other variables were changed.

All 225 tests used the same test matrix format.

A typical test series would be as shown in the table 4.1.3

4.1.3 TABLE SHOWING ONE TEST SERIES

8 Inch Diameter Carbon Steel Pipe, Schedule 40

15 Heats in ONE (1) test MATRIX

5 Heats in one test

Test Parameters	Heats 36 through 40	Heats 31 through 35	Heats 26 through 30
Hinge Length of VEE			
1 Inch	36, 37, 38, 39 40	31, 32, 33, 34, 35	26, 27, 28, 29, 30
3 Inch			
6 Inch			
Vee Width			
2 Inch	36, 37, 38, 39 40		
4 Inch		31, 32, 33, 34, 35	
6 Inch			26, 27, 28, 29, 30

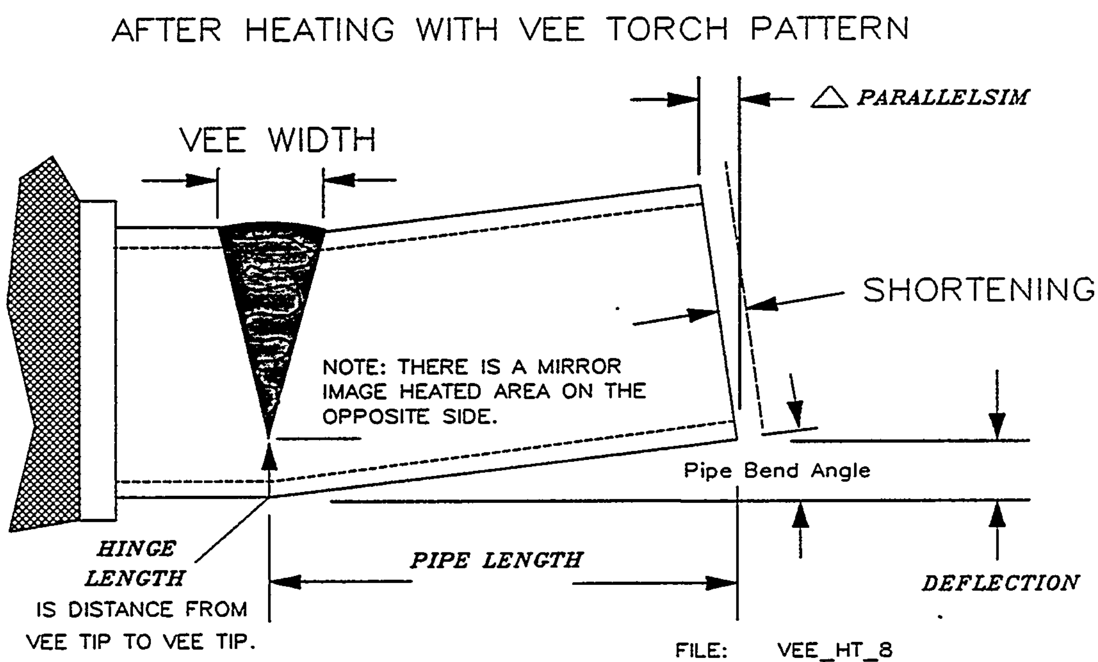
Test heats 36, 37, 38 39 & 40 are identical heat input on the same area of pipe. The reason for running identical heats on the same location is to determine the progression of dimensional changes as they occur over the (51 five heat sequence. The second major reaso is to isolate metallurgical damage, If any, to a localized-worst ca location.

Table 4.1.3 (Continued) 8 Inch Diameter Carbon Steel Pipe, Schedule 40

Test Parameters	Heats 36 through 40	Heats 31 through 35	Heats 26 through 30
Torch Temperature			
850 deg / 10 sec			
850 deg / 15 sec	36, 37, 38, 39 40	31, 32, 33, 34, 35	26, 27, 28, 29, 30
1000 deg / 10 sec			
1000 deg / 15 sec			
Vee Spot Size			
3/4"	36, 37, 38, 39 40	31, 32, 33, 34, 35	26, 27, 28, 29, 30
1"			
1 - 1/2"			
Vee Spot Overlap			
1/2 Overlap			
Touching Spots	36, 37, 38, 39 40	31, 32, 33, 34, 35	26, 27, 28, 29, 30
1/2" Space Spots			
1" Space Spots			
Line Heats	NONE	NONE	NONE
850 deg / 10 sec			
850 deg / 15 sec			
1000 deg / 10 sec			
1000 deg / 15 sec			

4.1.4 Relationship Between Vee Heat Pattern, Deflection and Shorten-ing

Before proceeding with the results, a review of terms and their loca-tions on a typical flame bending pipe may be helpful.



<u>Pipe deflection "D"</u> is defined as the lateral movement of the pipe end. Deflection <u>"D"</u> is defined as the sin of the pipe bend angle times the pipe length.

$$D = \sin(Bend\,Pipe\angle)\ X\ (Pipe\,Length)$$

Pipe Length is defined as the distance between the Vee Hinge and the end of the pipe.

Shortening is defined as shrinkage of the pipe at the center line.

$$Shortening = \frac{EndTop + Bottornpipe}{2}$$

Pipe Bend Angle is self defined. This is an important measurement since it can be used to predict both deflection and flange parallelism.

parallelism is defined as the sin of pipe bend angle times the diameter

$$D = \sin(\text{Bend PipeL}) \times (\text{Pipe Diameter})$$

The hinge length, vee width and moving spot are the primary variables which control movement on pipe bends.

4.1.5 Typical Time / Motion Plots

The Puget Sound Naval Shipyard is the only shipyard which currently flame bends pipe on a regular basis. Code 138 is present at each flame bending production job to assist and monitor. Most facilities rely on a highly skilled small core group of mechanics to perform this work. This core group of skilled mechanics are very good at predicting the amount of pipe movement. The emphasis in this study on motion is an attempt to build a significant data base sufficient to predict many pipe deflection questions and provide direction for future work.

Pipe movement (deflection and shortening) is information which the mechanic must have to predict what will happen when heat is applied to the pipe. Other factors of the job which are of importance to th mechanic are accessibility, pipe restraint, and safety.

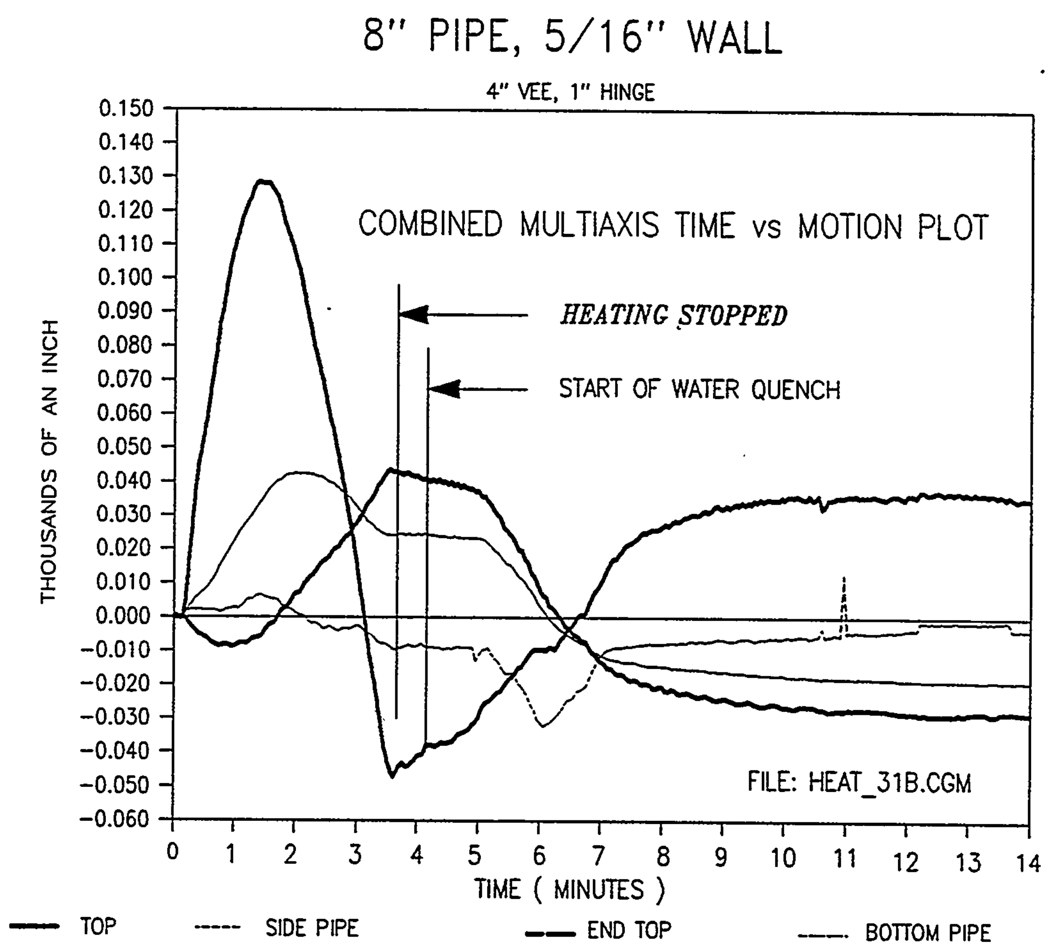
There are 225 individual plots of movement. This data are containe in APPENDIX A.

To assist the reader in understanding how a pipe moves as it is bei heated, a typical time versus movement (deflection) plot is explain in detail. The following figures are actual time - deflection curv obtained from a selected heat.

4.1.5.1 Time VS Deflection (Heat_31) 4" VEE, l" HINGE

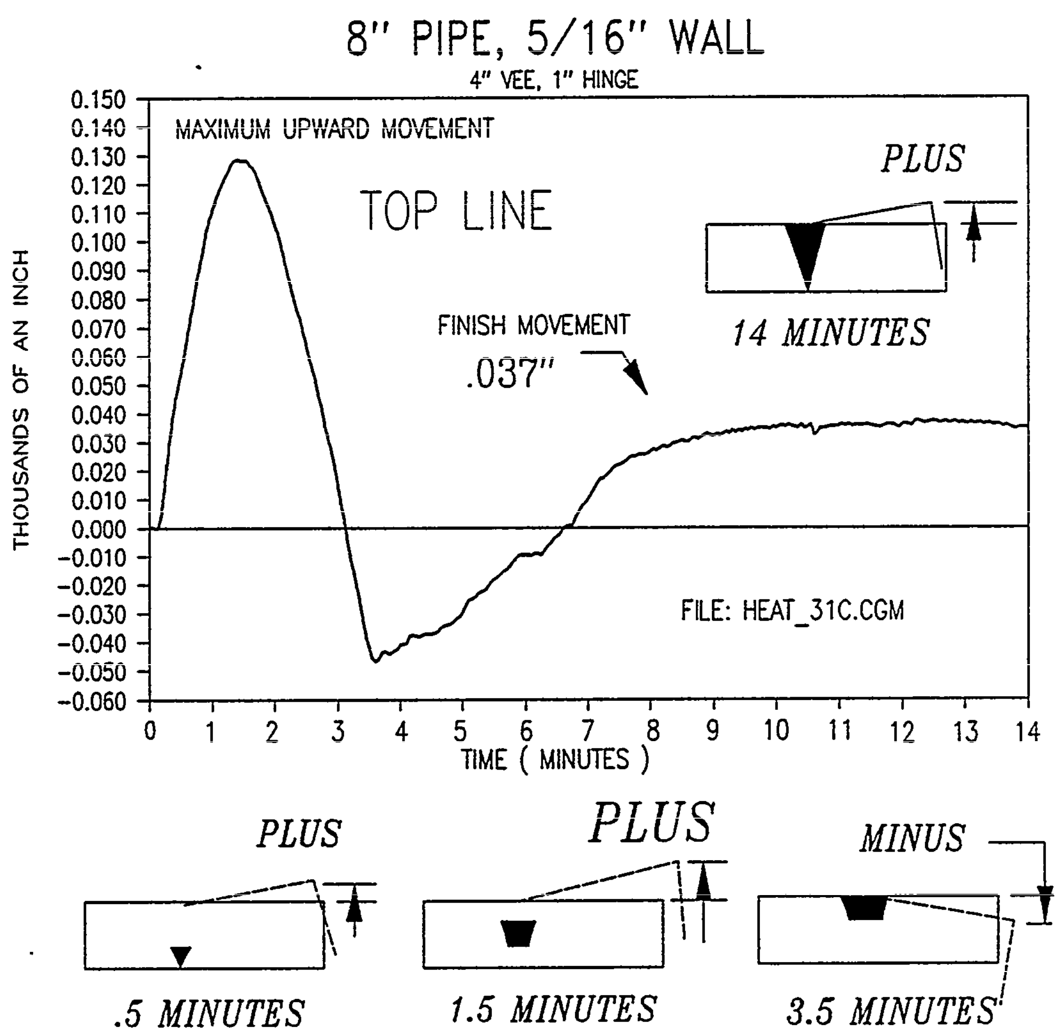
The X axis is numbered O through 14. This is time with each tick mark representing approximately one (1) minute. Our sample shows this time base convention. The convention on all the data in the appendix shows the time base as O to 280 which corresponds to O to 14 minutes. Our first example plot shows the time base extends to 14 minutes.

The Y axis is numbered in Thousands of an Inch. The plot is a record of movement in three axis. Four (4) transducers are used to measure X, Y, & Z with two (2) transducers on one axis. The result is four continuous line scans.



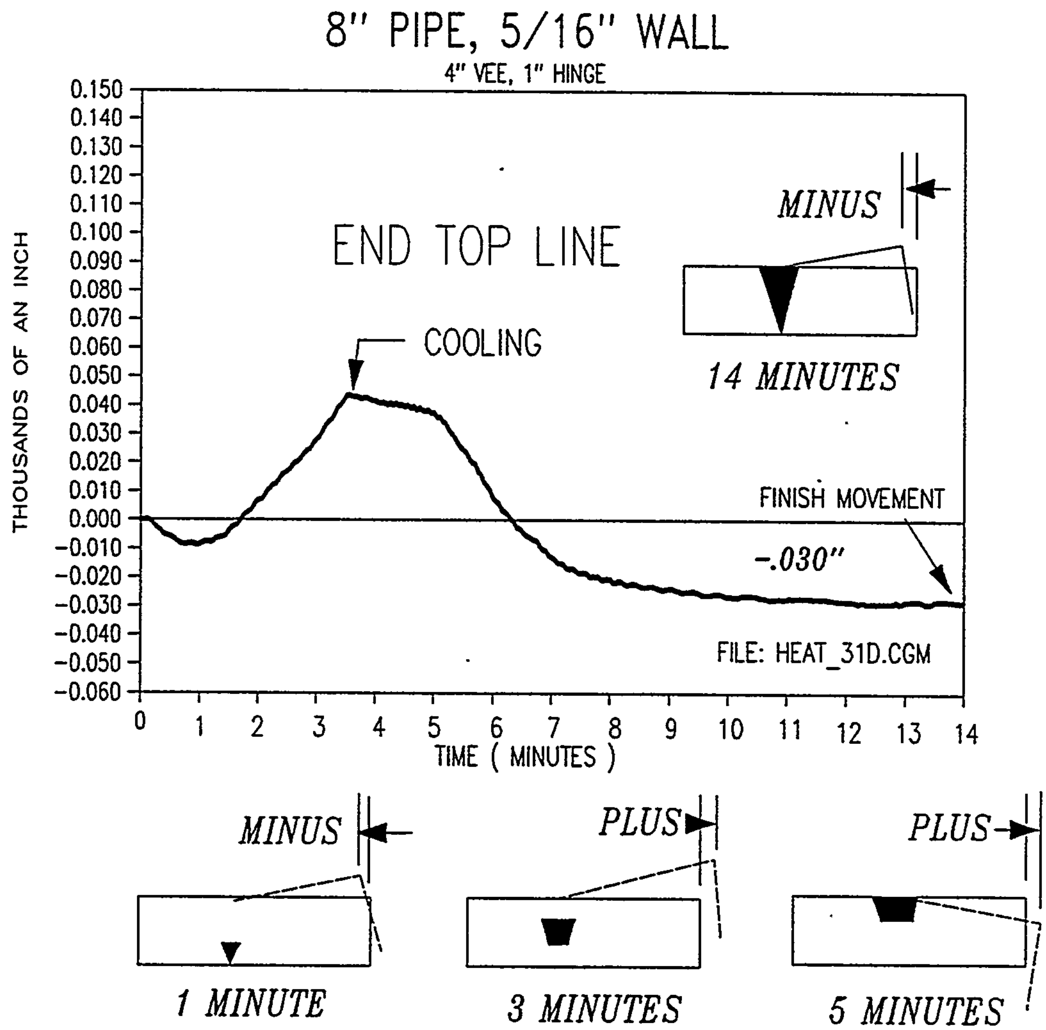
4.1.5.1.1

THE "TOP" LINE. The line marked "TOP" is a record of pipe movement 25" from the VEE on the pipe top. Notice that the pipe moves upward reaching .130" deflection within approximately 1.5 minutes due to heating below the neutral axis. At the 3 minute mark the pipe is back to 0. At 3.5 minutes the pipe is deflected to a negative -.040" due to heating above th neutral axis. THE WATER COOLING IS APPLIED TO SPEED COOLING AND THE PIPE IS TYPICALLY WELL BELOW 950° F AT THIS POINT. Th pipe begins upward movement and reaches 0 at approximately 7 minutes. At 14 minutes the pipe is at equilibrium (cold) and has a permanent deflection of .037".



4.1.5.1.2

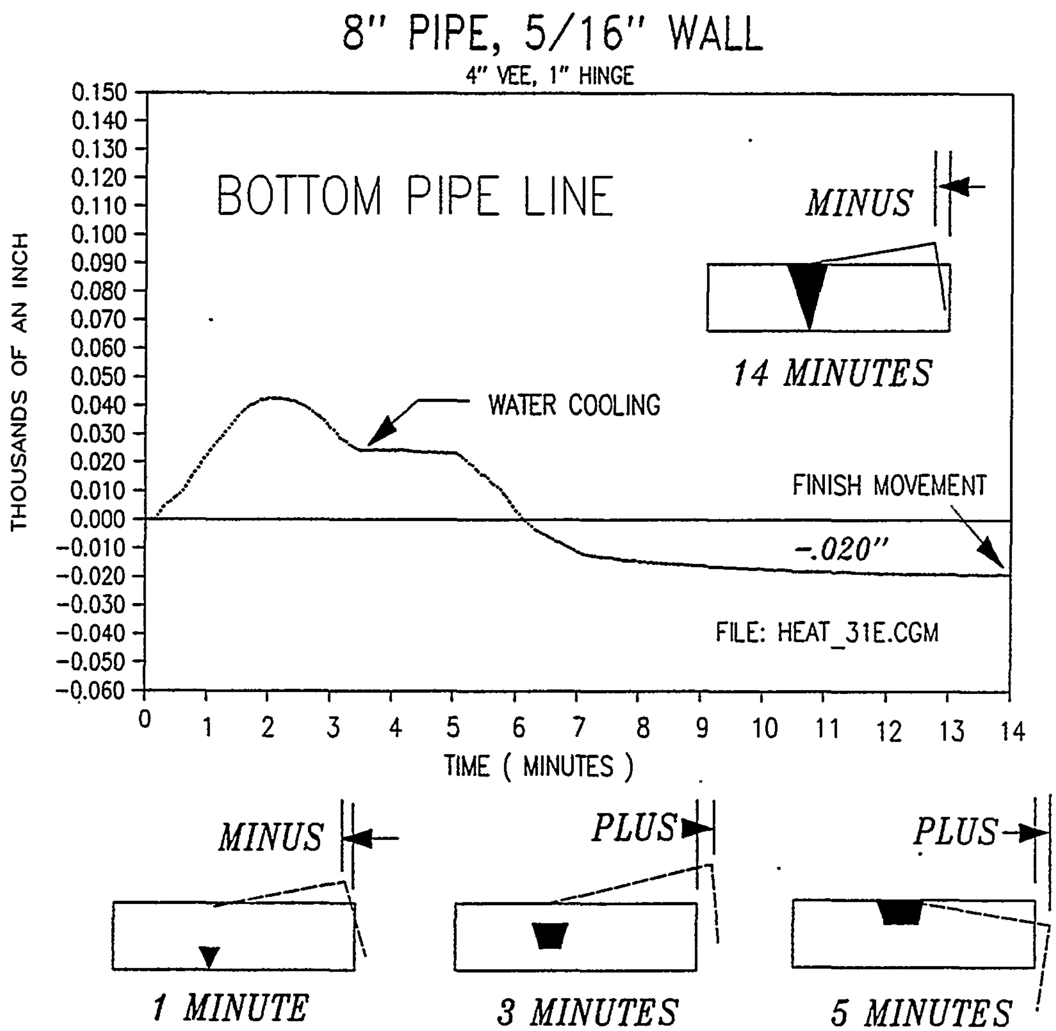
THE "END TOP" LINE. The line marked "END TOP" goes negative in less than 1 minute to -.010" due to lengthening the pipe below the neutral axis. It then goes through 0 and then positive to .043" at 3.5 minutes due to overall pipe length expansion. THE WATER COOLING EFFECT TAKES PLACE and the pipe length shortens. The pipe reaches its original length at approximately 6.5 minutes and is .020" shorter at 14 minutes.



4.1.5.1.3

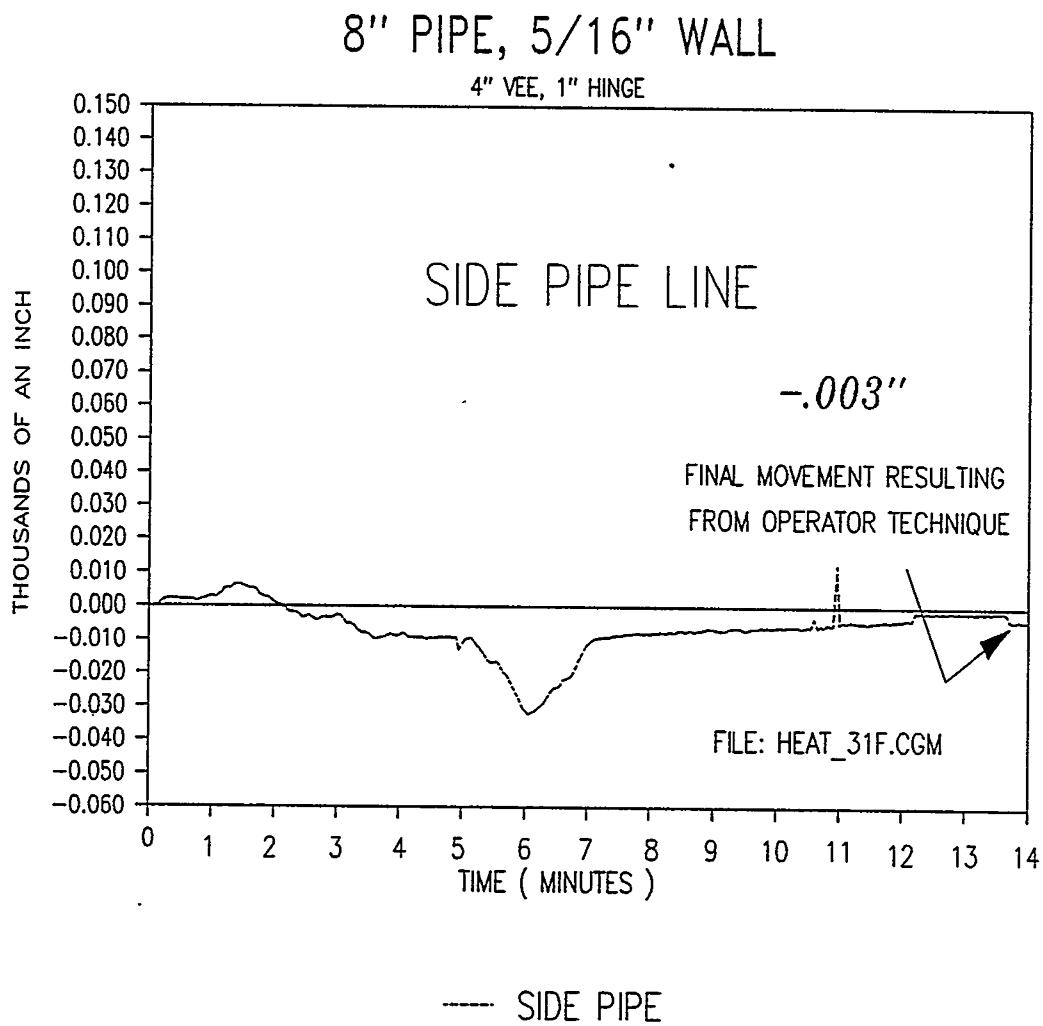
<u>THE "BOTTOM PIPE" LINE.</u> The line marked "BOTTOM PIPE" is the measure of movement at the pipe end bottom, on the same plane as the pipe hinge. The movement detail is read on this plot line as described in the previous "TOP" and "END TOP".

This measurement is always positive while the pipe is hot. During cooling, the measurement decreases and eventually is negative reflecting a shortened pipe. The pipe end bottom shortens less than the pipe end top reflecting a change in parallelism.



4.1.5.1.4

THE "SIDE PIPE" LINE. This line shows operator technique and directly reflects the effect of relative torch motion, torch position and torch temperature. If one operator holds the torch at a different distance from the pipe surface, the plot will show the result. The net result of our sample plot is that "SIDE PIPE" deflection was negative toward the operator that put more heat into one (1) vee segment. An ideal heat would be when the “SIDE LINE” returns to zero.



4.1.5.2 The Relationship of Hinge Size and Vee Width Versus Deflection

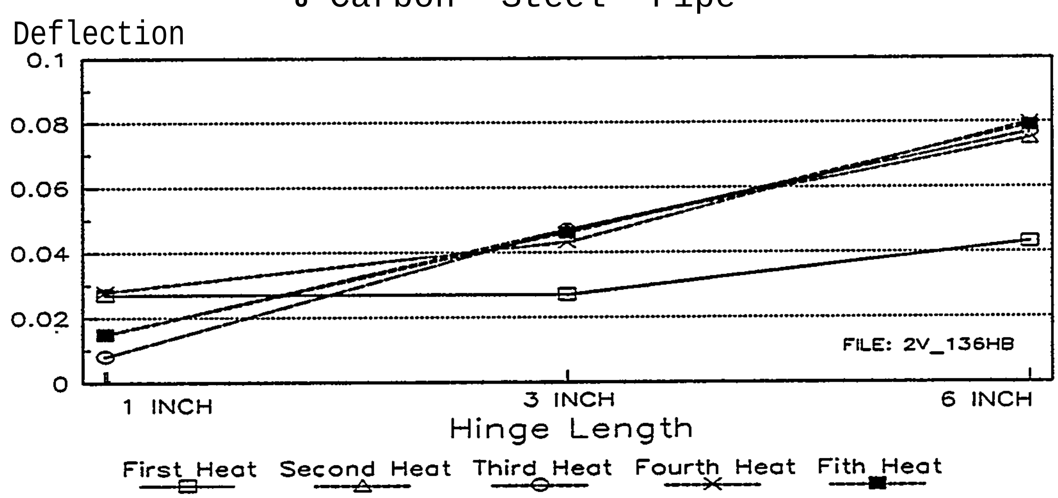
The following graphs illustrate how the pipe ends deflect upward as the vee width and hinge length change.

Notice that there are five (5) lines which represent each heat. The first group of data (5) are the 1" hinges, the second group c five (5) are the 3" hinges and the third group of five (5) are th 6" hinges. Also note that most data are grouped into very tight clusters which indicates that the pipe end has moved the same amount each time it was heated.

4.1.5.2.1 FIXED (2") VEE SIZE with Increasing Hinge

The following graph shows two (2) important results; First th pipe material deflects approximately the same amount each time it is reheated and Second increasing hinge length results in increased deflection.

2" Vee with Increasing Hinge Size
8" Carbon Steel Pipe



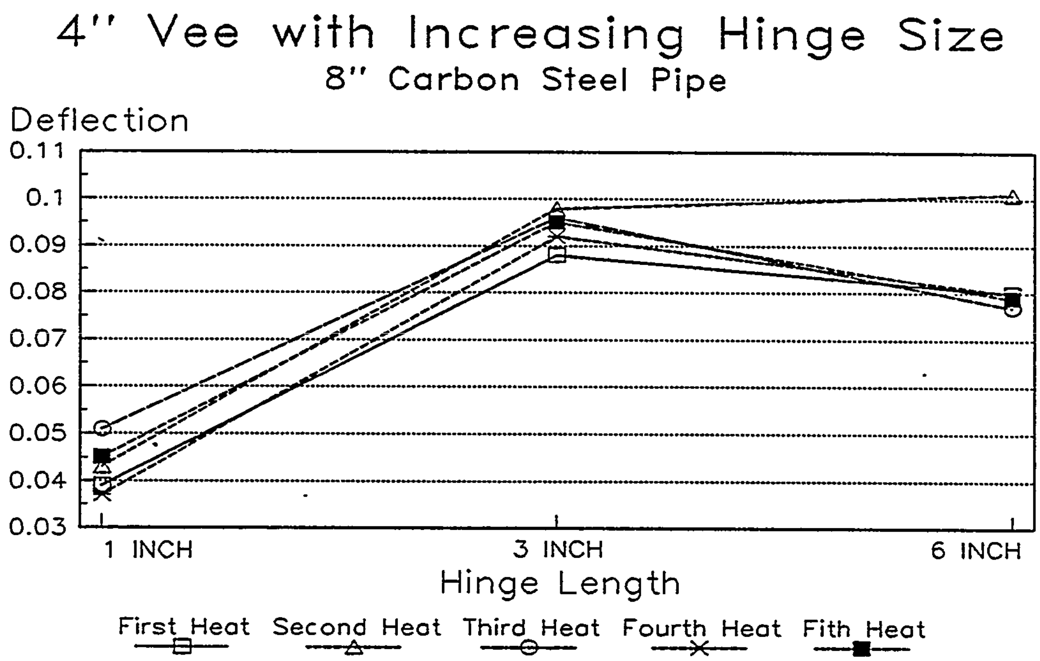
Graph 4.1.5.2.1 shows 5 heats on 8" carbon steel pipe. All parameters were held constant except the hinge length was increased on each set.

The first heat (solid line / square boxes) does not follow the other tight grouped data points. The (3) and (6) inch first heat hinge deflections may be low because of restraint by the small vee area versus the large hinge length. It has been suggested that buckling may cause the differences in data deflection after the first heat.

Heats 2, 3, 4 and 5 are verytight data sets and can be reliec upon to repeat.

4.1.5.2.2 FIXED (4") VEE SIZE with Increasing Hinge

The following graph shows the 3" hinge with a 3 vee to be the best combination when maximum deflection is required.



Graph 4.1.5.2.2 shows 5 heats on 8" carbon steel pipe. All parameters were held constant except the hinge length was increased on each set.

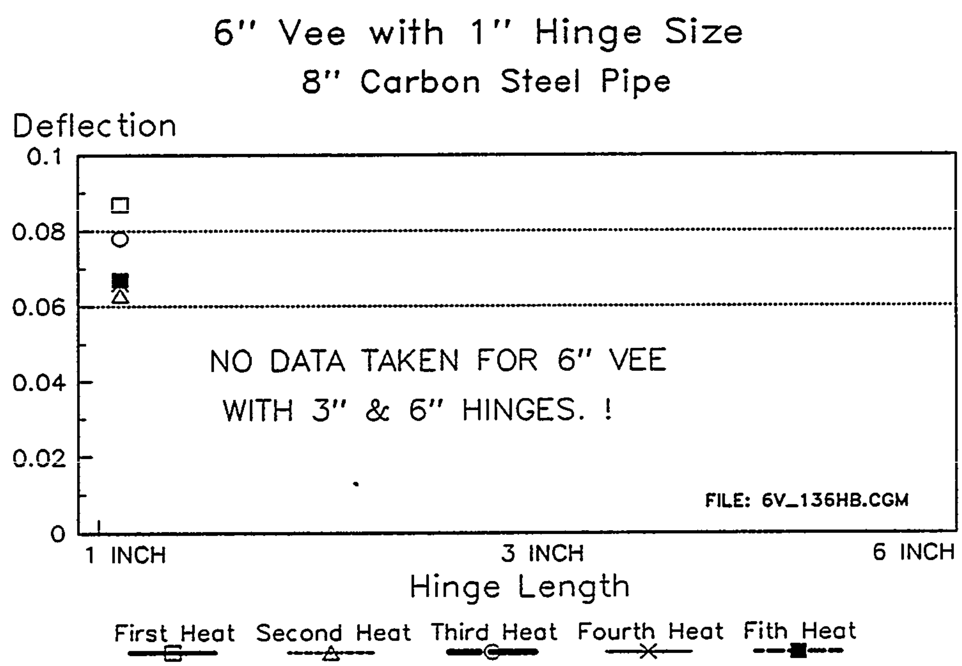
You will note that the data is very tight on each set except the 4" vee with a 6" hinge shows spread on the 2nd heat.

There appears to be a relationship between the total area of the vee heat surface and the hinge length. The heats with very tight groups of data show a dimensionless ratio of from .005 to .03.

$$R = \frac{(Hinge\ Length)}{(Total\ Vee\ Area)}$$

This relationship could allow the user to predict a particular combination of vee size and hinge length that may deflect the same amount on each heat.

4.1.5.2.3 VEE (6") FIXED Hinge Increasing



Graph 4.1.5 .2.3 shows 5 heats on 8" carbon steel pipe. All parameters were held constant and the results for heats on hinge size 3" and 6" are missing.

As in the other heats data sets are very close grouped.

4.1.6 Discussion of Results on Vee Hinges

It has been shown that vee heats are predictable. There are some general relationships that apply to all vee heats on pipe. The primary parameters which control these relationships are:

Hinge length
Vee width
Spot temperature

Regardless of how these parameters are adjusted, the finish pipe ALWAYS SHORTER AFTER HEATING.

4.2.6.1 Relationship of Hinge, Vee & Shortening

Short hinges + narrow vees = maximum shortening and minimum deflection.

Short hinges + wide vees = maximum shortening at the End Bottom and maximum shortening and maximum deflection.

Long hinges + narrow vees = minimum shortening and minimum deflections.

Long hinges + wide vees = zero (0) to minimum shortening at the End Bottom and medium deflections.

Long hinges = higher residual stress, increased pipe movement and greater instability.

Wide vees = chance for increased buckling.

4.1.7 Torch Travel Speed and Temperature Gradient

The average travel speed of the moving spot was in the range of 1.5 inches/minute to 3.5 inches/minute.

The overall average was 2.5 ipm. The amount of upset (movement or deflection) did not move significantly outside of a group of data points when the slower travel speed was compared to the higher trave speed.

The essential variable was spot size control and surrounding tempera ture of the support base metal of the pipe. The operators adjusted the torch standoff distance to control spot size and color. To do this they adjusted the travel speed in the range of 1.5 to 3.5 ipm.

These values were calculated from the time base on selected data plots for 8" diameter pipe.

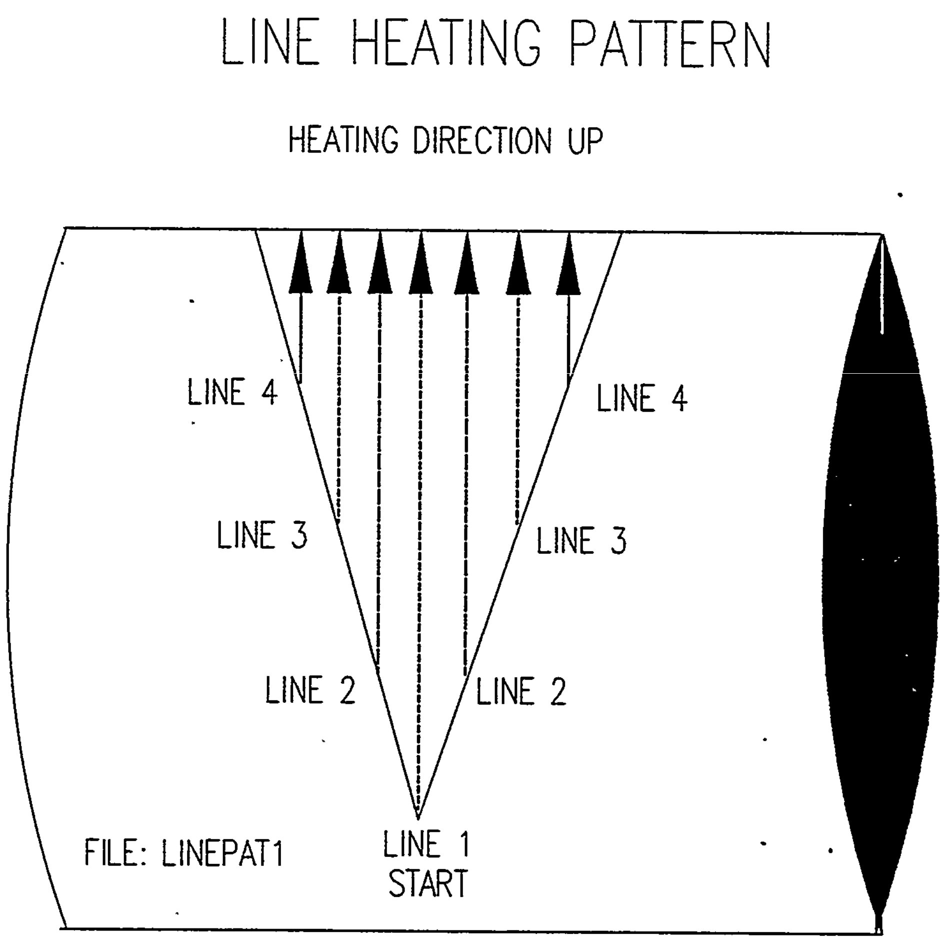
4.1.8 Determination of Residual Stress

No experiments were conducted for measurement of residual stress.

4.2 Line Heat Testing

Line heats are made in using a series of straight line heating patterns with the torch moving from the hinge area to the pipe top-or from th pipe top down to the hinge area.

The tests in our study placed the lines in an area that mirrors the ve heat pattern area. Figure 4.2 is a typical LINE HEAT UP pattern.



Line heats have advantages when bending pipe With very thin wall thic ness or pipe with diameters larger than 12 inches.

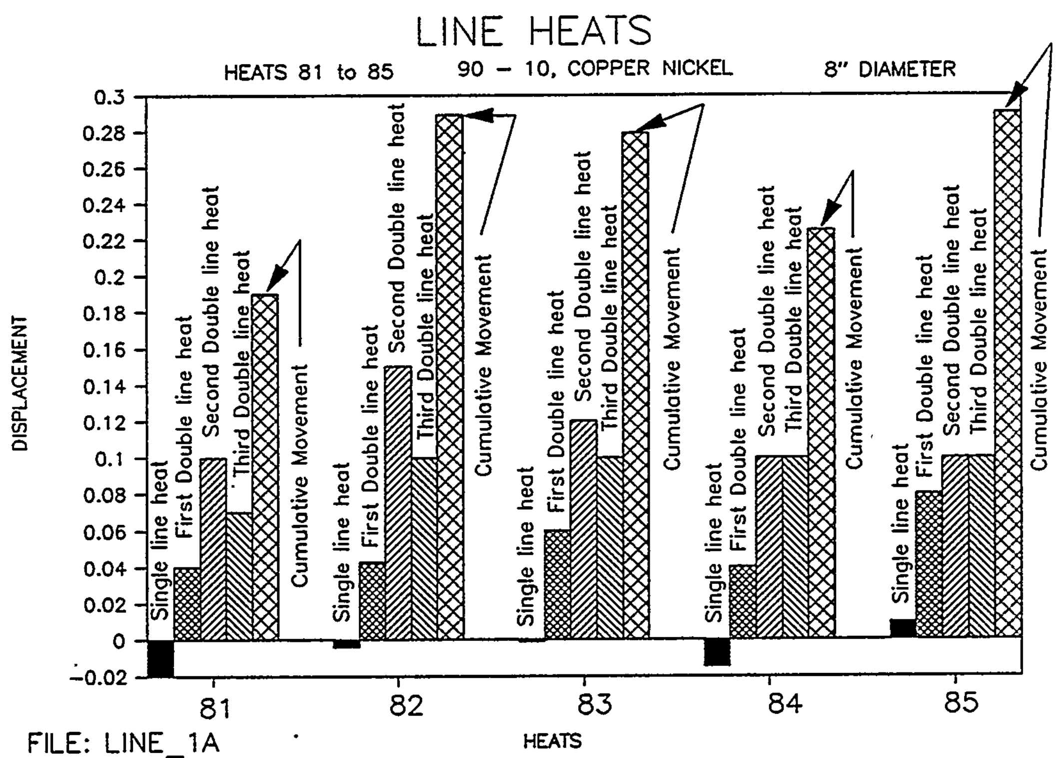
Line heats will reduce the tendency for buckling. Vee heats will buck on thin wall and/or large diameter-thin wall pipe.

4.2.1 Relationship Between Line/Vee Heat Pattern and Deflection

Line heats move in a series of discrete steps. The example shown in Figure 4.2.1 is a LINE HEAT UP PATTERN.

The first line heat causes the pipe to move down approximately .020". The second double line heat causes the pipe to move upward .040". The third double line heat causes the pipe to move upward .1". The fourth double line heat causes the pipe to move upward .070".

The combined movement of the seven (7) discrete heated lines is .190" of upward pipe movement."



Vertical Up Line Heat Patterns follow the same general pattern of pipe movement regardless of pipe diameter or material.

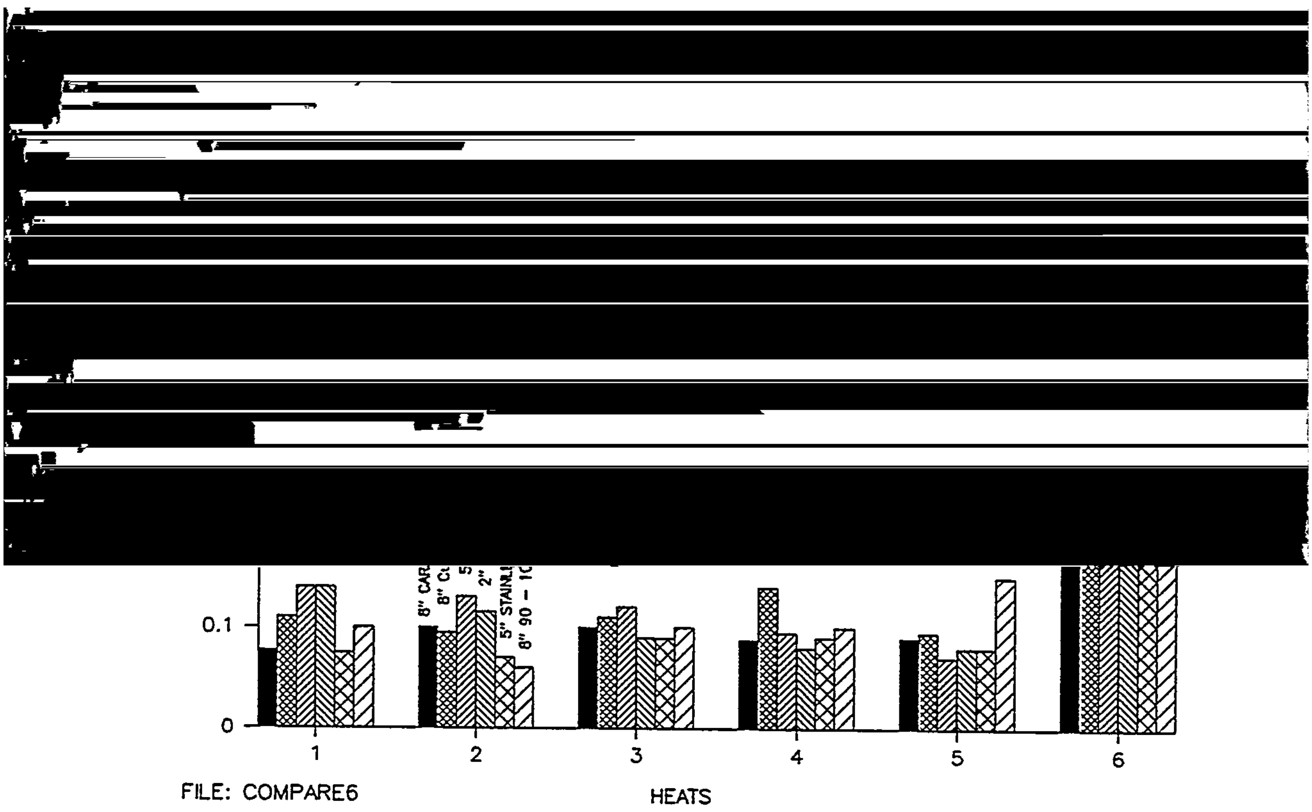
Line heats produce more pipe movement when compared to vee heats.

4.2.2 Effects of Multiple Heats

This series of heats show four (4) different materials with three (3 different pipe diameters.

ALL of these tests share a common vee size to hinge size ratio. All tests were made with a 30° vee and a corresponding hinge. Maintaining this ratio produces pipe movements with similar values. This means that the shop can predict pipe movement with a reasonable degree of certainty. The pipe range on which we now have data is from 2" to 8" diameter with Carbon Steel, Stainless Steel, 70-30 Copper Nickel and 90-10 Nickel Copper.

As the vee size to hinge ratio is changed "then the average group heights will change.



4.2.3 Temperature Measurement Techniques

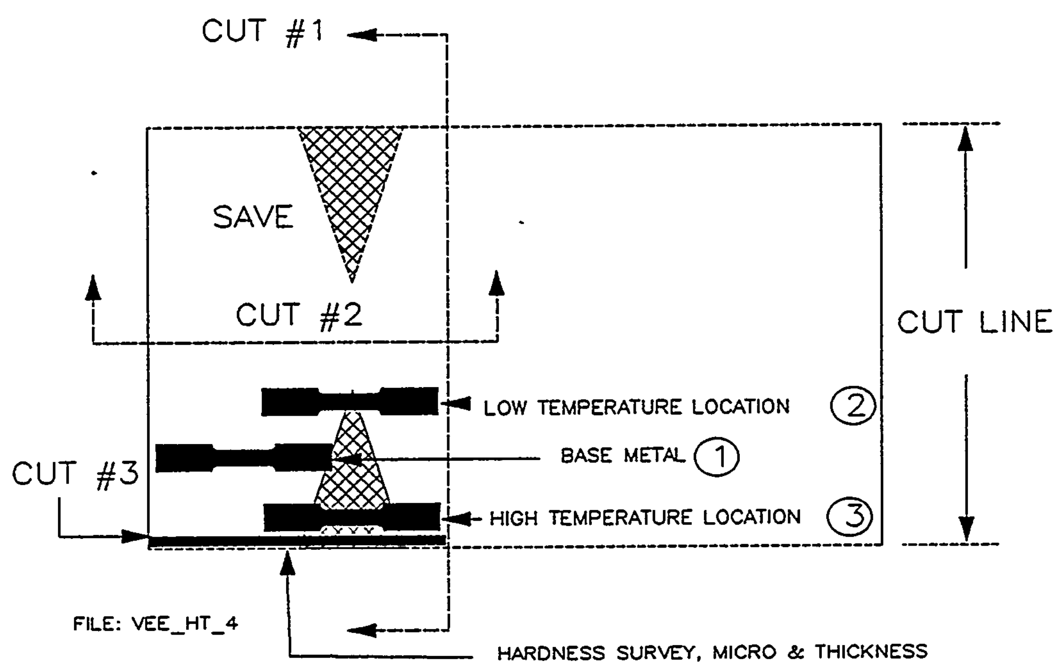
Line heats were monitored for maximum temperature using the same method as was used for the vee heats.

4.3 Mechanical & Metallurgical Testing

One of the major objectives of this program was to determine how mechan ical and metallurgical properties are affected by the flame bending pro cess.

A simple method was used to verify and compare mechanical and metallurgical properties. The method involved selecting pipe specimens from th test matrix which received high heat. The maximum peak temperature was recorded on each test pipe. This recorded test temperature data was used to select the pipe for mechanical and metallurgical tests:

4.3.1 Mechanical Test Specimen Removal Diagram



4.3.2 Tensile Strength, Yield Strength & Microstructure

The table 4.3.2.1 shows the relationship between heating and final mechanical properties. The specimens were removed from the BASE METAL, HIGH TEMPERATURE VEE LOCATION and the LOW TEMPERATURE START LOCATION. This removal sequence is shown in figure 4.3.1.

*Metallographic evaluations of carbon steel, 90:10 and 70:30 CuNi and CRES are shown in Appendix B.

4.3.2.1 Stainless Steel

PHYSICAL TEST SUMMARY For 300 Series (CRES) Stainless Steel

Sample Series 131	Tensile Load PSI	Elongation	Specification Requirements	
Base Metal 131-1	86,500	64%	75,000	35%
Low Temperature 131-2	86,500	53%	75,000	35%
High Temperature 131-3	87,000	58%	75,000	35%

The tensile value differences between the original stainless steel base metal and the heat affected stainless are. less than 1%. These values are less than the calibration requirement for the Tensile Test Machine.

Elongation is related to grain size. **The base metal has the highest elongation with a relatively small grain size. The heat affected tensile tests both show lower elongation with larger grain size.**

The physical tests show that CRES (Stainless Steel) can be heated in the range of 1000° to 1500° F with a small reduction in elongation.

These results are well within the acceptable requirements for CRES (Stainless Steel) PIPE.

An intergranular corrosion test was conducted on the multiple heated area of flame bent Stainless Steel pipe. The test was conducted *in* accordance with ASTM 262 Practice E.

Mr. Al Ruedibusch and Mr. Mike Allen. reported "ASTM 262 intergranular corrosion test was conducted for 24 hours and the bars evaluated. There was no sign of fissures or cracks which would indicate the presence of intergranular attack." (7)

7 **The Puget Sound Naval Shipyard, Quality Assurance Office, Laboratory Division; Report 90Ps00424, dated January 9, 1990.**

4.3.2.2 Carbon Steel

PHYSICAL TEST SUMMARY For
Carbon Steel Pipe

Sample Series 50	Tensile Load PSI	Elongation	Specification Requirements	
Base Metal 50-1	81,000	38%	60,000	22%
Low Temperature 50-2	81,000	32%	60,000	22%
High Temperature 50-3	79,500	37%	60,000	22%

The tensile value differences between the original carbons steel base metal and the heat affected carbon steel are less than 1%. These values are less than the calibration requirement for the Tensile Test Machine. (In other words the differences are insignificant)

The carbon steel base metal has slightly higher elongation with a uniform grain size. The heat affected tensile tests exhibit very small grain size at the surface.

The resultant is a fine grain annealed heat affected region. This region is characterized by lowering of hardness with the tensile strength maintained by the fine grain structure. This fine grain indicates higher impact properties or toughness.

These results are well within the acceptable requirements for Carbon Steel Pipe.

4.3.2.3 Copper Nickel (90 / 10)

PHYSICAL TEST SUMMARY For
90 / 10 Copper Nickel

Sample Series 76	Tensile Load PSI	Elongation.	Specificatic Requiremen	
Base Metal 76-1	40,500	60%	38,000	30%
Low Temperature 76-2	42,600	34%	38,000	30%
High Temperature 76-3	46,000	47%	38,000	30%

The tensile values of the low and high temperature heat affected 90/10 areas are 5% to 13% greater than the as received base metal. The elongation values on both heat affected specimens are substantially less than the base metal, but still meet the specification minimums.

The 90/10 copper nickel base metal shows a large number of close packed flow lines. The heat affected pipe shows significantly fewer flow lines indicating that the segregated constituents are going into solution as a result of multiple heats.

Lack of significant grain growth is an indication that the flame bending temperatures did not exceed that of the original pipe processing annealing temperature.

These results meet the minimum acceptable requirements for 90/10 Copper Nickel Pipe.

4.3.2.4 **Copper Nickel (70 / 30)**

PHYSICAL TEST SUMMARY For
70 / 30 Copper Nickel
NEW PIPE

Sample Series 121	Tensile Load PSI	Elongation	Specification Requirements	
Base Metal 121-l	57,000	31%	50,000	30%
Low Temperature 121-2	56,500	26%	50,000	30%
High Temperature 121-3	57,500	51%	50,000	30%

70/30 Copper Nickel
SUBMARINE MAIN SEAWATER PIPE
In Service for 20 Years

Sample Series 176	Tensile Load PSI	Elongation	Specification Requirements	
Base Metal 176-l	57,500	28% (note 8)	50,000	30%
Low Temperature 176-2	51,900	27%	50,000	30%
High Temperature 176-3	60,500	40%	50,000	30%

The two charts above are shown together for comparison purposes. Note that the all tensile values for both the NEW PIPE and the SEA WATER SERVICE PIPE are within 10%. The major change is on the NEW PIPE which shows an increased elongation in the high temperature zone.

Three (3) of the Five (5) elongation test values are below the specification minimum requirement. However these values were measured in a region of mixed heat treatment. Values taken in these regions can be in error by +/- 5%. The lowest elongation value was under the minimum by 4%.

8 Note: THE NEU MANUFACTURE BASE HATERIAL ELONGATION IS BELOW THE SPECIFICATION REWIREHENT AS RECEIVED FROM THE STOCK SYSTEM.

The microstructure of 70/30 Copper Nickel test samples 121 (NEW) and 176 (Seawater) were evaluated by Metallurgists Mike Allen Al Ruedebusch. Their report, Reference 8, states that "AS seen from enclosures 4 and 5, there appears to be no significant difference between the samples taken from the base metal or the HAZ. There also appears to be no difference between the NEW 70/30 and the **SEA WATER 70/30.** (See Appendix B)

The net result that flame bending has minimum negative metallurgical impact on the 70/30 COPPER NICKEL pipe microstructure.

4.3.3 Effect of Cooling Methods On Microstructure

The method of cooling on all 225 heats employed a circular water cooling sequence when the pipe was below 1000° F in the heated area.

Pipe alloys in this study are not sensitive to rapid cooling below 1600° F. Maximum measured top temperatures were 1500° F.

No adverse metallurgical conditions were identified as a direct result of the rapid water quench.

4.3.4 Material Thickness Changes

4.3.5 Surface Conditions after Flame Bending

The surface conditions of all 225 heats on 5 different material types shows no significant surface damage.

The microphotos support the visual examinations.

4.3.6 Internal Sea Water Contamination Metallurgical Results

Metallurgical examination was performed on both new 70/30 Conner-Nickel pipe and sea water service pipe. The internal surface con tions after multiple flame heats were compared. No significant differences were noted by the metallurgy department.

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8 METALLURGICAL EVALUATION OF MICROSTRUCTURE AFTER FLAME BENDING PROCEDURE, Puget Sound Naval Shipyard, Code 134.6; Report No. 89PS05135, Dated 19 May, 1989.

4.3.7 Hardness Surveys

Surface hardness measurements were taken from unaffected base metal and from the heat affected zone of the pipes. Table 4.3.7 details the results.

Hardness Survey Results
Readings are all Rockwell B scale

Pipe Material Tested	Stainless Steel (CRES) **Pipe No. 131**	Carbon Steel (CFe) **Pipe No. 50**	Copper Nickel 90/10 **Pipe No. 76**	Copper Nickel 70/30 **Pipe No. 121**	Copper Nickel (Submarine) **Pipe No. 176**
Base Metal	80 Rb	82 Rb	28 Rb	39 Rb	47 Rb
Heat Affected Zone	55 Rb to 71 Rb	52 Rb to 75 Rb	18 Rb to 22 Rb	17 Rb to 58 Rb	26 Rb to 50 Rb

5 Future Work

5.1 Write Shop Working Instruction

The shop working instruction should be a document which is no longer than about 25 pages.

5.2 Develop Operator Qualification Procedure

Operator qualification procedures can be written from the engineering report in cooperation with shop 56.

5.3 Cooling Methods

Only one method was used on the 225 tests of this study. The method that was used in this work closely matches the method used by Puget Sound Naval Shipyard.

5.4 Effects of External Restraint

The experimental work did not cover the effects of external restraint on pipe bending.

5.5 Low Temperature Flame Bending

Richard E. Holt determined that the ideal flame bending temperature for most structural alloys is in the range of 700 degrees F.

Work needs to be performed to verify that low temperatures will work for pipe materials.

5.6 Thickening in the Flame Bent Area

More accurate values of thickening should be made in the hot region.

5.7 Charpy Impact Values

Limitedwork has shown impacts are improved on some materials but ad tional work needs to be performed on a broad range of naval materia

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9 Holt, R. E., "PRIMARY CONCEPTS FOR FLAME BENDING", Welding Journal, June 1971.

6 CONCLUSIONS

6.1 Precise & Simple Torch Calibration

A method of oxyacetylene torch heat calibration has been developed using precision flow meters and test ring.

6.2 **Vee Heating Pattern VS Line Heating Patterns**

Vee heats are more predictable for smaller diameter pipe in the range of 2" diameter to 8" diameter. Vee heats should be used as a first choice by the shop.

The majority of-naval and commercial shipyard pipe flame bending can be performed using 3" VEE HEATS. This VEE size will produce significant deflection with minimum buckling.

6.3 Line Heats on Large and/or Thin Wall Pipe

Line heats were found to be more controllable on pipe diameters larger than 10 inches. Pipe with very thin wall in relation to its diameter should be flame bent using the line heat method.

Line heats with a given surface heated area produce greater deflection than the equivalent vee heat with the same heated surface area.

6.4 Dimensionless Ratio for Hinge / Vee Area

There is a relationship between the hinge length and total surface area of the vee heat. When the above two values yield a number from .005 to 03 then the mechanic can assume that each heat sequence will deflect the pipe the same amount on each heat.

$$R = \frac{\text{CHingeLength)}}{\text{CTotaLVeeArsa)}}$$

The mechanic can reheat pipe material in the same area repeatedly and obtain predictable movement.

6.5 Ideal Travel Speed

The ideal travel speed for most small diameter flame bending application is in the range from 1.5 to 3.5 ipm.

6.6 Maximum Number of Heats on the Same Area

It has been determined by experimentation that no more than three (3) heats should be applied to the same area. This maximum is not a metallurgical limit but is determined by the pipe materials tendency to buckle after the third heat.

6.7 Pipe Movement On Carbon Steel

Carbon steel moves approximately the same amount (with a given heated area) each time it is heated in the same location.

6.8 Stainless Steel

The physical tests show that CRES (Stainless Steel) can be heated in the range of 1000° to 1500° F with a small reduction in elongation and limited metallurgical damage. ASTM 262 intergranular corrosion tests were conducted with no sign of fissures or cracks.

6.9 Carbon Steel Metallurgical Property Improvement

Carbon steel showed generally improved overall physical properties.

6.10 Copper Nickel Metallurgical Properties after Flame Bending

Flame bending produces minimum metallurgical damage on the 70/30 COPPER NICKEL pipe microstructure.

6.11 Effect of Flame Bending on Sea Water Pipe

There is no measurable metallurgical or mechanical property difference between the NEW 70/30 and the SEA WATER CONTAMINATED 70/30 as a result of flame bending.

There is a slight reduction in Tensile, Yield strength and elongation on both new and sea water flame bent pipe: The reduction is less than 1%.

6.12 Dye Penetrant Testing

Each material type was PT tested after five heats and no evidence of cracking was found on any of the material tested.

6.13 Scaling and Flaking (internal)

90/10 copper nickel shows measurable internal scaling and flaking after flame bending. It is recommended that flame bending on 90/10 not be performed unless purged during bending or flushed after bending. This should apply to all FEMA and hydraulic piping.

All other materials tested showed discoloration but did not scale.

6.14 Flow Meter Calibration

A flow meter may be substituted as the primary calibration method once the initial ring/flame length calibration is performed. Individual flow meters will significantly reduce out of balance heat input.

6.15 Larger Hinge Lengths

Tests show that larger hinge lengths in the range of 4" to 5" on 5" to 8" pipe yield controllable deflections. Current methods use 2" hinge lengths which are too small for most applications.

6.16 Optimum Average Vee and Hinge Ratios

Most shop work can be accomplished with a 30° vee angle and hinge which is 1/4 or (25%) of the circumference:

6.17 When to Use Longer Hinges

Longer hinges should be used when pipe shortening must be held to a minimum.

6.18 Sea Water Pipe Bends

70/30 sea water pipe was tested using a standard AWS B4.O-77 guided bend test. There was no indication of cracking. Dye penetrant tests on this material before bending showed no indications.

6.19 Trained Mechanics

Do not use personnel who have no formal flame bending training. Operators should train on similar grades, diameters and wall thicknesses.

6.20 Flame Bending of Stainless Steel (CRES)

Based on the test work Stainless steel can be flame bent with no significant loss of mechanical or metallurgical properties.

APPENDIX A

CODAS CALIBRATION DATA GATHERING METHOD

ENTER SELECTION : (ie) 6 filename [with no extension]

SET COLOR MONITOR: <CTL> <ALT> <BACK ARROW> [monitor is now showing a display.

TO START DATA GATHERING TO HARD DISK

<F10> [monitor is now showing byte count in lower right hand corner]

TO STOP DATA GATHERING TO HARD DISK

<F9> [monitor is now showing final byte count in lower right corner]

<Q> TO RETURN TO DOS [monitor shows prompt]

TO DISPLAY DATA GATHERED DURING FLAME BENDING TEST

TYPE IN: POSTACQ filename.ext [postacq is the name of the data display and manipulation program. The file name is the name given to the initial flame bend test.]

TO DISPLAY TEE 8 DATA SCREENS

<SHIFT O>

<F1> [enable the data cursor]

< <---------> > [position the cursor to the desired position]

<F4> [enable the final data gathering point]

<F6> [enables end of data gathering sequence]

SCREEN SHOWS: ENTER THE NAME OF DATA FILE:

Enter any name that you want to use to identify this particular data record. This file may be the whole test or part of the test sequence.

Note: If the data is going to be used in LOTUS then an extension of .WK1 should be used.

If the data is going to be printed directly, then use an extension of .HCU.

ENTER FILE NAME: <heat_X.wk1>

MENU APPEARS: [select #5 or #6]

INPUT TEXT: [two lines of text can be input at this point]

HIT <RETURN>

WINDOW DISPLAY RETURNS: [hit <Q> to quit.

CALIBRATION CONSTANTS: [y/n]

BACK TO DOS:

APPENDIX "B"

PUGET SOUND NAVAL SHIPYARD
QUALITY ASSURANCE OFFICE
Laboratory Division
19 May 1989

Code 134.6 MFA:lms

Metallurgy Branch Report No. 89PS05135

Subj: METALLURGICAL EVALUATION OF MICROSTRUCTURE AFTER FLAME BENDING PROCEDURE

Ref: (a) American Society for Testing and Materials, Annual Book of ASTM Standards, Volume 1.05, Designation A 262-86, 1987

Encl: (1) Photomicrographs of Pipe 131
(2) Photomicrographs of Pipe 50
(3) Photomicrographs of Pipe 76
(4) Photomicrographs of Pipe 121
(5) Photomicrographs of Pipe 176

1. Five samples were provided by Code 138 for hardness testing and evaluation of the microstructure. The samples were taken from sections of pipe that had been cycled through a flame bending procedure. The cycle consisted of heating from room temperature to approximately 1500°F and then water quenching. There were a total of five cycles.

2. Hardness. Surface hardness measurements were taken from the unaffected base metal and from the heat affected zone of the pipes, see table below.

Results of the Hardness Transverse					
Area Tested	131 Cres New	50 CFe New	76 90/10 New	121 70/30 New	176 70/30 *
Base Metal (Ave)	80 HRB	82 HRB	28 HRB	39 HRB	47 HRB
HAZ (Range)	71 to 55	75 to 52	22 to 18	58 to 17	50 to 26

*Pipe sample was obtained from an inactive boat and had been exposed to sea water.

3. Microstructure. Two samples were sectioned from each pipe to determine what effects the flame bending procedure had on the microstructure, if any. One sample was taken from the base metal and one from the heat affected zone.

Pipe 131:

Due to stainless steel’s susceptibility to sensitization, an oxalic acid etch test was performed on this sample. ASTM Standard A 262, Practice A, was used to determine what degree of sensitization the flame bending procedure produced in the steel. As seen in enclosure (l), there is a difference between the sample from the HAZ and the base metal. The base metals figure 1, shows a step structure while the sample from the HAZ, figure 2, has a dual structure with some ditching. This indicates that there is some sensitization which increases its susceptibility to intergranular attack. While Practice A cannot be used to reject the material, it does show that more testing is required.

Pipe 50:

Enclosure **2, figures 1 and 29 shows that the** flame bending Procedure has a recrystallization effect on the carbon steel. The sample from the HAZ has smaller grains near the surface, whereas the sample from the base metal has uniform grain size throughout.

Pipe 76:

The flame bending cycle, for the 90/10, appears to alter the flow pattern of the material. As seen in enclosure (3), figure 1, there are a large number of flow lines present in the base metal sample. Figure 2 is from the HAZ and the number of flow lines have been significantly reduced. There is no indication of recrystal-lization-or grain growth.

Pipes 176 and 121:

As seen from enclosures 4 and 53 there appears to be no significant difference between the samples taken from the base metal or the HAZ. There also appears to be no difference between the new 70/30 and the sea water 70/30.

Code 134.6

Report No. 89PS05135

4. Tensile Tests.

TENSILE TEST RESULTS						
SAMPLE	UTE KSI	% ELONG.	FAILED INSIDE GAUGE MARKS		REQ'D KSI	REQ'D ELONG.
			Y	N		
131-1	86.5	64	X		75.0	35%
131-2	86.5	53	X			
131-3	87.0	58	X			
50-1	81.0	38	X		60.0	22%
50-2	81.0	32	X			
50-3	79.5	37	X			
76-1	40.5	60	X		38.0	30%
76-2	42.6	34	X			
76-3	46.0	47	X			
121-1	57.0	31		X	50.0	30%
121-2	56.5	26*		X		
121-3	57.5	51	X			
176-1	57.5	28*		X	50.0	30%
176-2	51.9	27*		X		

*These values are below the accepted minimum.

Michael J Allen
Metallurgist

G Ruedebusch
Head, Metallurgy Branch

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Code 138(2 copies)

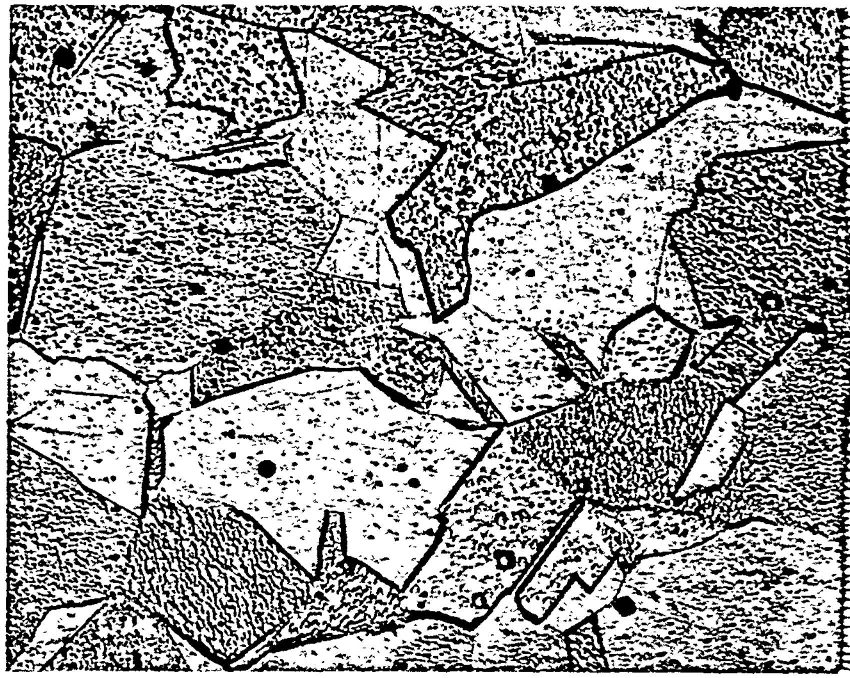


Figure 1, Base Metal
Etch: Oxalic 6A/cm² 500x

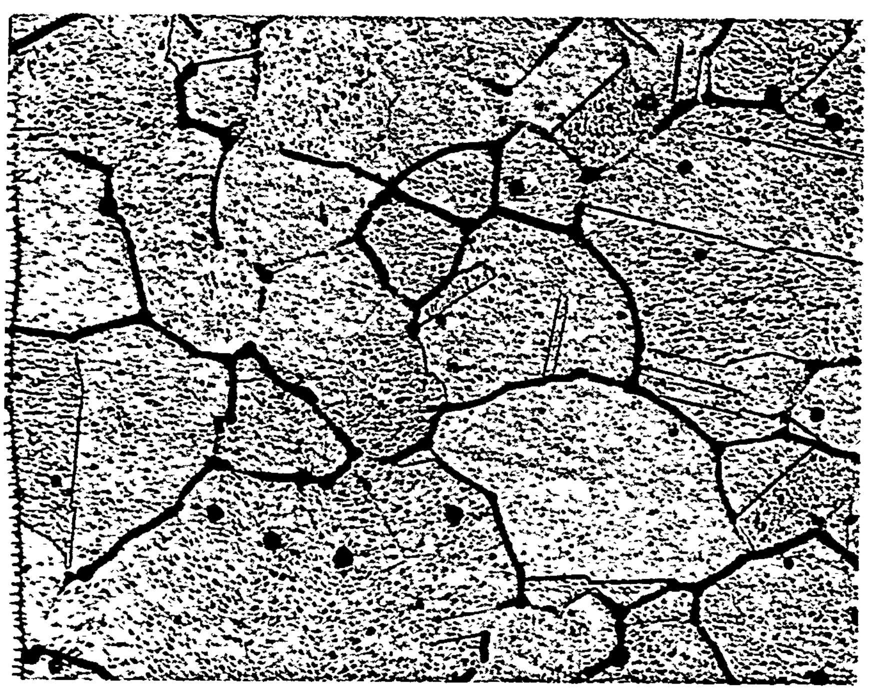


Figure 2, HAZ
Etch: Oxalic 6A/cm² 500x

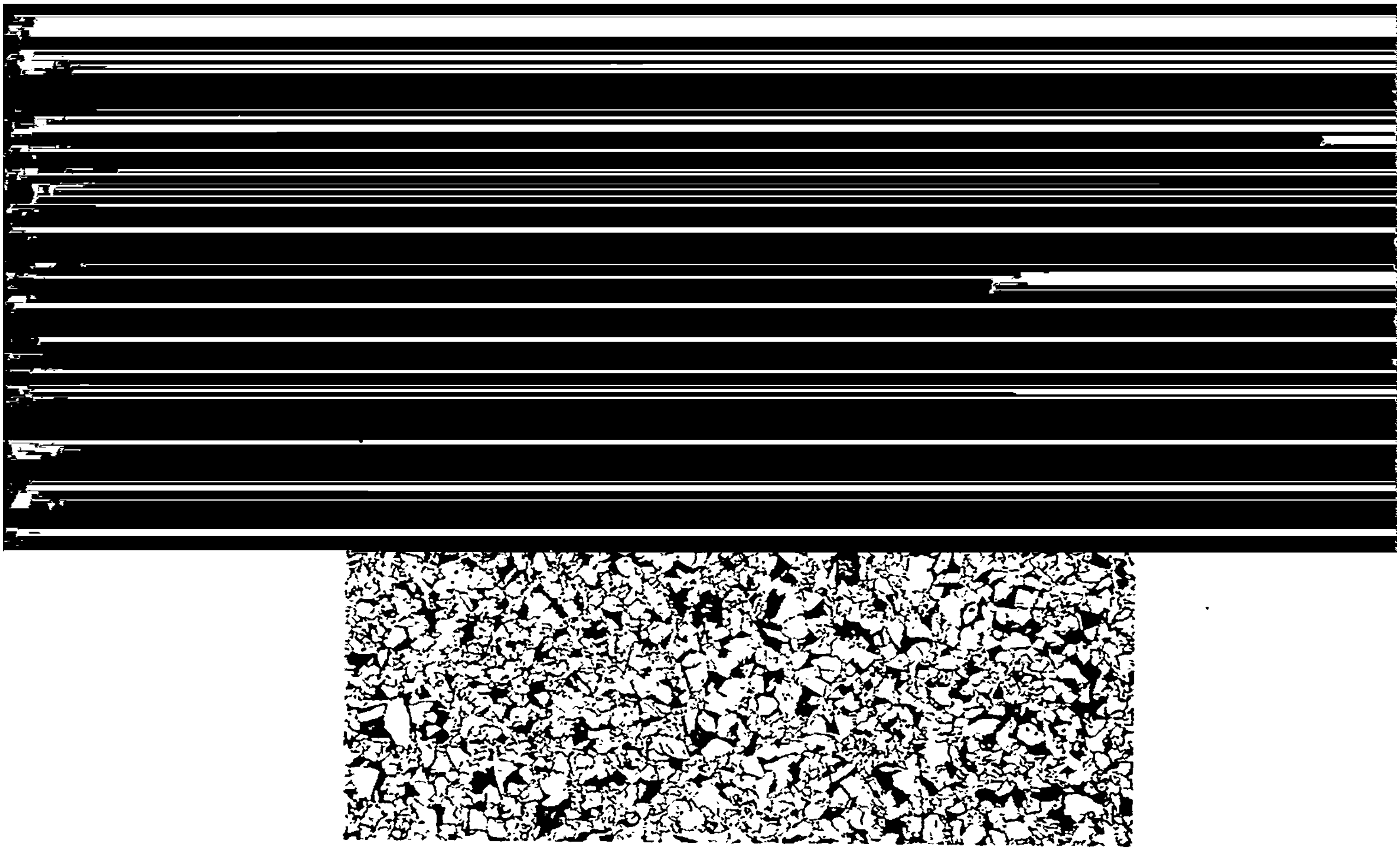


Figure 1, Base Metal
Etch: 2% Nital 100x

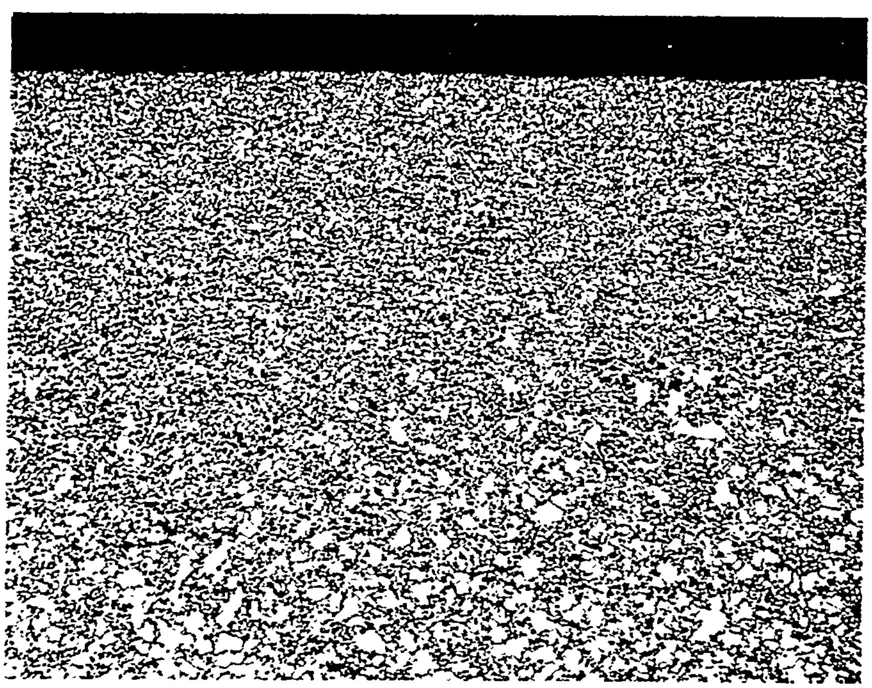


Figure 2, HAZ
Etch: 2% Nital 100x

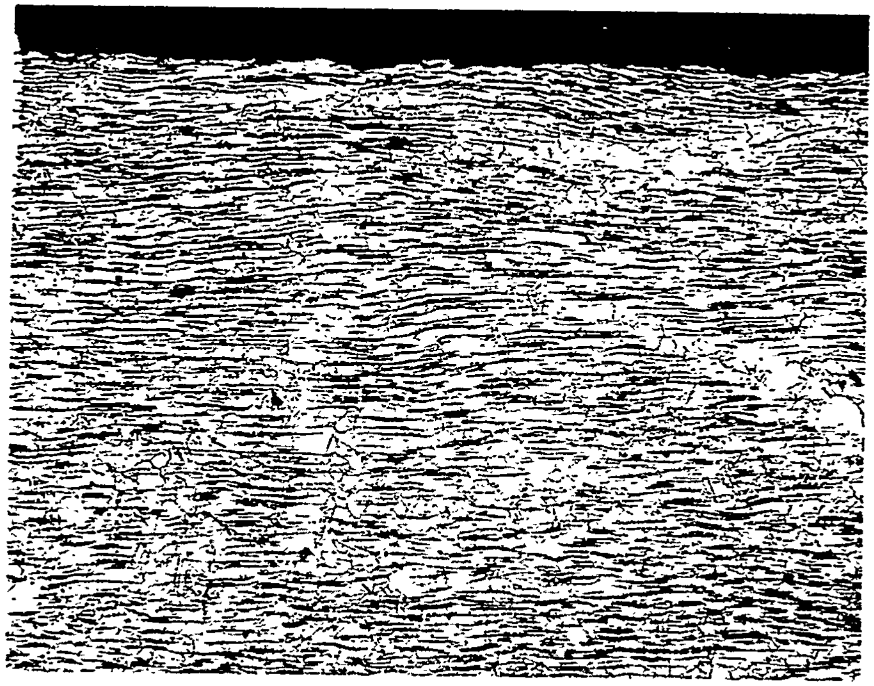


Figure 1, Base Metal
Etch: 10% NaCN, HOCOCOOH 100x

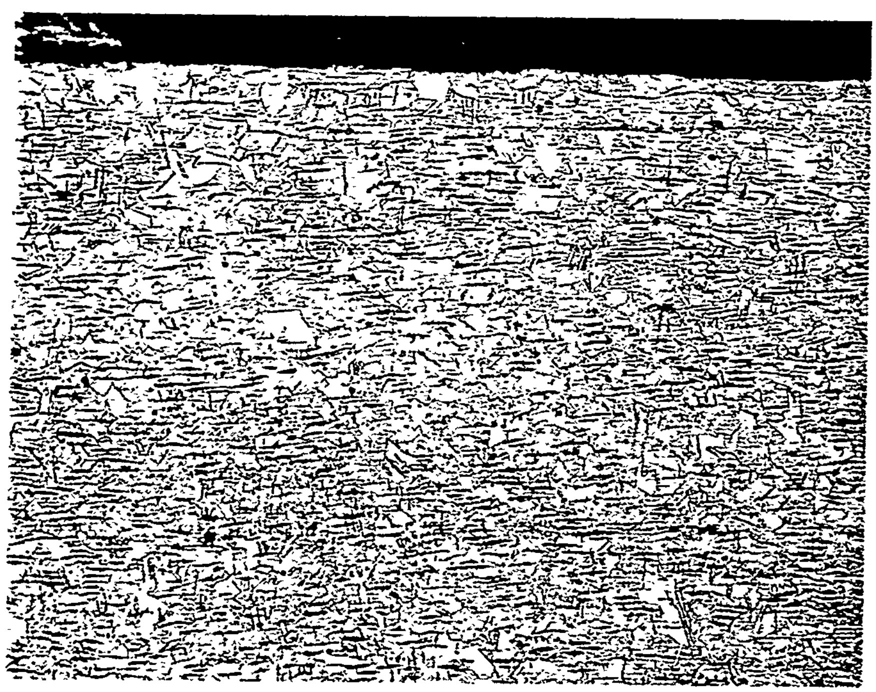


Figure 2, HAZ
Etch: 10% NaCN, HOCOCOOH 100x

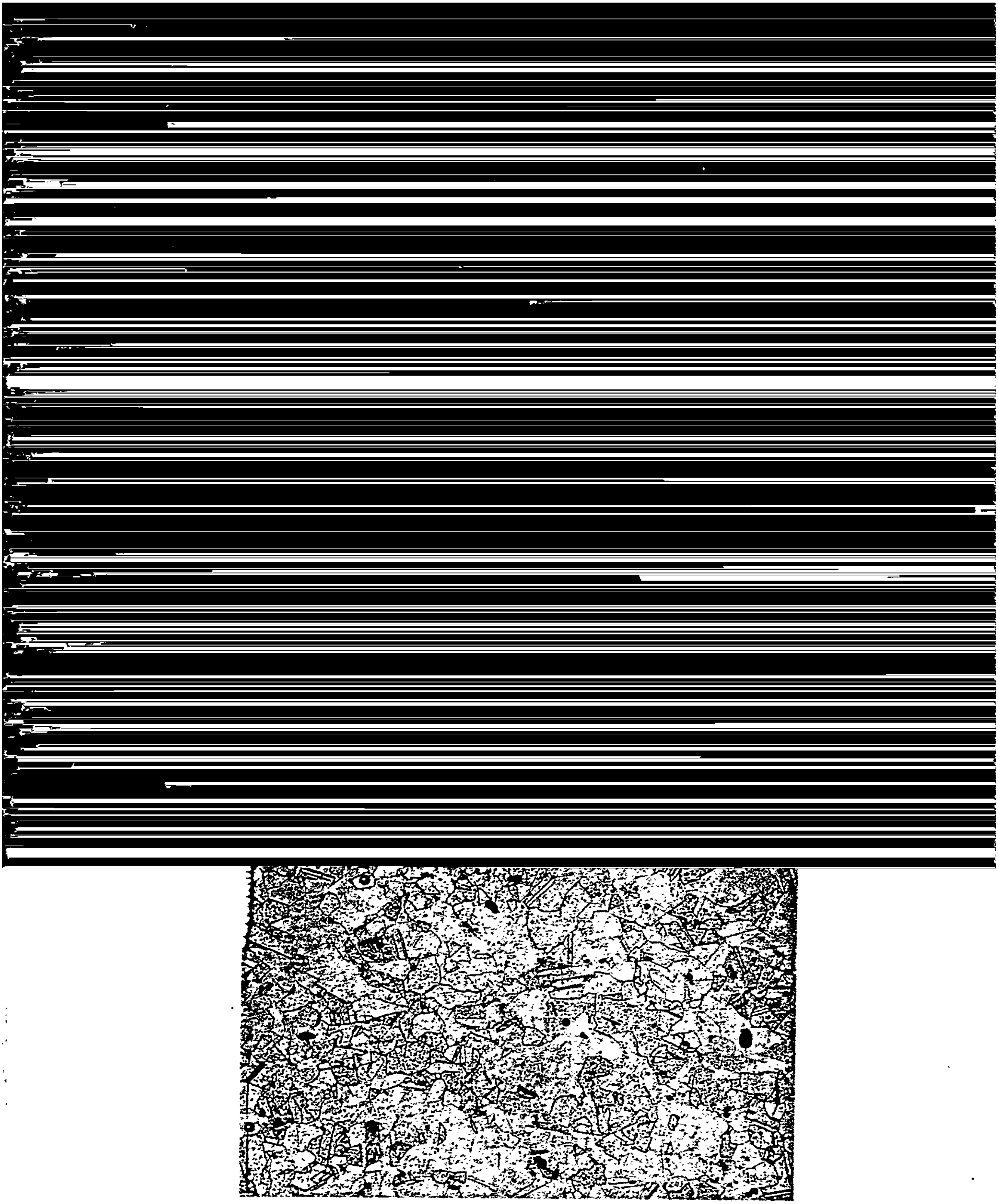


Figure 2, 121 HAZ

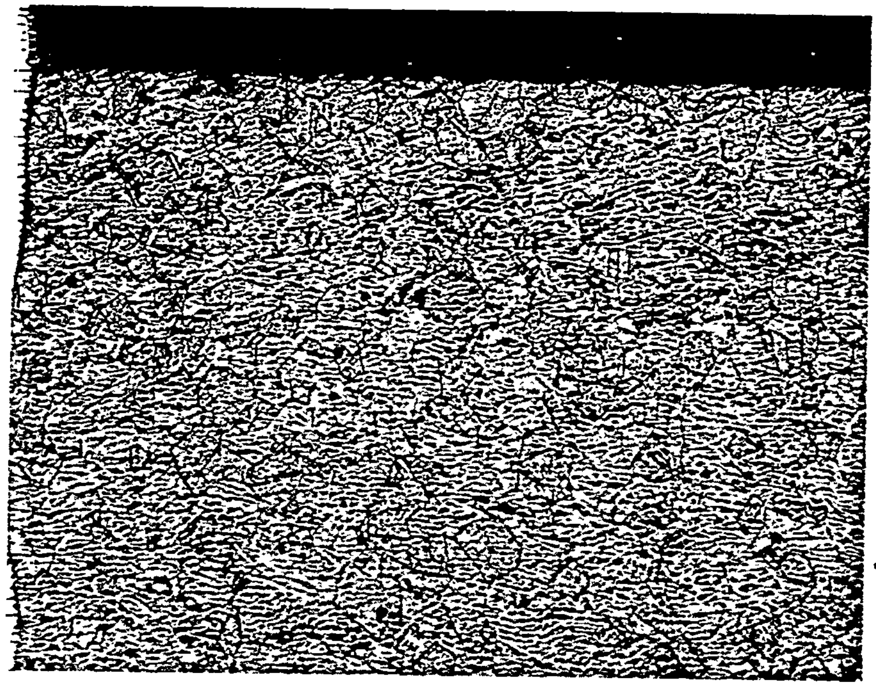


Figure 1, Base Metal
Etch: 10% NaCN, HOCOCOOH 100x

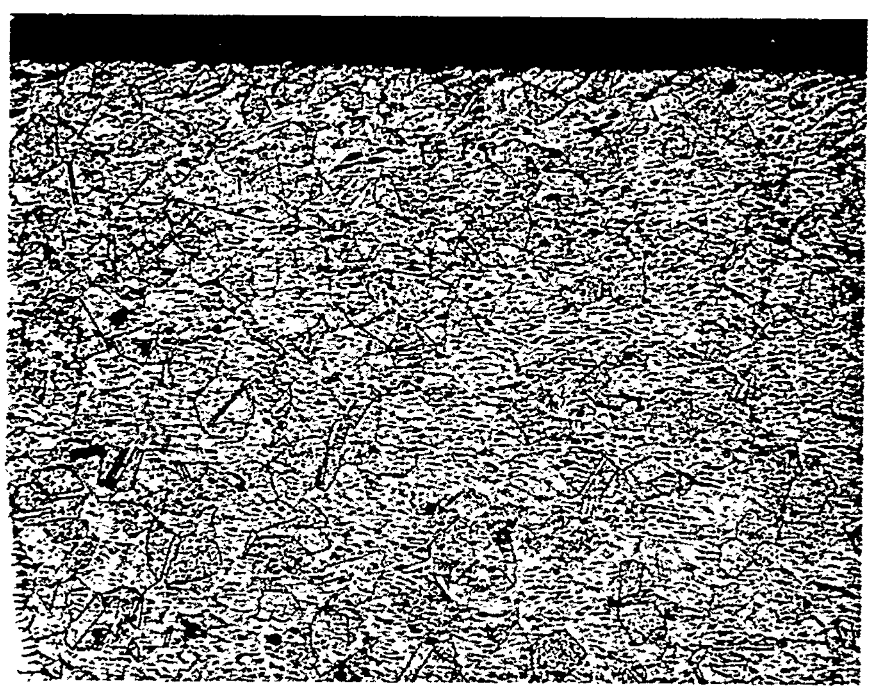


Figure 2, HAZ

TIME* vs PIPE DEFLECTION CHARTS

*NOTE: On Time Scale 20 minor divisions equals 1 minute
i.e. 0 - 280 = 14 minutes

Cu-Ni 90:10, 8" PIPE, 5/16" WALL

CHART #	HEAT #	TECHNIQUE		PAGE
16	1st	4" Vee	6" Hinge	1
17	2d			1
18	3d			2
19	4th			2
20	5th			3
20	1st	2" Vee	3" Hinge	3
22	2nd			4
23	3rd			4
25	5th			5
26	1st	6" Vee	1" Hinge	6
27	2nd			6
28	3rd			7
29	4th			7
30	5th			8
31	1st	4" Vee	1" Hinge	8
32	2nd			9
33	3rd			9
34	4th			10
36	1st	2" Vee	1" Hinge	10
37	2nd			11
39	4th			12
40	5th			12
41	1st	4" Vee	3" Hinge	13
43	3rd			13
44	4th			14
46	1st	6" Vee	3" Hinge	14
47	2nd			15
48	3rd			15
49	4th			16
50	5th			16

Continuation 1 APPENDIX C

CHART #	HEAT #	TECHNIQUE		PAGE
51	1st	2" Vee	6" Hinge	17
52	2nd			17
53	3rd			18
54	4th			18
55	5th			19
56	1st	4" Vee	6" Hinge	19
57	2nd			20
58	3rd			20
59	4th			21
60	5th			21 & 2

Cu Ni 90:10, 8" PIPE, 3/16" WALL

CHART #	HEAT #	TECHNIQUE		PAGE
66	1st	4" Vee	6" Hinge	22
67	2nd			23
68	3rd			23
69	4th			24
70	5th			24
71	1st	4" Vee	6" Hinge	25
72	2nd			25
73	3rd			26
74	4th			26
75	5th			27
76	1st	2" Vee	6" Hinge	27
77	2nd			28
78	3rd			28
79	4th			29
80	5th			29
81	4th	Line heat,	6" Hinge	30
82	4th			30
83	4th			31
84	4th			31

CHART #	HEAT #	TECHNIQUE	PAGE
811	1st	Line --- Heat Uphill, 6" Hinge	32
812	2nd		32
813	3rd		33
814	4th		33
821	1st	Line --- Heat Uphill, 6, Hinge	34
822	2nd		34
823	3rd		35
824	4th		35

CHART #	HEAT #	TECHNIQUE	PAGE
831	1st	Line --- Heat Uphill, 6" Hinge	36
832	2nd		36
833	3rd		37
834	4th		37
841	1st	Line --- Heat Uphill, 6" Hinge	38
842	2nd		38
843	3rd		39
844	4th		39
851	1st	--- Line Heat Uphill, 6" Hinge	40
852	2nd		40
853	3rd		41
854	4th		41
861	1st	Line --- Heat, Downhill, 6" Hinge	42
862	2nd		42
863	3rd		43
864	4th		43
871	1st	--- Line Heat, Downhill, 6" Hinge	44
872	2nd		44
873	3rd		45
874	4th		45
881	1st	--- Line Heat, Downhill, 6" Hinge	46
882	2nd		46
883	3rd		47
884	4th		47
891	1st	--- Line Heat, Downhill, 6" Hinge	48
892	2nd		48
893	3rd		49
894	4th		49
Ht 91	1st	4" Vee, 6" Hinge, Downhill	50
Ht 92	2nd		50
Ht 93	3rd		51
Ht 94	4th		51
Ht 95	5th		52
901	1st	--- Line Heat, Downhill, 6" Hinge	52
902	2nd		53
903	3rd		53
904	4th		54
962	2nd	--- Line Heat, Uphill, 12" Hinge	54
963	3rd		55
972	2nd	--- Line Heat, Uphill, 12" Hinge	55
973	3rd		56

CHART #	HEAT #	TECHNIQUE	PAGE
982	2nd	--- Line Heat, Uphill, 12" Hinge	56
983	3rd		57
992	2nd	--- Line Heat, Uphill, 12" Hinge	57
993	3rd		58
1002	2nd	--- Line Heat, Uphill, 12" Hinge	58
1003	3rd		59

70:30 Cu-Ni, 8" PIPE, 3/16" Wall

CHART #	HEAT #	TECHNIQUE	PAGE
101	1st	4" Vee, Uphill, 6" Hinge	59
102	2nd		60
103	3rd		60
104	4th		61
105	5th		61
1061	1st	Line Heat, Uphill, 6" Hinge	62
1062	2nd		62
1063	3rd		63
1064	4th		63
1071	1st	Line Heat, Uphill, 6" Hinge	64
1072	2nd		64
1073	3rd		65
1074	4th		65
1081	1st	Line Heat, Uphill, 6" Hinge	66
1082	2nd		66
1083	3rd		67
1084	4th		67
1091	1st	Line Heat, Uphill, 6" Hinge	68
1092	2nd		68
1093	3rd		69
1094	4th		69
1101	1st	Line Heat, Uphill, 6" Hinge	70
1103	3rd		70

CARBON STEEL PIPE, 8" NPS, 5/16" Wall

CHART #	HEAT #	TECHNIQUE	PAGE
1111	1st	Line Heat, Uphill, 6" Hinge	71
1112	2nd		71
1113	3rd		72
1114	4th		72

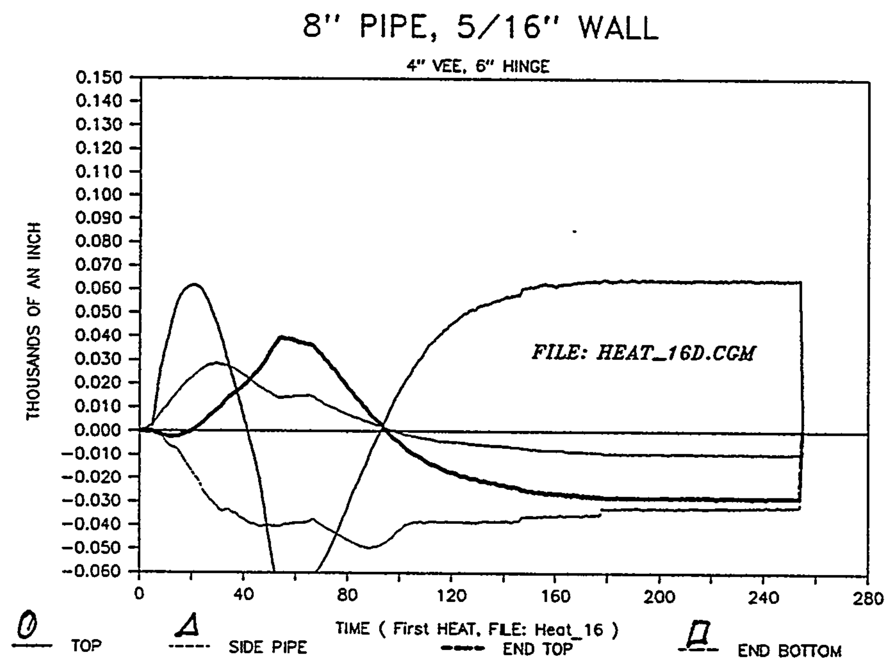
Continuation 4 APPENDIX C

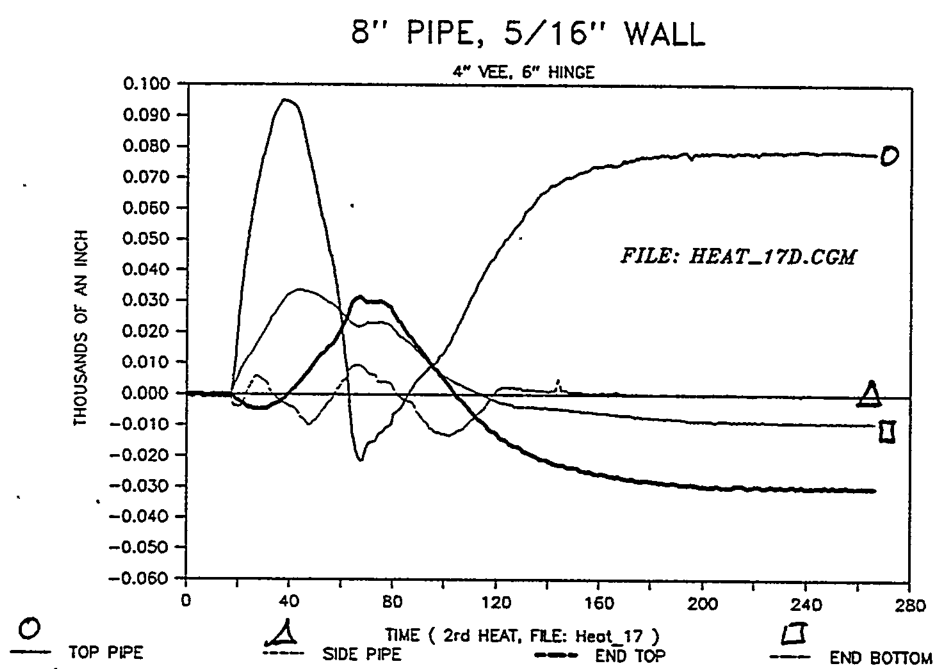
70:30 Cu Ni, 5" NPS PIPE, 1/4" WALL

STAINLESS STEEL PIPE, 5" NPS, 1/4" WALL

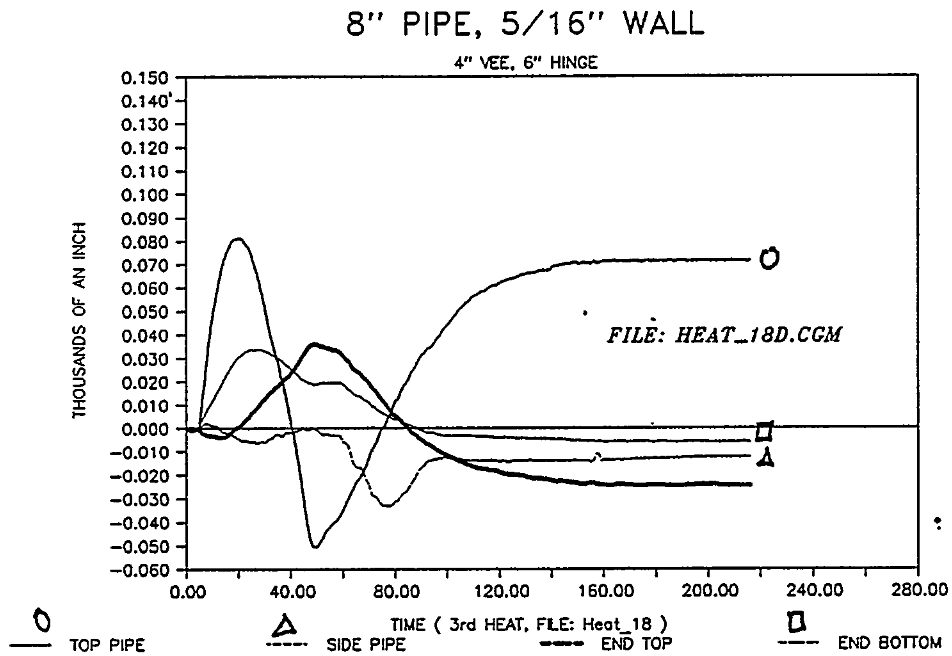
Continuation 5 APPENDIX C

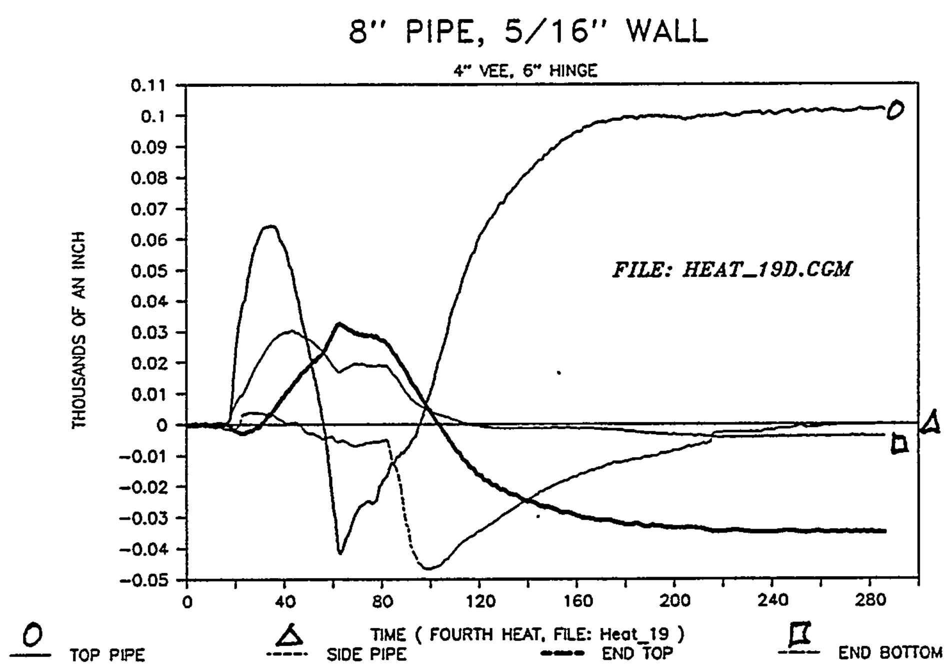
CHART #	HEAT #	TECHNIQUE	PAGE
151	1st	2" Vee, 1.75" Hinge	89
152	2nd		89
153	3rd		90
154	4th		90
155	5th		91

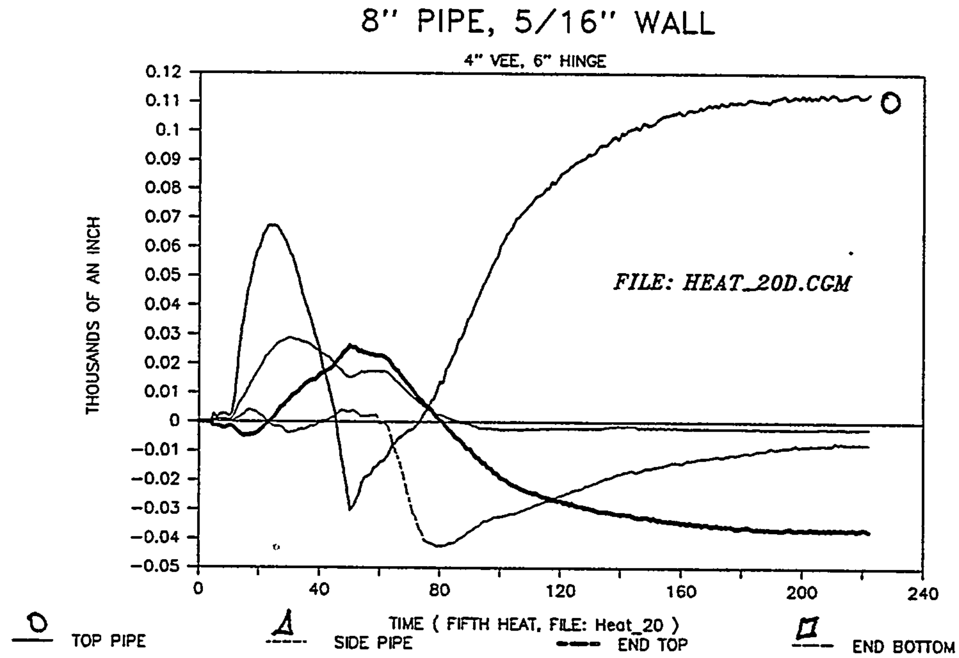

8" PIPE, 5/16" WALL
4" VEE, 6" HINGE
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
FILE: HEAT_16D.CGM
TIME (First HEAT, FILE: Heat_16)
TOP
SIDE PIPE
END TOP
END BOTTOM

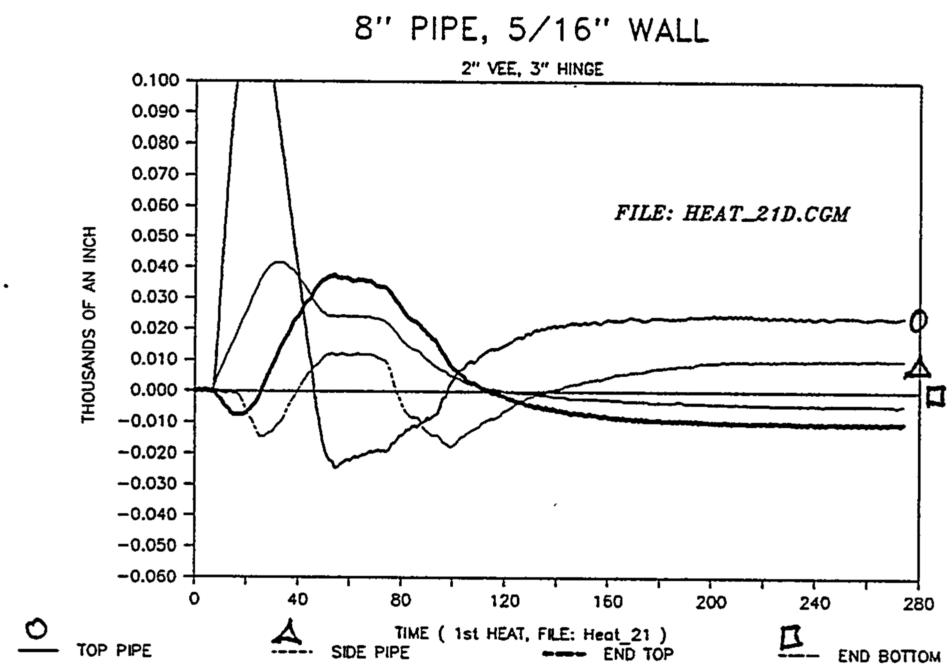

8" PIPE, 5/16" WALL
4" VEE, 6" HINGE
THOUSANDS OF AN INCH
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
FILE: HEAT_17D.CGM
TIME (2rd HEAT, FILE: Heat_17)
TOP PIPE
SIDE PIPE
END TOP
END BOTTOM

APPENDIX C
FLAME BENDING GRAPHS



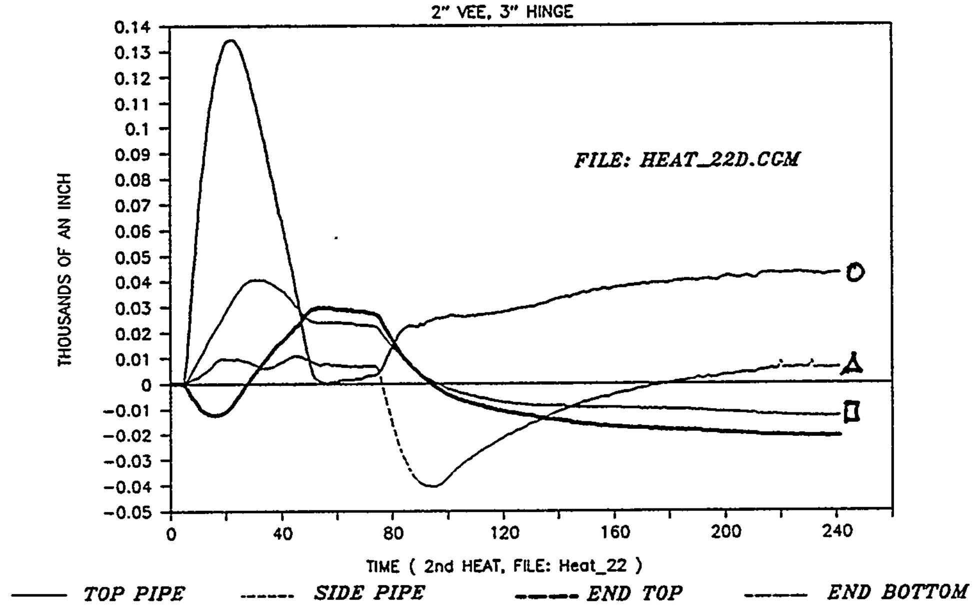



8" PIPE, 5/16" WALL
4" VEE, 6" HINGE
THOUSANDS OF AN INCH
FILE: HEAT_20D.CGM
TIME (FIFTH HEAT, FILE: Heat_20)
TOP PIPE
SIDE PIPE
END TOP
END BOTTOM


8" PIPE, 5/16" WALL
2" VEE, 3" HINGE
THOUSANDS OF AN INCH
FILE: HEAT_21D.CGM
TIME (1st HEAT, FILE: Heat_21)
TOP PIPE
SIDE PIPE
END TOP
END BOTTOM

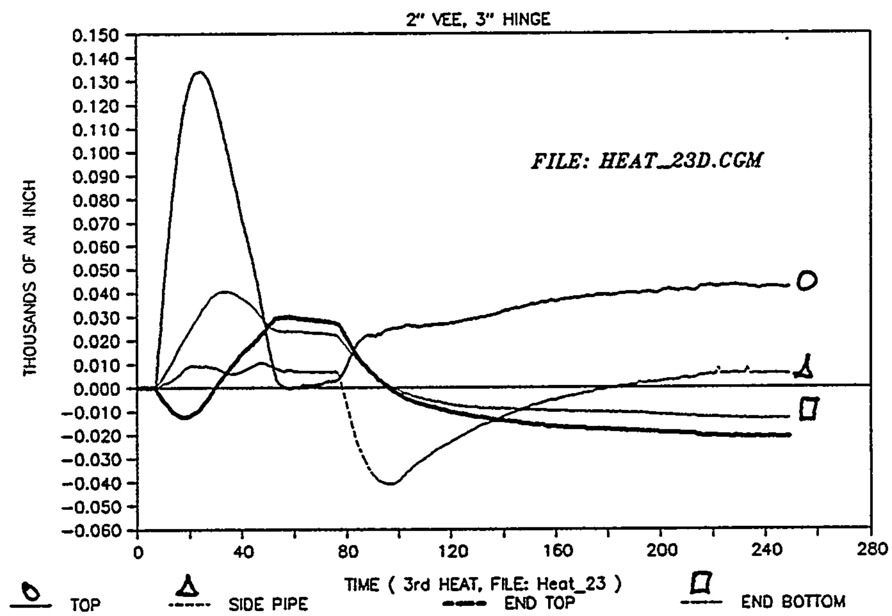
8" PIPE, 5/16" WALL

2" VEE, 3" HINGE

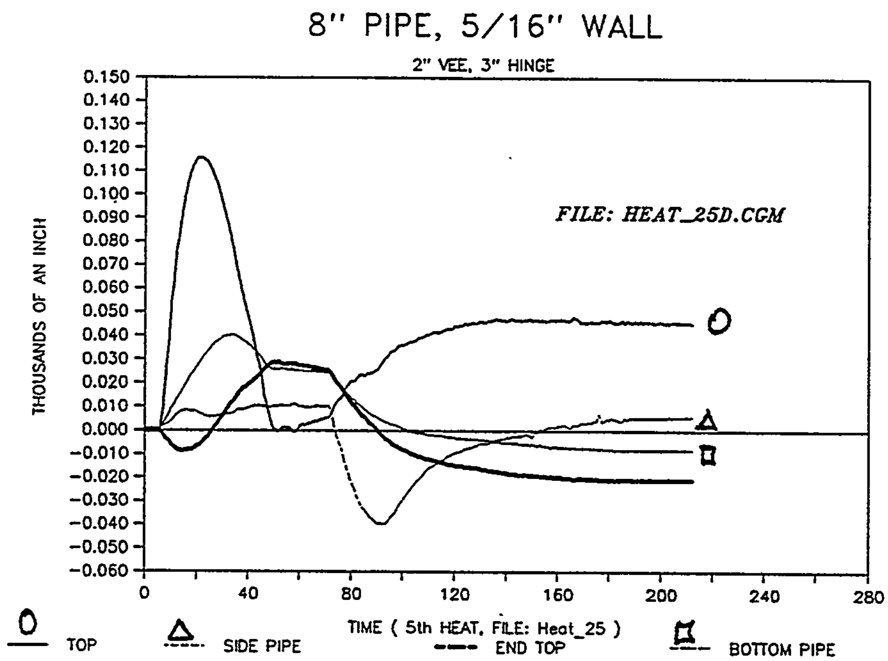


8" PIPE, 5/16" WALL

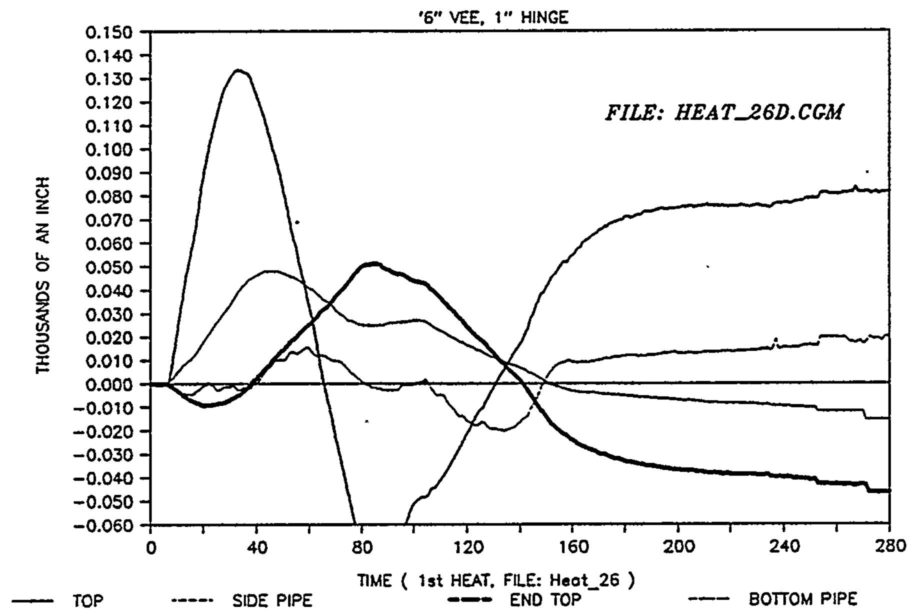
2" VEE, 3" HINGE



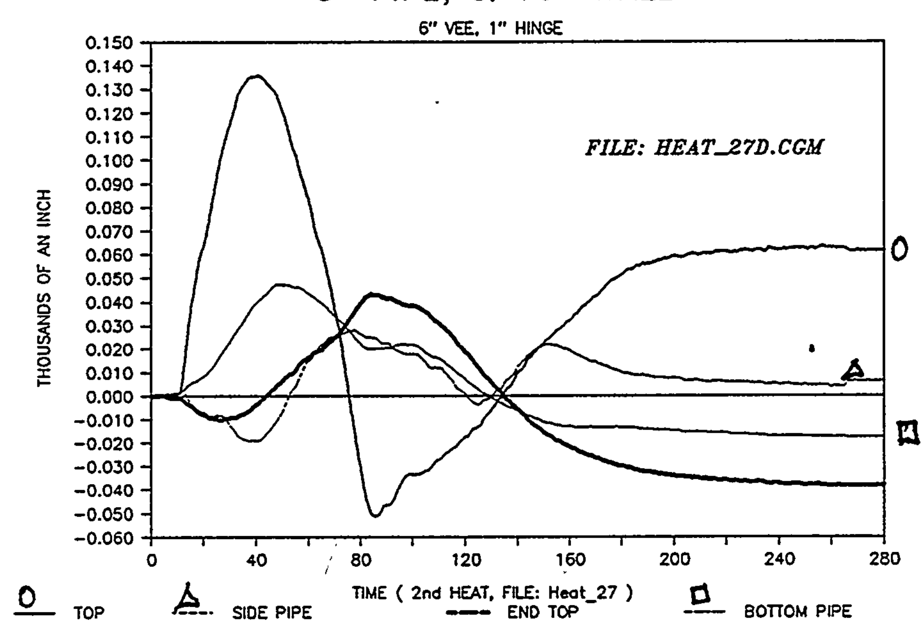
[PICTURE]

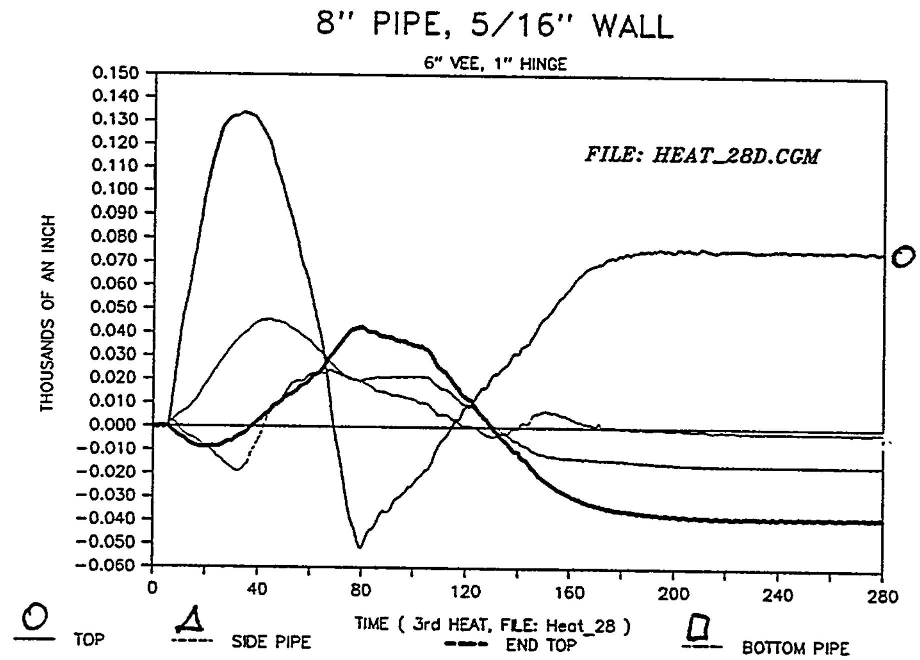

8" PIPE, 5/16" WALL
2" VEE, 3" HINGE
FILE: HEAT_25D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (5th HEAT, FILE: Heat_25)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

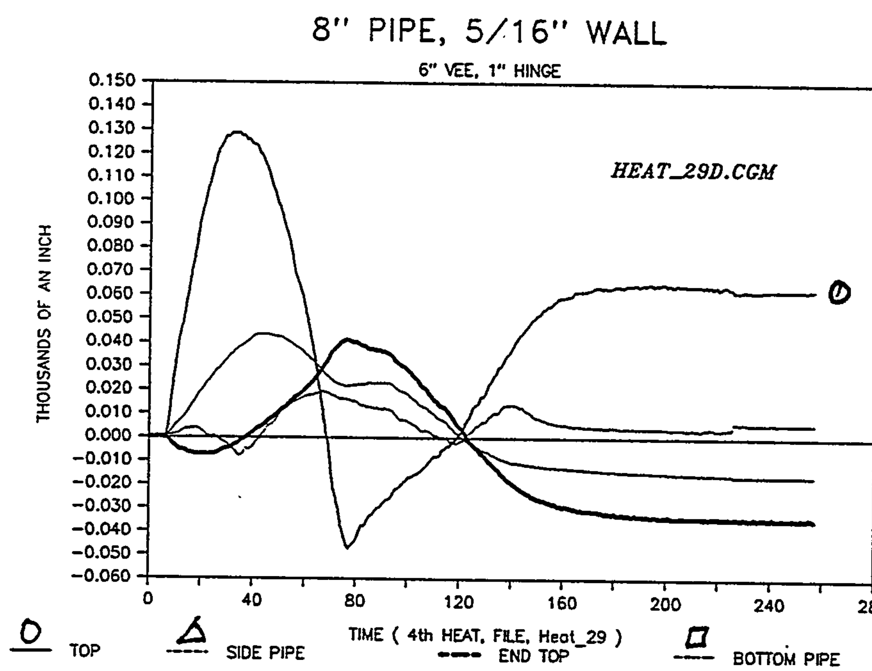
8" PIPE, 5/16" WALL

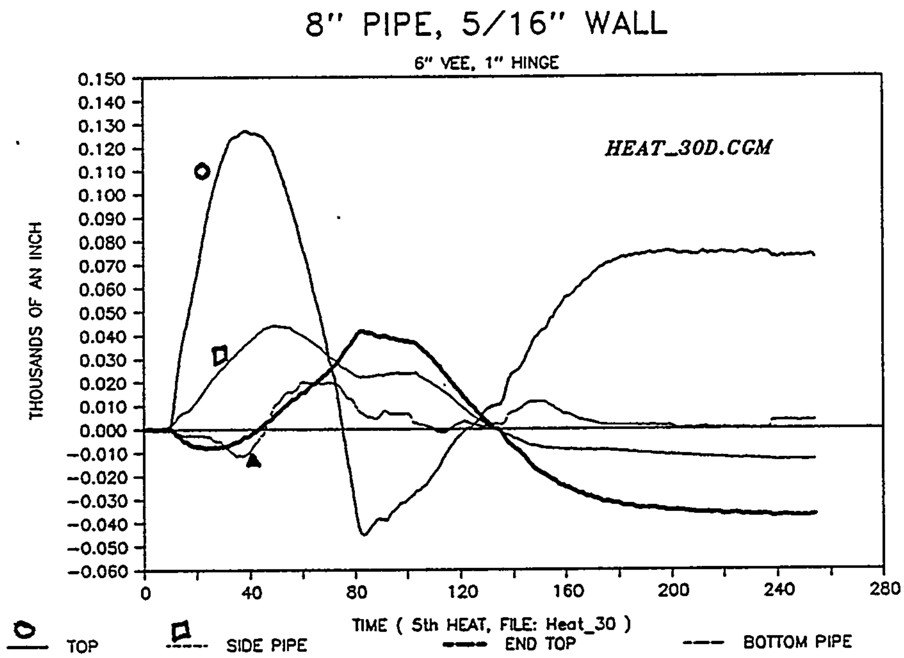


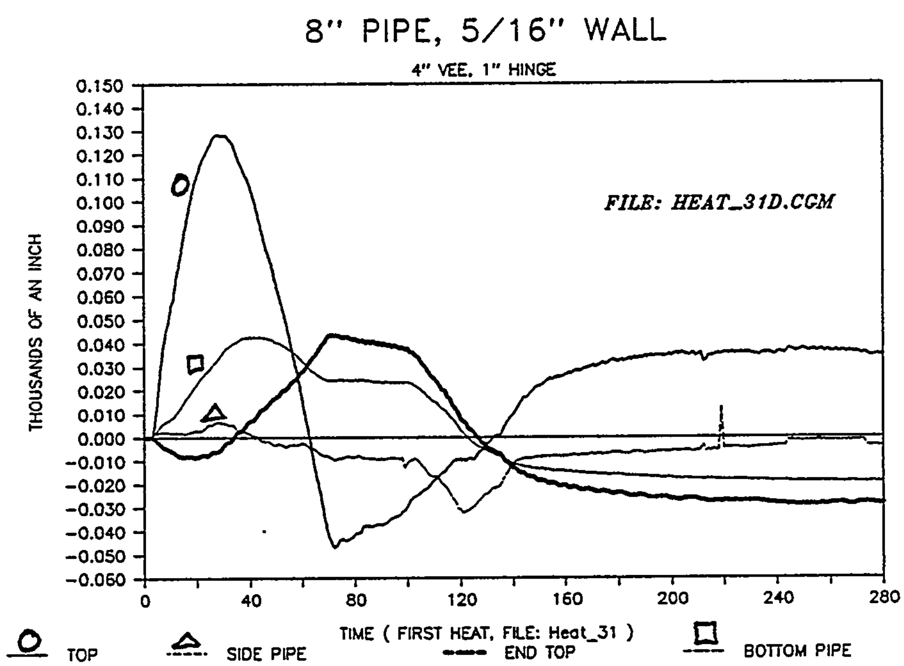
8" PIPE, 5/16" WALL

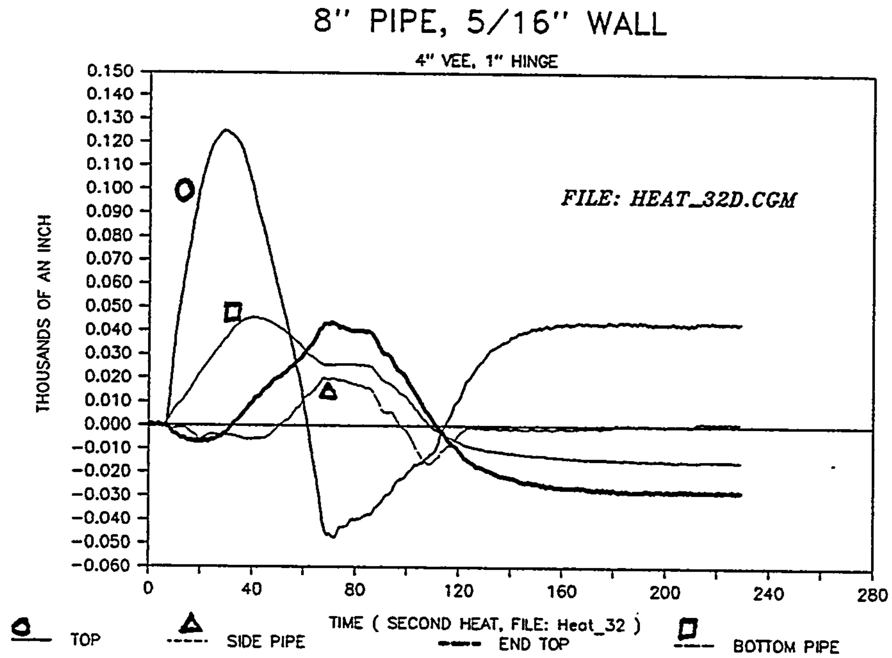


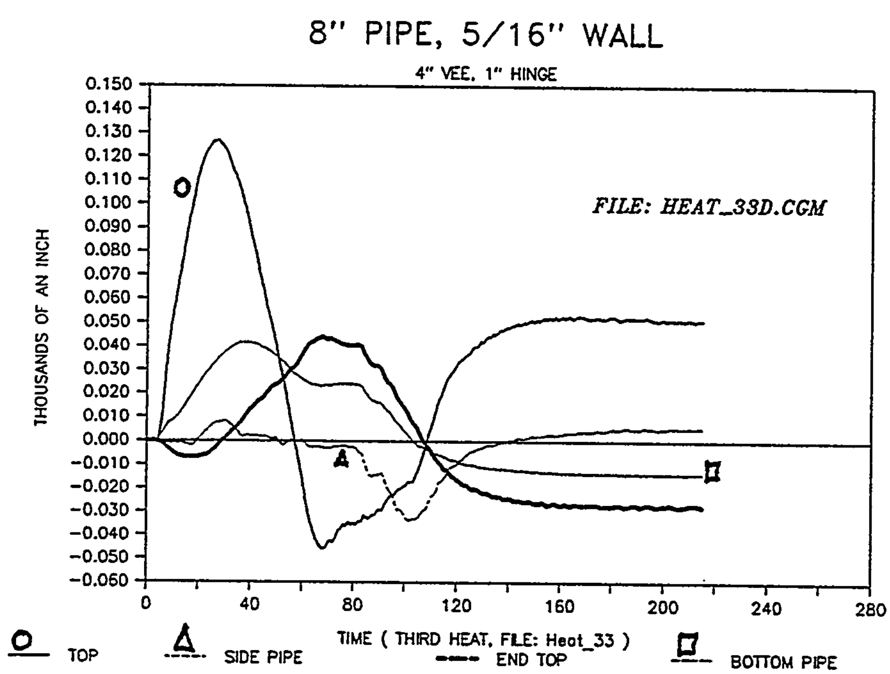

8" PIPE, 5/16" WALL
6" VEE, 1" HINGE
FILE: HEAT_28D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_28)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

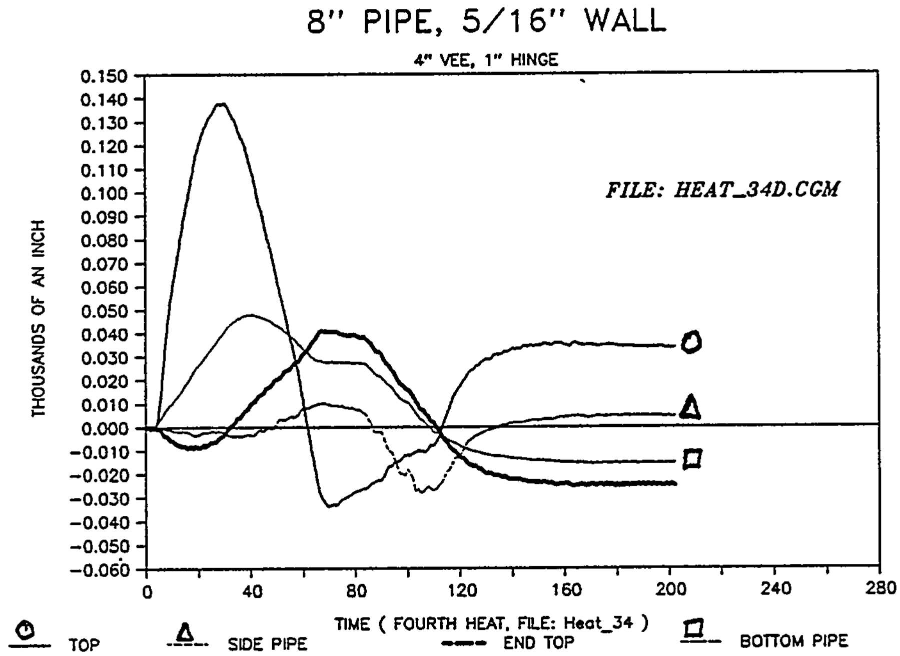

8" PIPE, 5/16" WALL
6" VEE, 1" HINGE
HEAT_29D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE, Heat_29)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

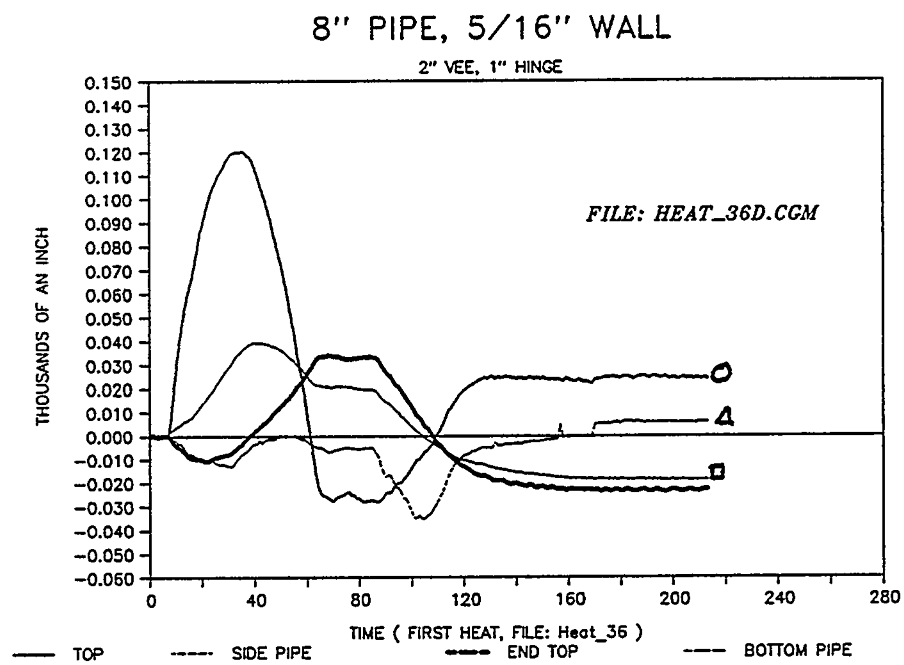

8" PIPE, 5/16" WALL
6" VEE, 1" HINGE
HEAT_30D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (5th HEAT, FILE: Heat_30)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

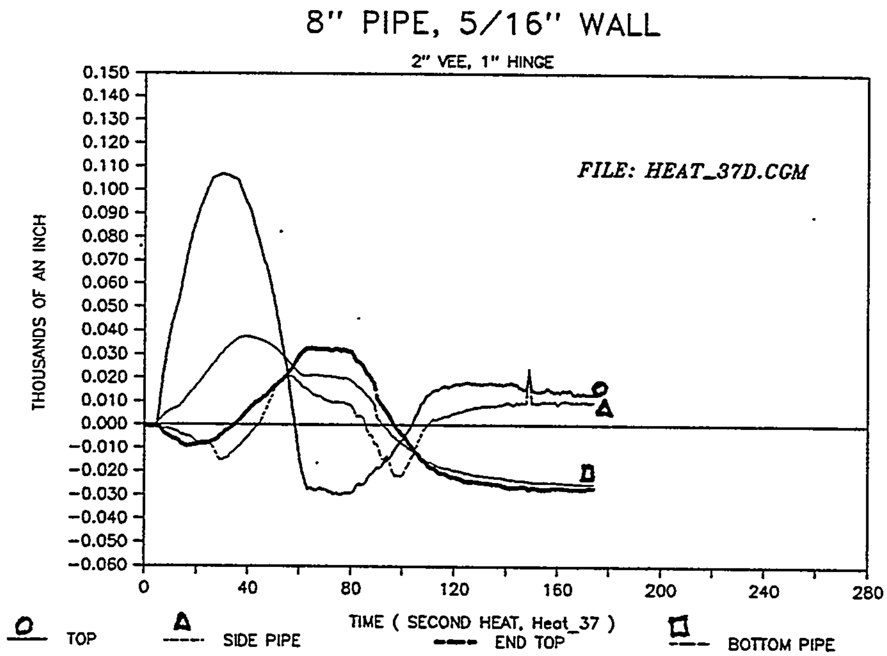

8" PIPE, 5/16" WALL
4" VEE, 1" HINGE
FILE: HEAT_31D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (FIRST HEAT, FILE: Heat_31)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 5/16" WALL
4" VEE, 1" HINGE
FILE: HEAT_32D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (SECOND HEAT, FILE: Heat_32)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

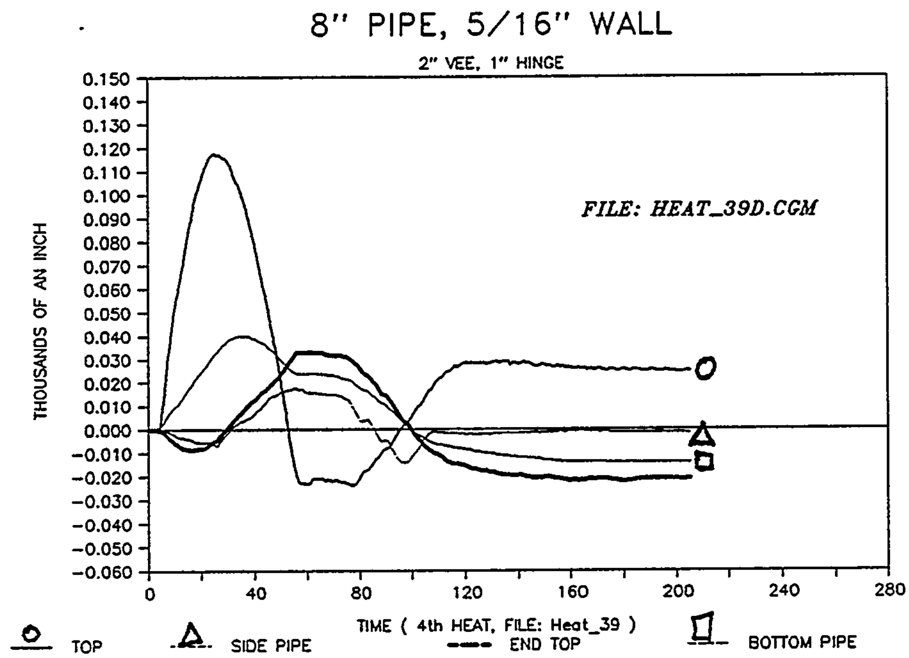

8" PIPE, 5/16" WALL
4" VEE, 1" HINGE
FILE: HEAT_33D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (THIRD HEAT, FILE: Heat_33)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

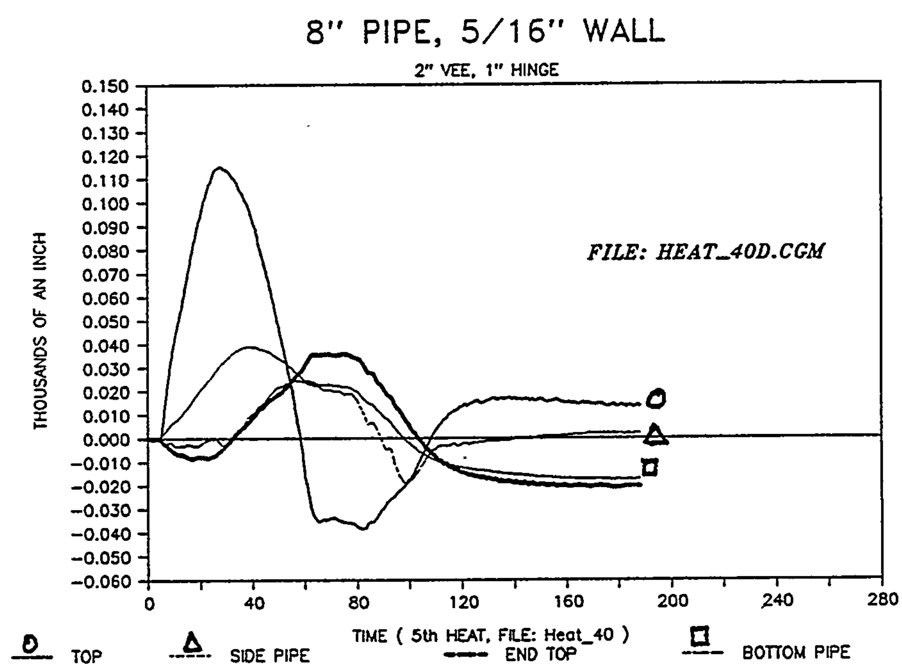

8" PIPE, 5/16" WALL
4" VEE, 1" HINGE
FILE: HEAT_34D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (FOURTH HEAT, FILE: Heat_34)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

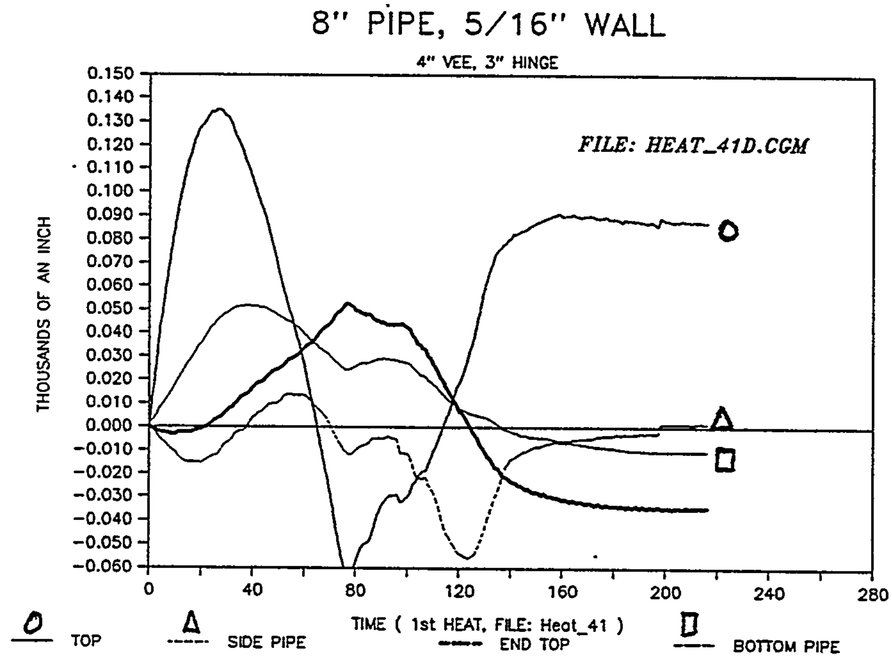

8" PIPE, 5/16" WALL
2" VEE, 1" HINGE
FILE: HEAT_36D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (FIRST HEAT, FILE: Heat_36)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

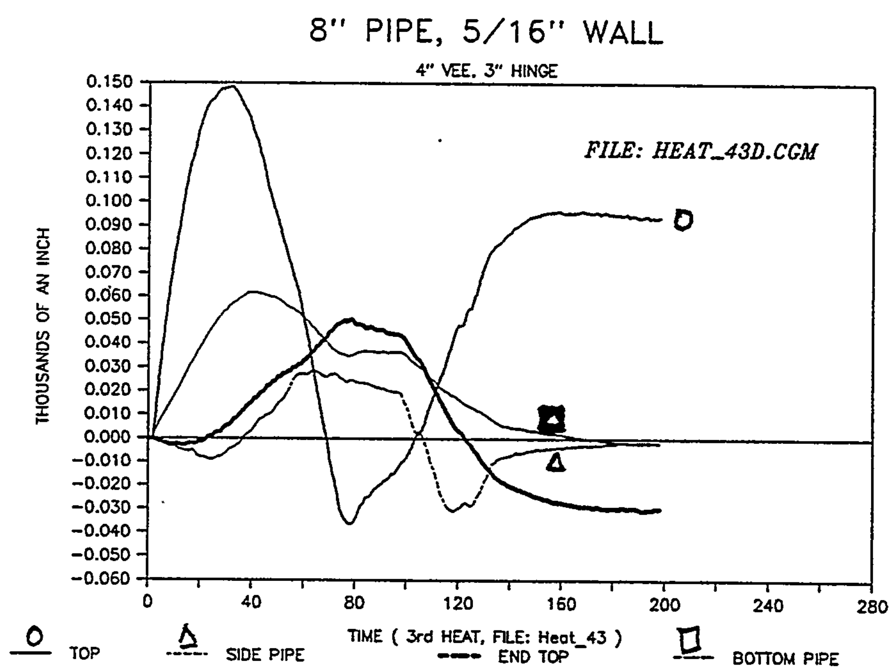

8" PIPE, 5/16" WALL
2" VEE, 1" HINGE
FILE: HEAT_37D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (SECOND HEAT, Heat_37)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

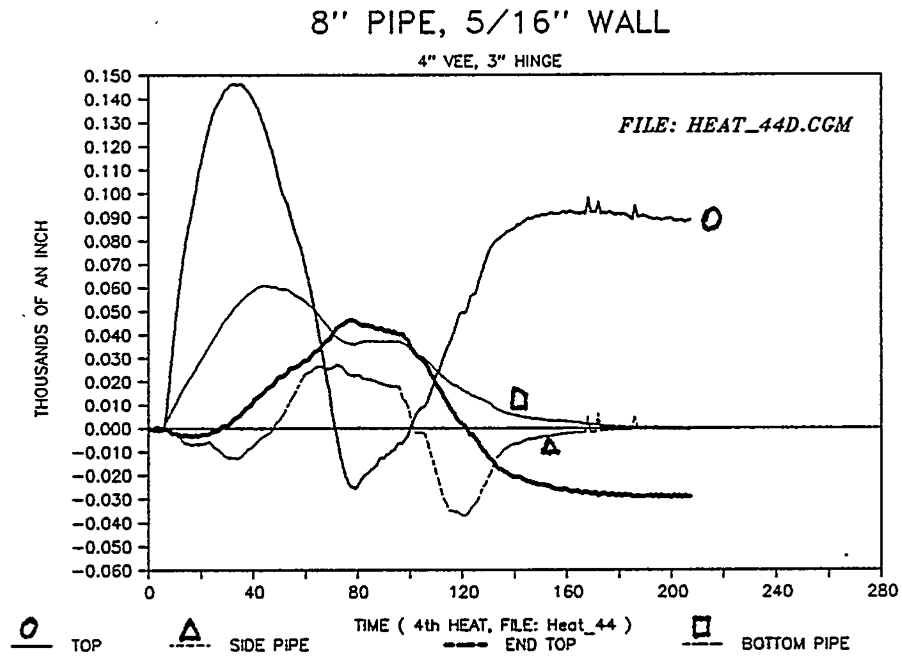
APPENDIX C
FLAME BENDING GRAPHS

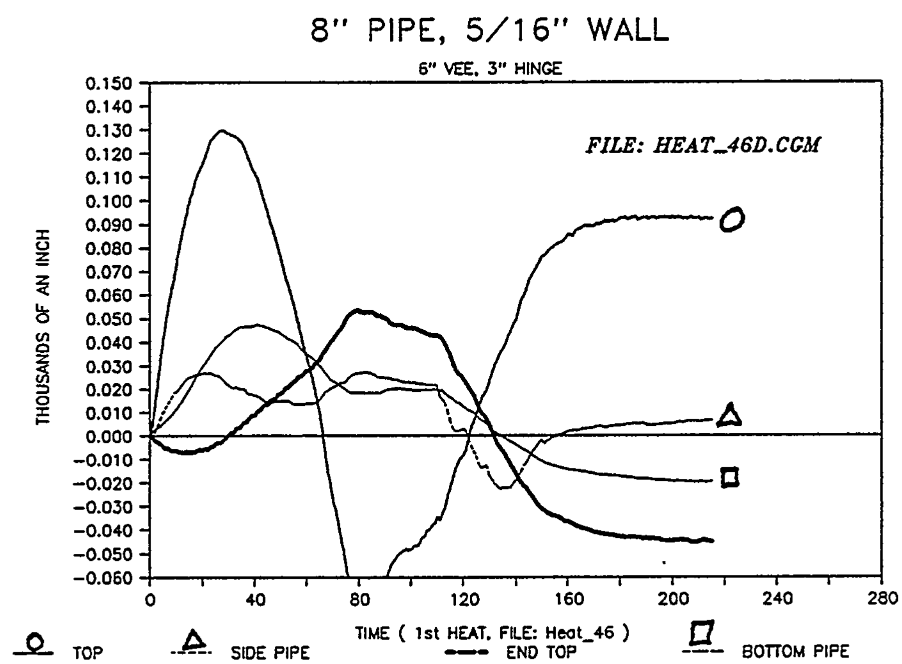


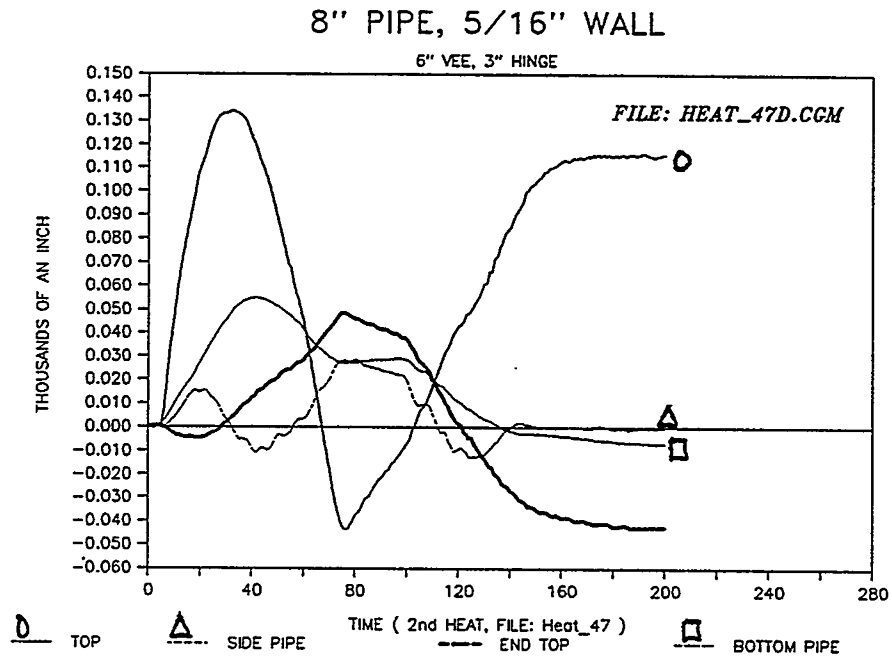


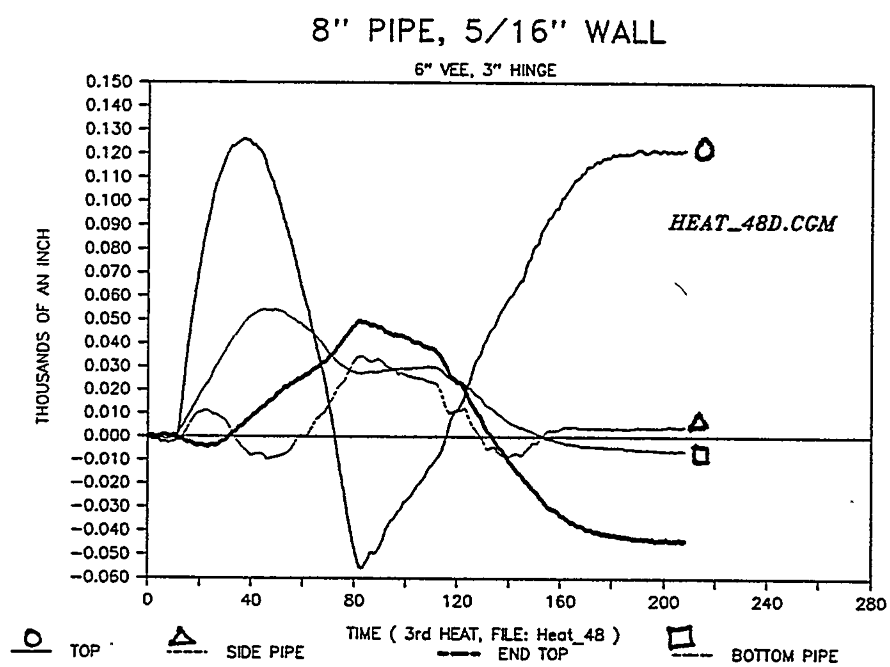

8" PIPE, 5/16" WALL
4" VEE, 3" HINGE
FILE: HEAT_41D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_41)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

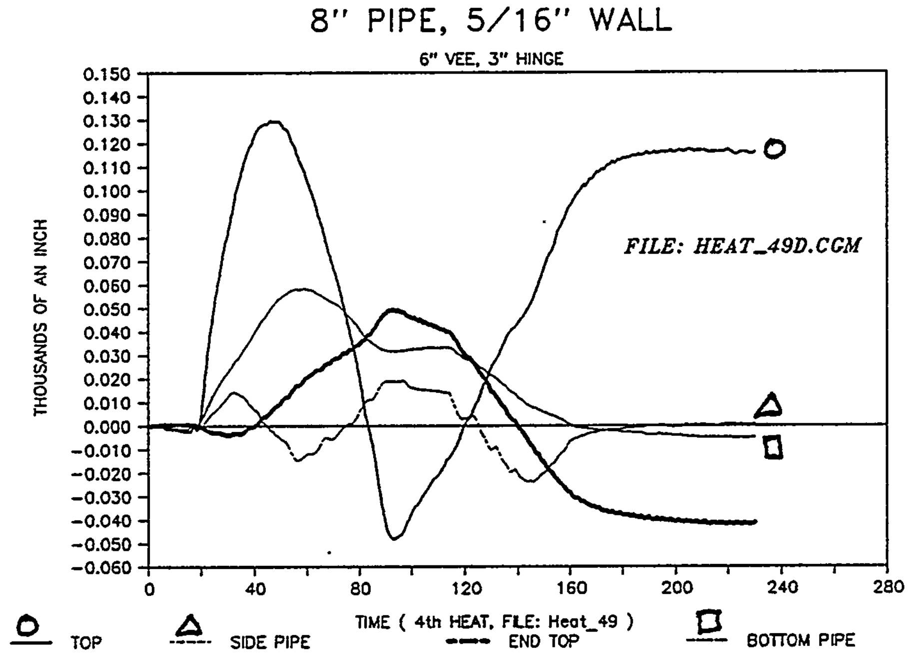

8" PIPE, 5/16" WALL
4" VEE, 3" HINGE
FILE: HEAT_43D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_43)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

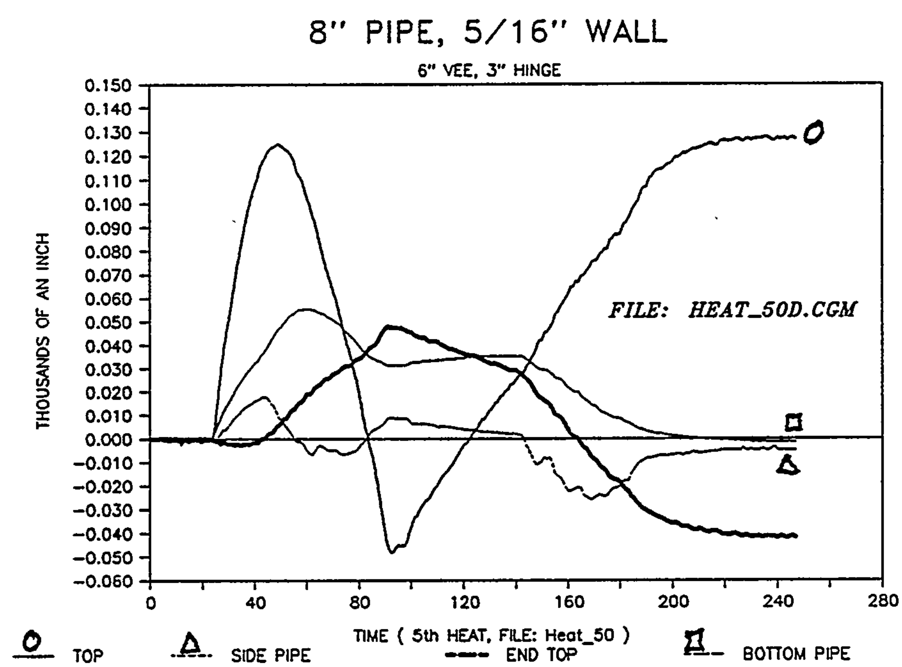

8" PIPE, 5/16" WALL
4" VEE, 3" HINGE
FILE: HEAT_44D.CGM
THOUSANDS OF AN INCH
TIME (4th HEAT, FILE: Heat_44)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

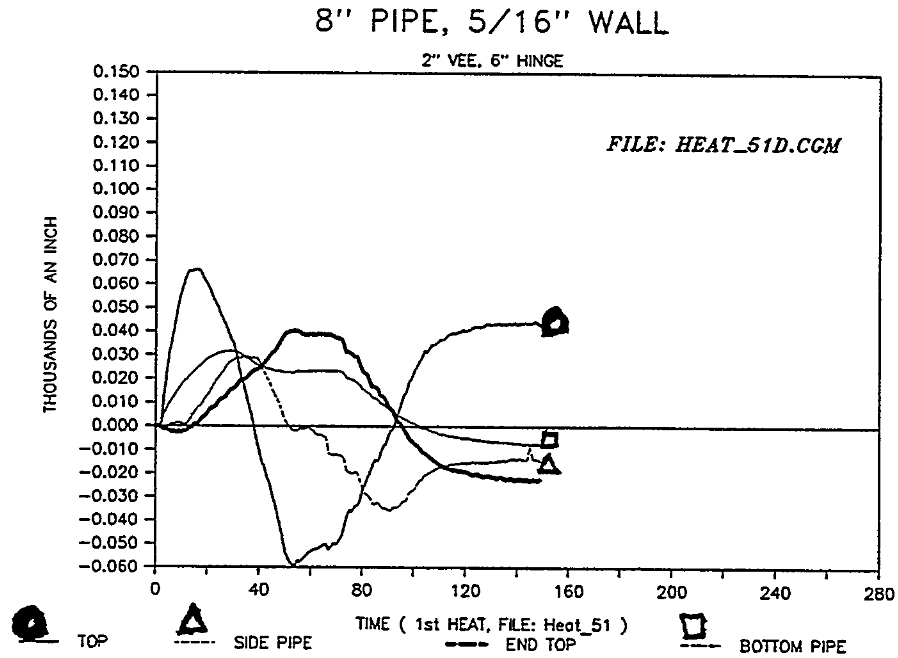

8" PIPE, 5/16" WALL
6" VEE, 3" HINGE
FILE: HEAT_46D.CGM
THOUSANDS OF AN INCH
TIME (1st HEAT, FILE: Heat_46)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

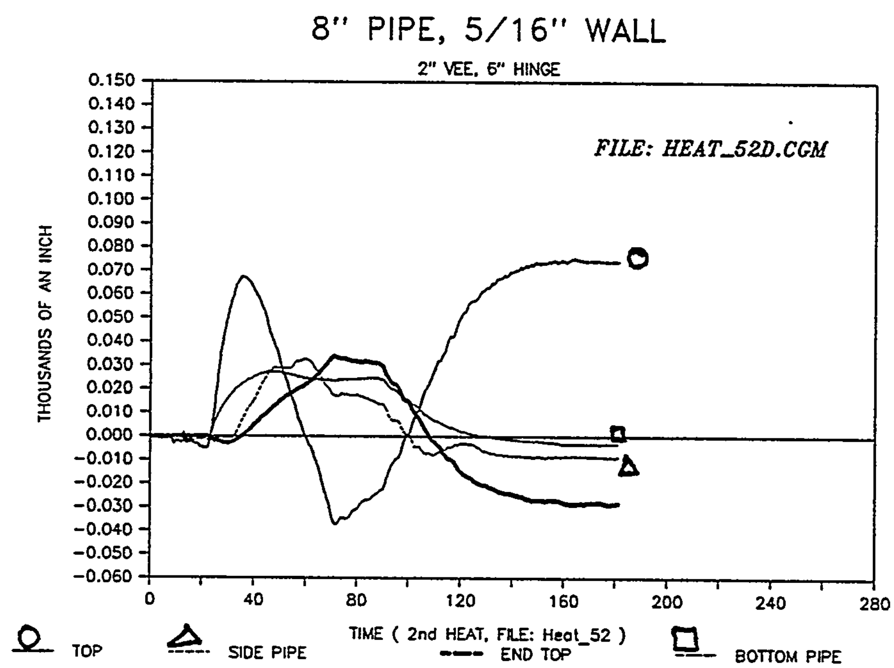

8" PIPE, 5/16" WALL
6" VEE, 3" HINGE
FILE: HEAT_47D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_47)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

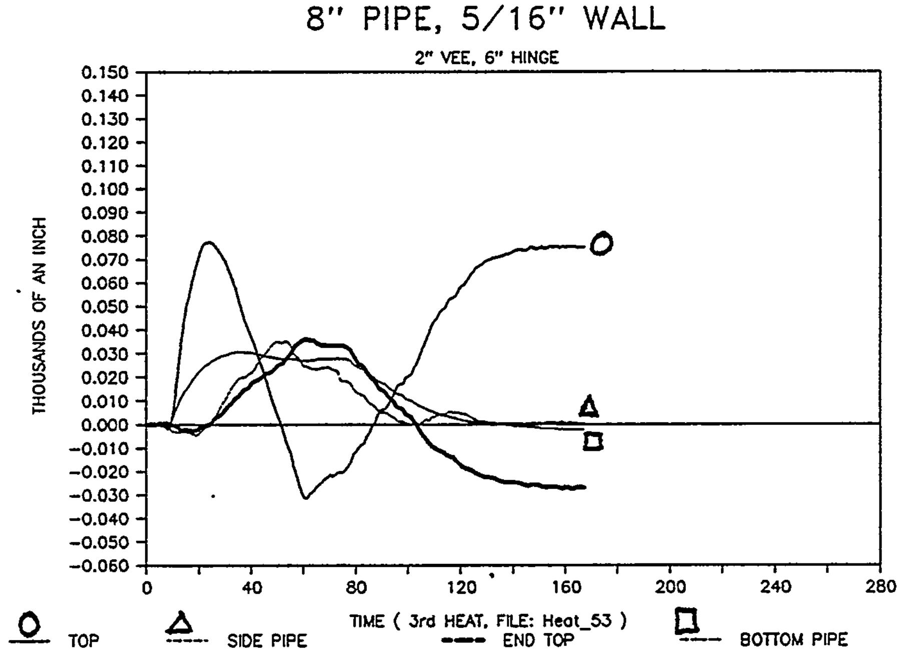

8" PIPE, 5/16" WALL
6" VEE, 3" HINGE
HEAT_48D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_48)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

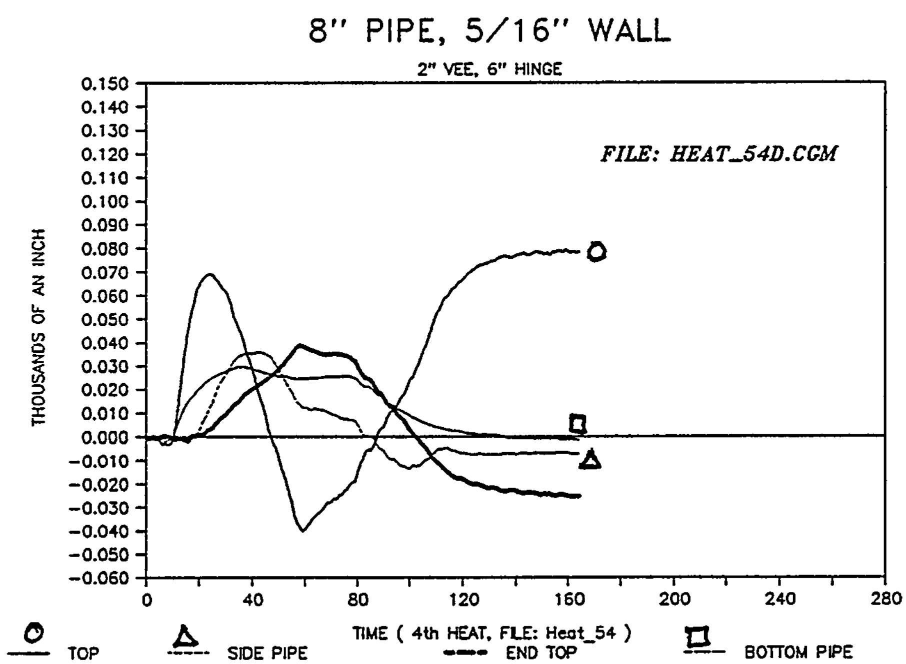

8" PIPE, 5/16" WALL
6" VEE, 3" HINGE
THOUSANDS OF AN INCH
FILE: HEAT_49D.CGM
TIME (4th HEAT, FILE: Heat_49)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

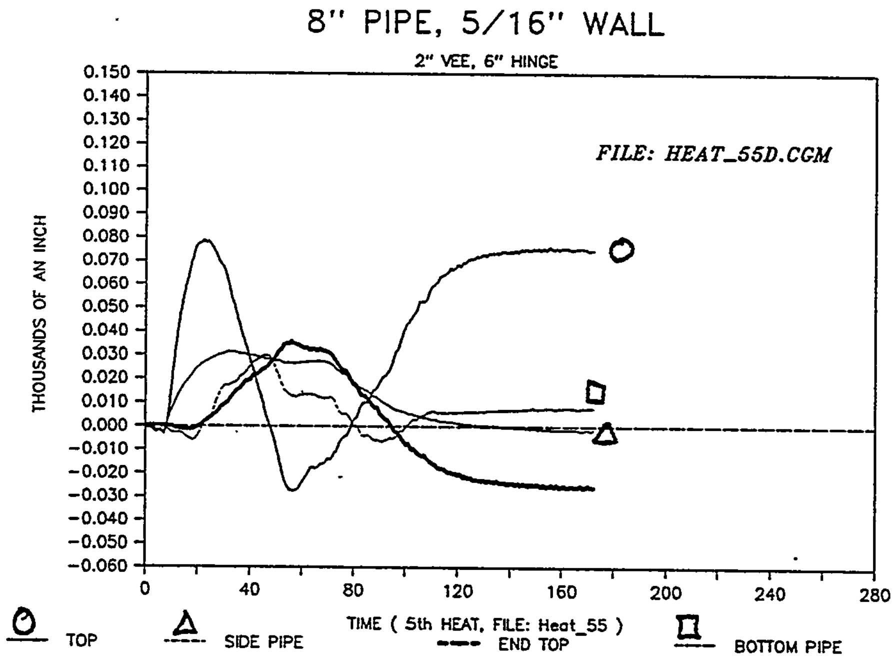

8" PIPE, 5/16" WALL
6" VEE, 3" HINGE
THOUSANDS OF AN INCH
FILE: HEAT_50D.CGM
TIME (5th HEAT, FILE: Heat_50)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

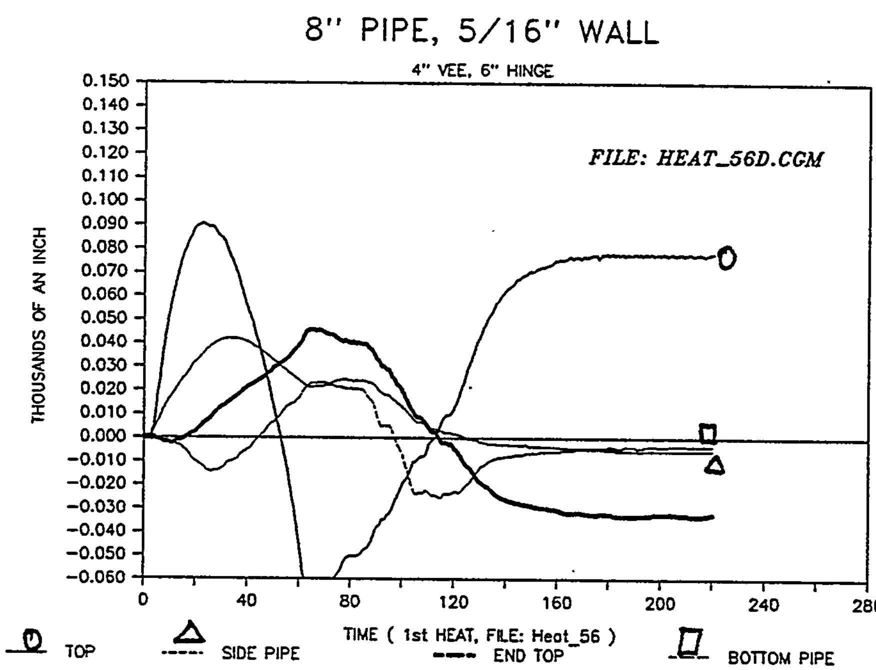

8" PIPE, 5/16" WALL
2" VEE, 6" HINGE
FILE: HEAT_51D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_51)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

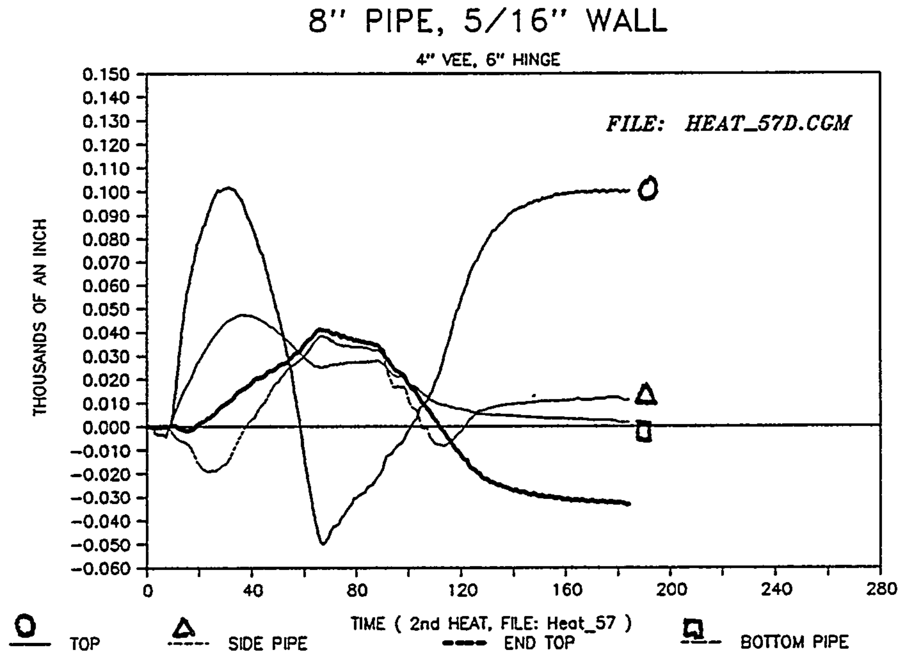

8" PIPE, 5/16" WALL
2" VEE, 6" HINGE
FILE: HEAT_52D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_52)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

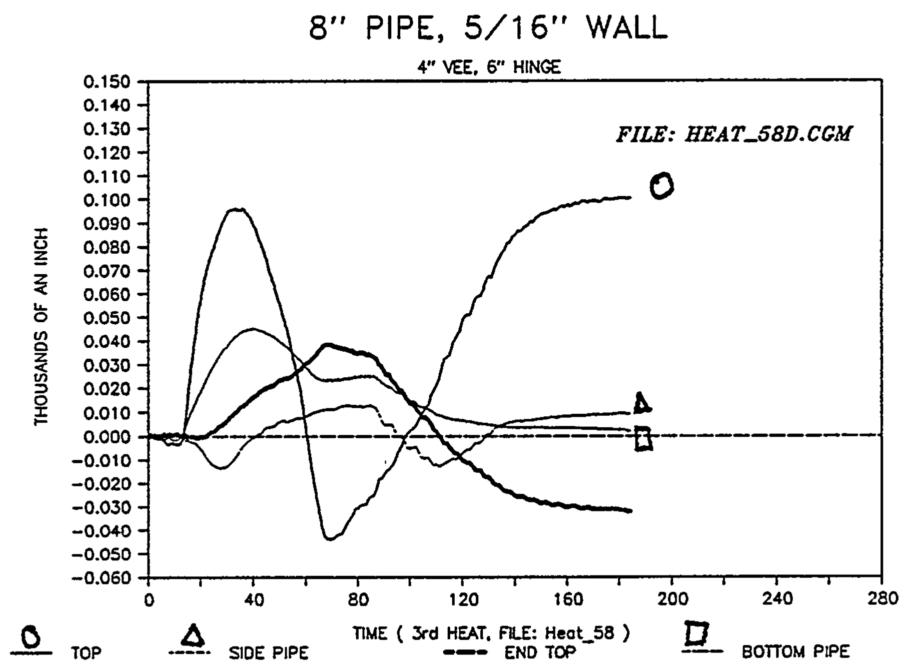

8" PIPE, 5/16" WALL
2" VEE, 6" HINGE
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_53)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

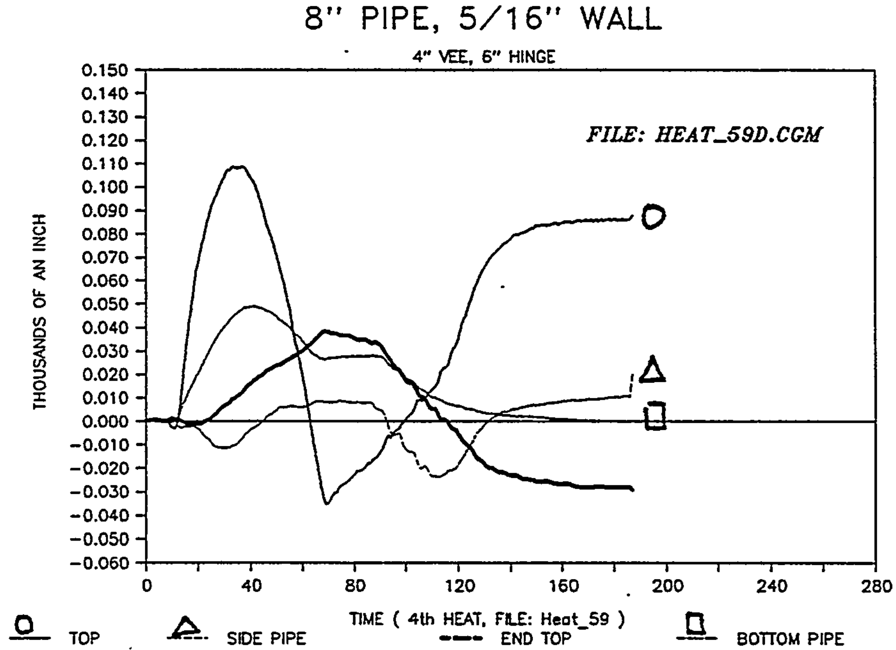

8" PIPE, 5/16" WALL
2" VEE, 6" HINGE
FILE: HEAT_54D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FLE: Heat_54)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

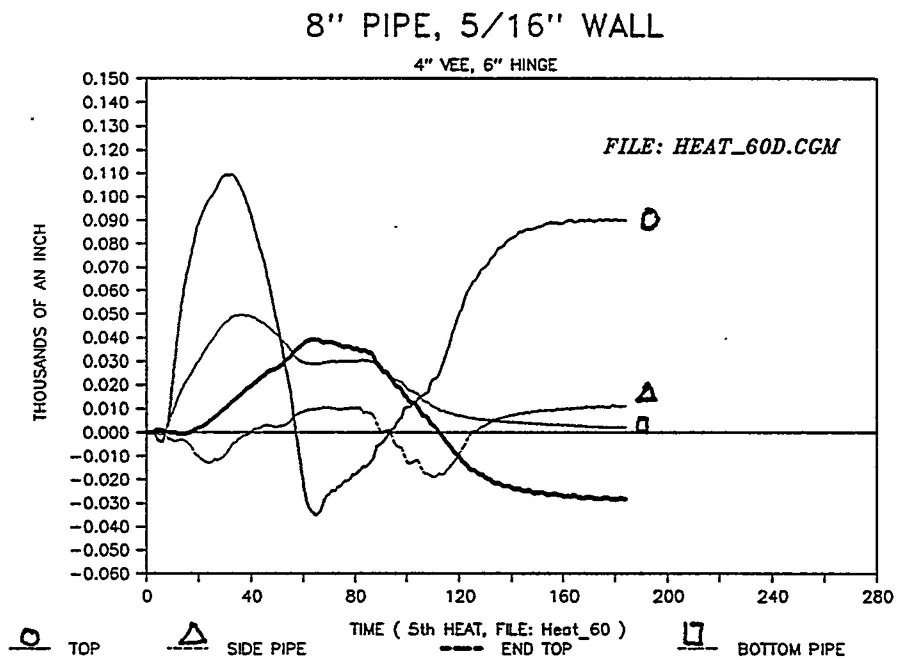

8" PIPE, 5/16" WALL
2" VEE, 6" HINGE
FILE: HEAT_55D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (5th HEAT, FILE: Heat_55)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 5/16" WALL
4" VEE, 6" HINGE
FILE: HEAT_56D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_56)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

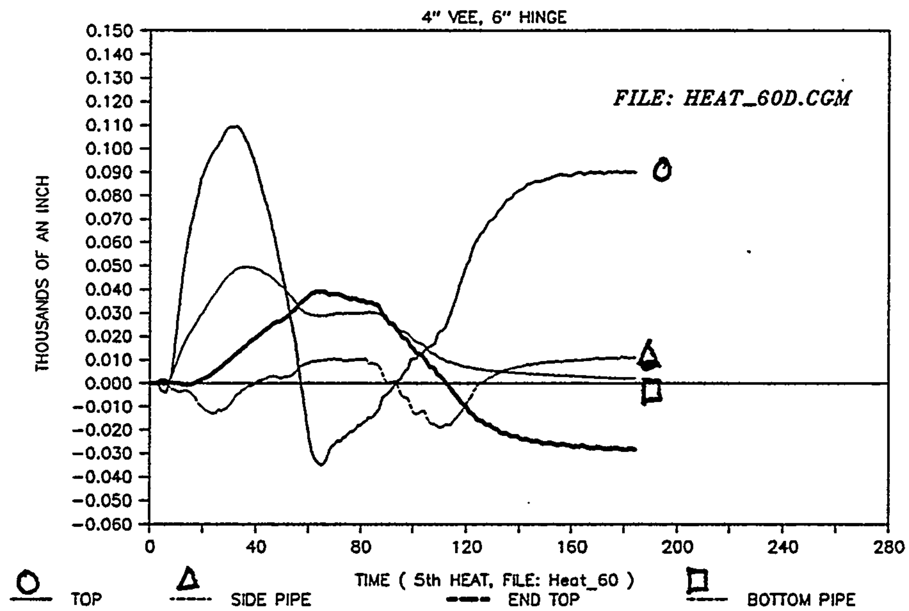

8" PIPE, 5/16" WALL
4" VEE, 6" HINGE
FILE: HEAT_57D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_57)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 5/16" WALL
4" VEE, 6" HINGE
FILE: HEAT_58D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_58)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

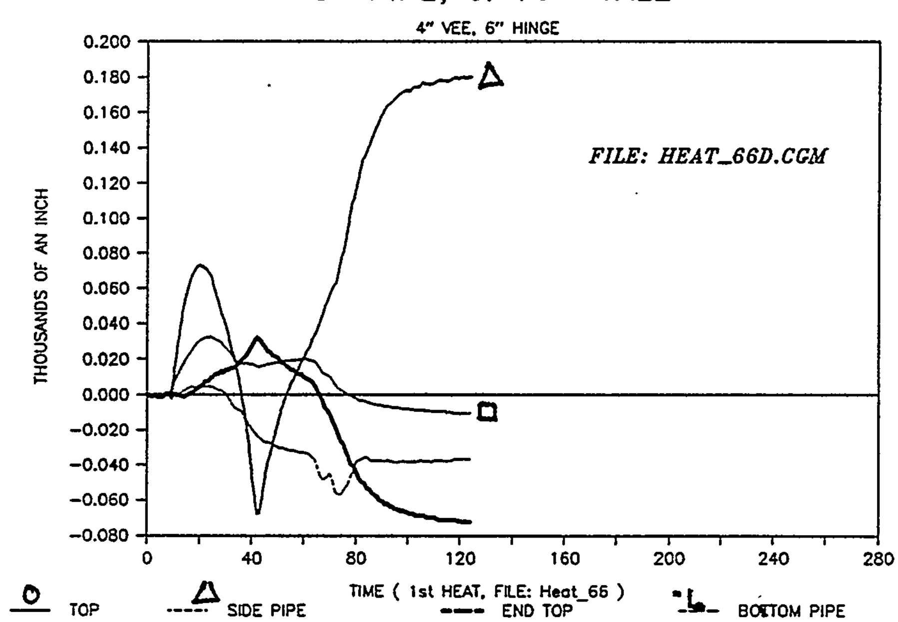

8" PIPE, 5/16" WALL
4" VEE, 6" HINGE
FILE: HEAT_59D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
−0.010
−0.020
−0.030
−0.040
−0.050
−0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: Heat_59)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 5/16" WALL
4" VEE, 6" HINGE
FILE: HEAT_60D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
−0.010
−0.020
−0.030
−0.040
−0.050
−0.060
0
40
80
120
160
200
240
280
TIME (5th HEAT, FILE: Heat_60)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

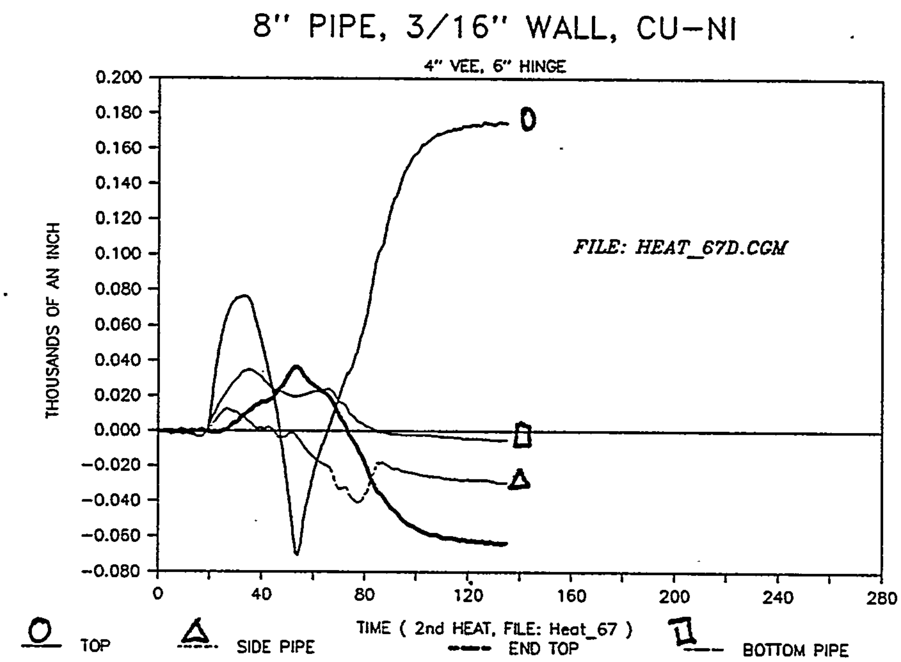
8" PIPE, 5/16" WALL

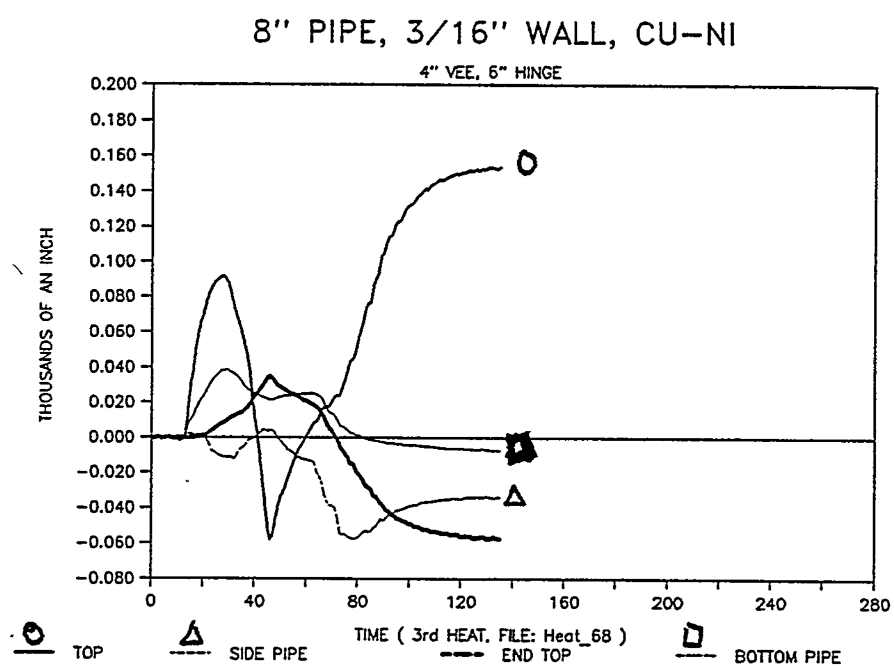


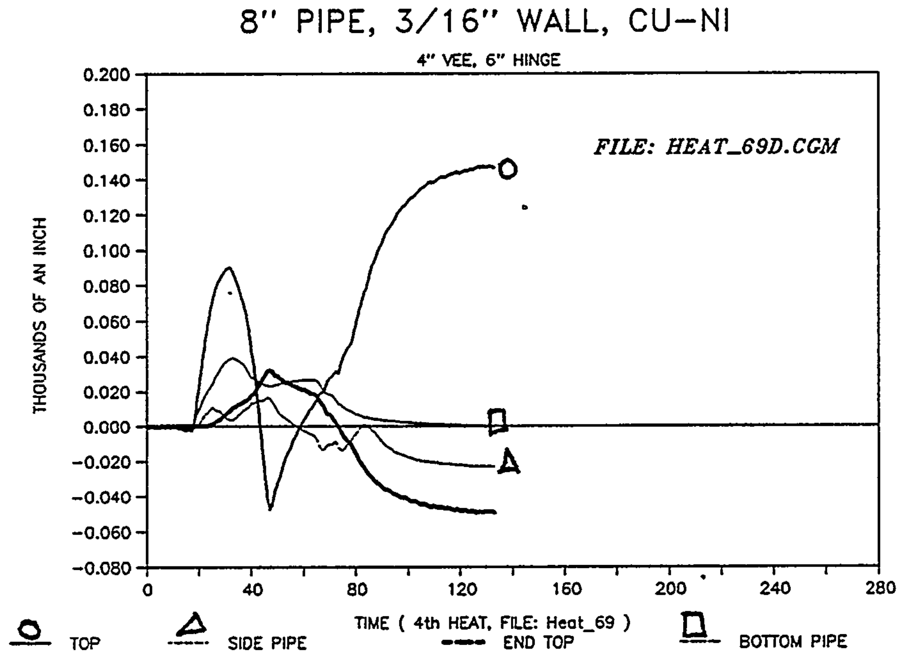
8" PIPE, 3/16" WALL

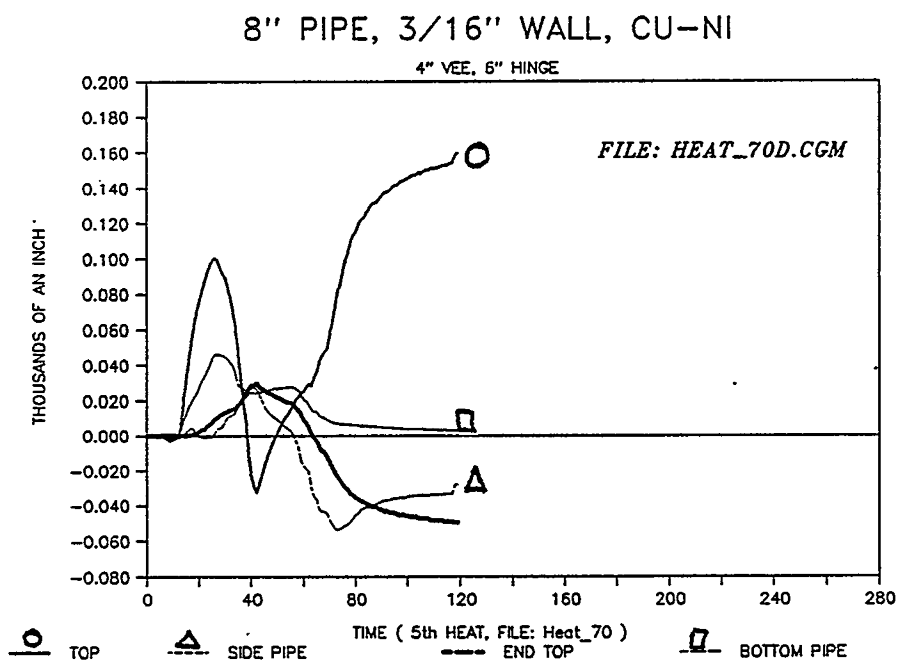


APPENDIX C
FLAME BENDING GRAPHS

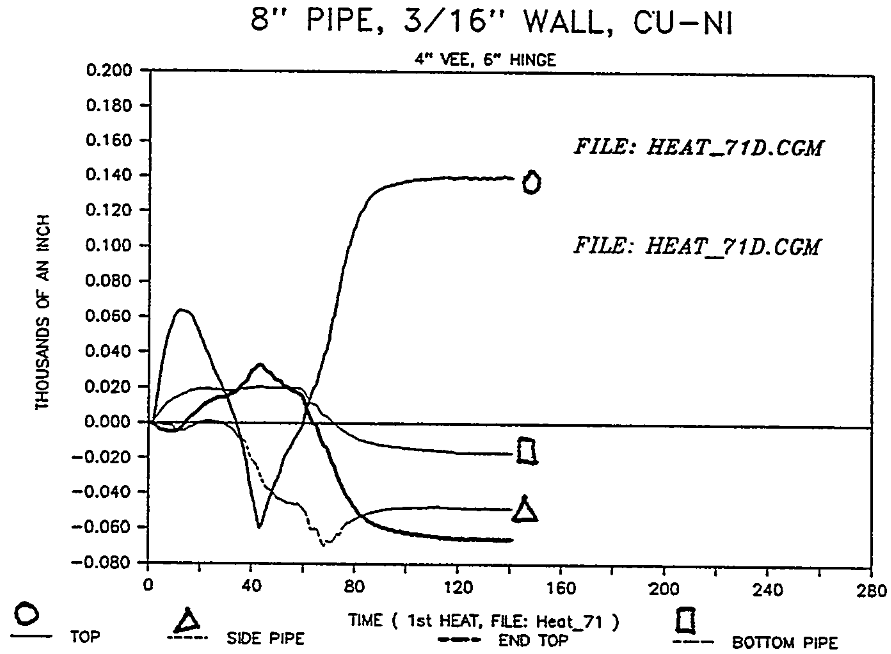


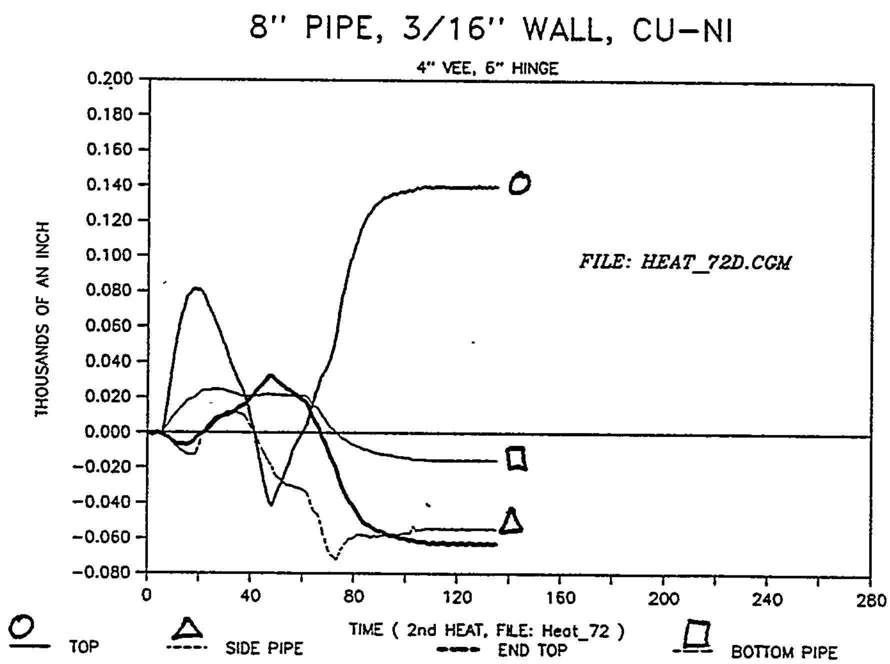


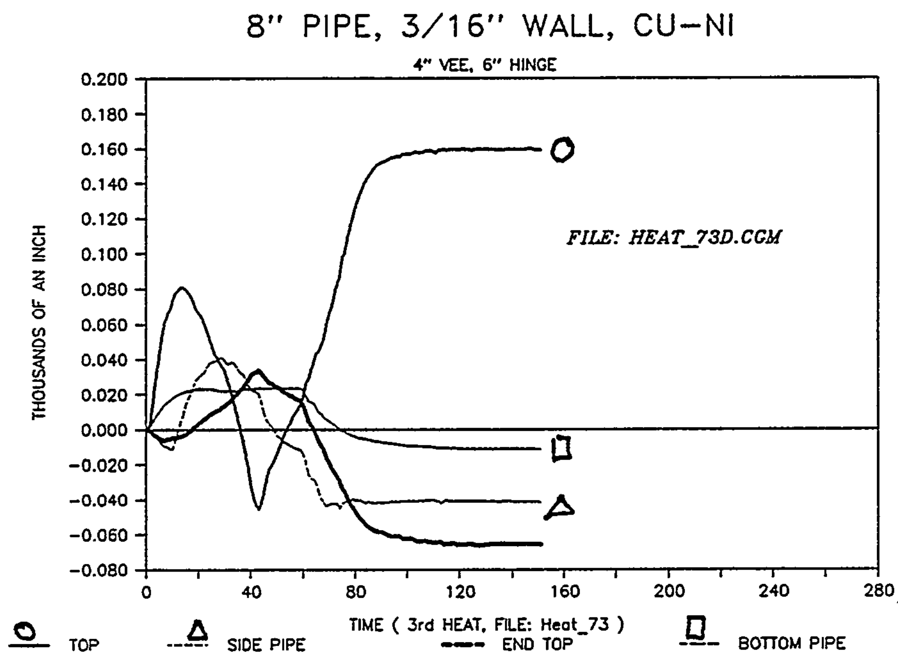

8" PIPE, 3/16" WALL, CU-NI
4" VEE, 6" HINGE
FILE: HEAT_69D.CGM
THOUSANDS OF AN INCH
TIME (4th HEAT, FILE: Heat_69)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

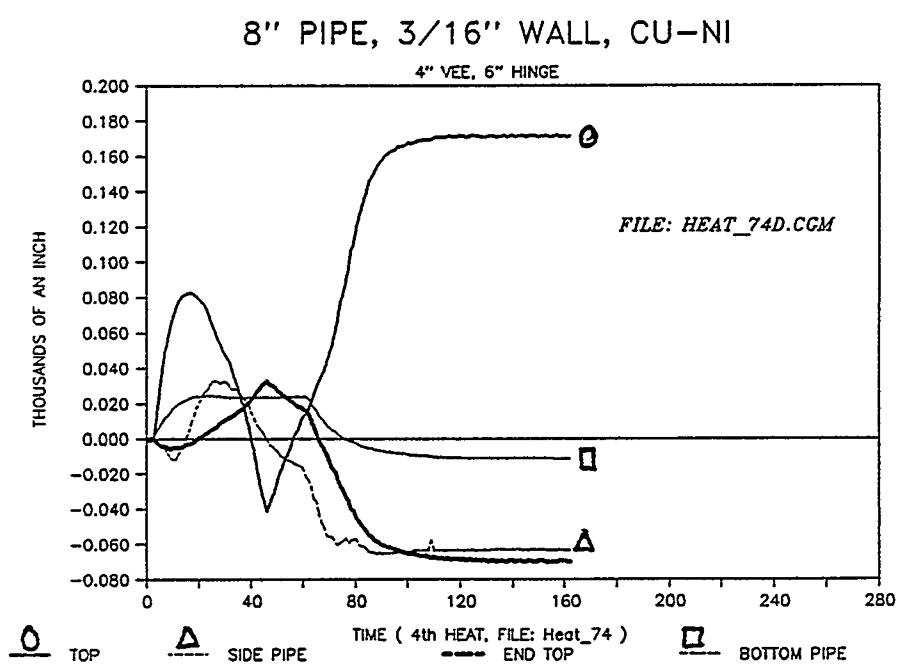

8" PIPE, 3/16" WALL, CU-NI
4" VEE, 6" HINGE
FILE: HEAT_70D.CGM
THOUSANDS OF AN INCH
TIME (5th HEAT, FILE: Heat_70)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

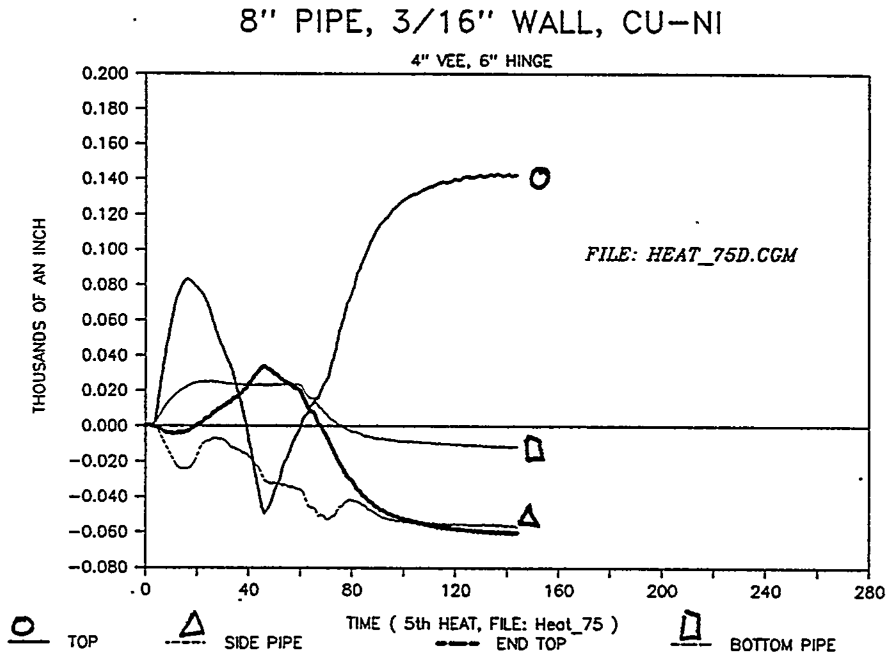
APPENDIX C
FLAME BENDING GRAPHS

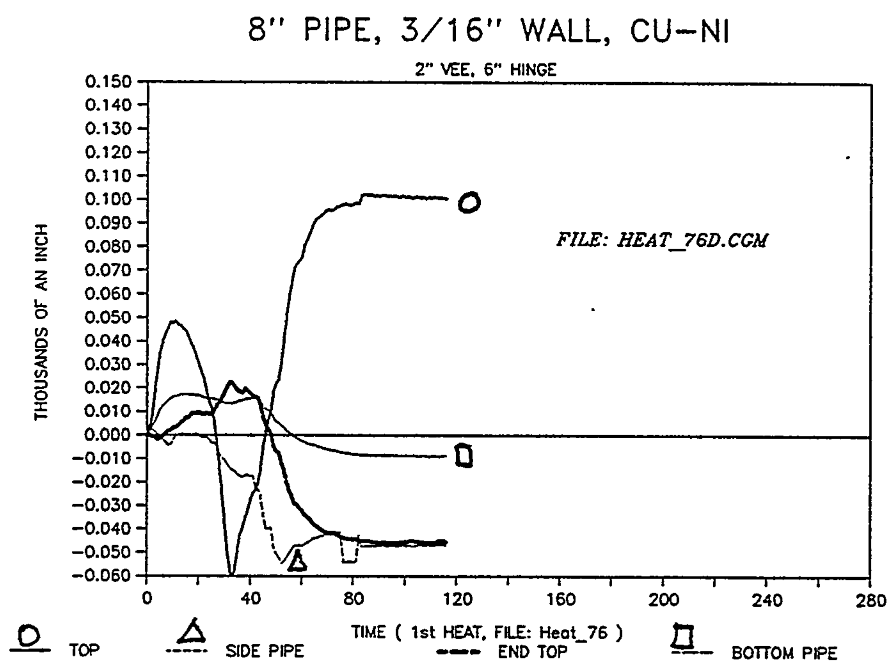




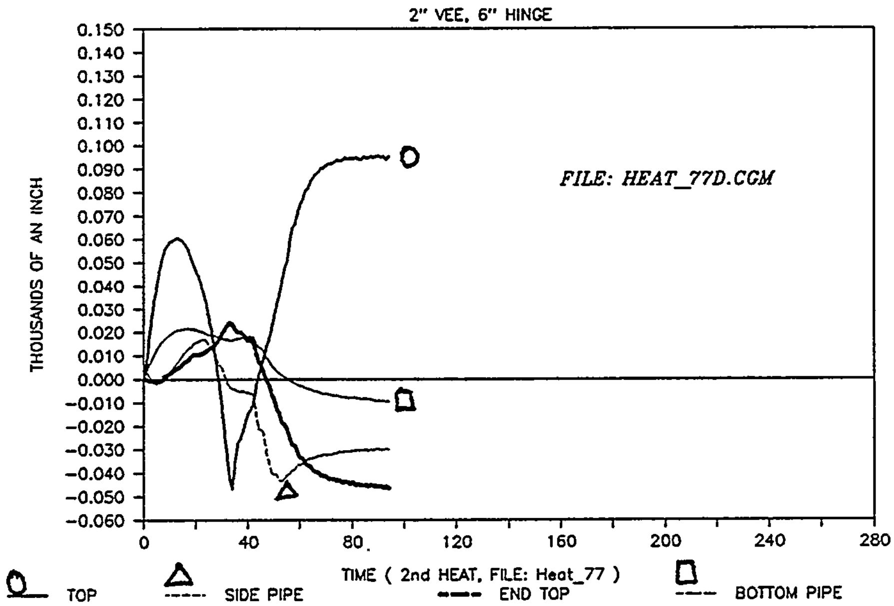

8" PIPE, 3/16" WALL, CU-NI
4" VEE, 6" HINGE
THOUSANDS OF AN INCH
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
0
40
80
120
160
200
240
280
FILE: HEAT_73D.CGM
TIME (3rd HEAT, FILE: Heat_73)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, CU-NI
4" VEE, 6" HINGE
THOUSANDS OF AN INCH
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
0
40
80
120
160
200
240
280
FILE: HEAT_74D.CGM
TIME (4th HEAT, FILE: Heat_74)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

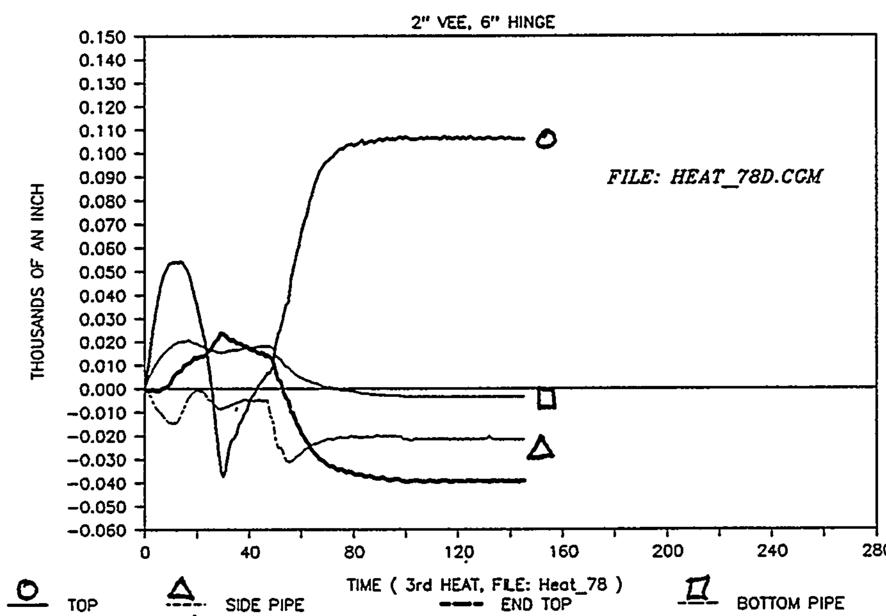

8" PIPE, 3/16" WALL, CU-NI
4" VEE, 6" HINGE
THOUSANDS OF AN INCH
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
0
40
80
120
160
200
240
280
FILE: HEAT_75D.CGM
TIME (5th HEAT, FILE: Heat_75)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

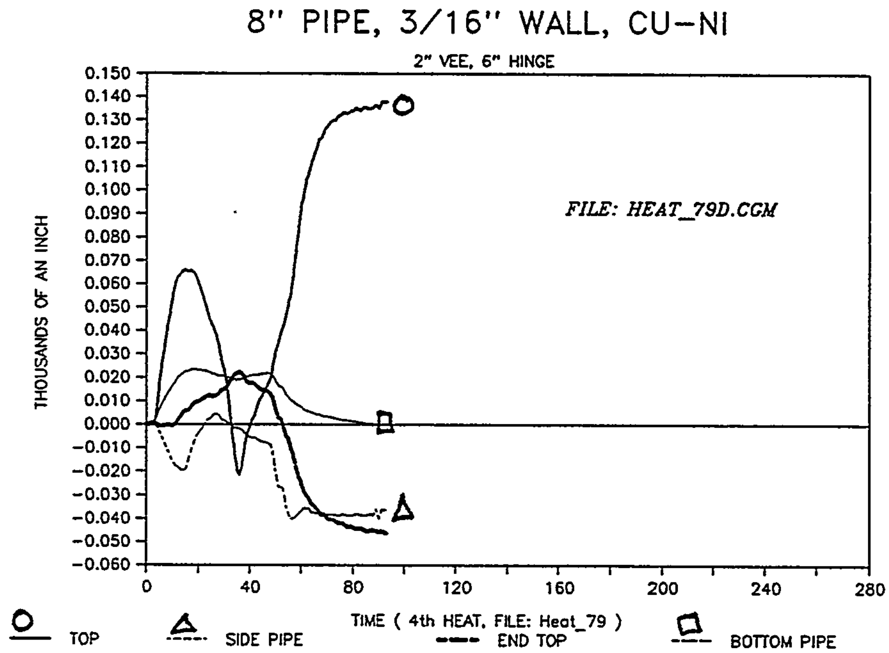

8" PIPE, 3/16" WALL, CU-NI
2" VEE, 6" HINGE
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
FILE: HEAT_76D.CGM
TIME (1st HEAT, FILE: Heat_76)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

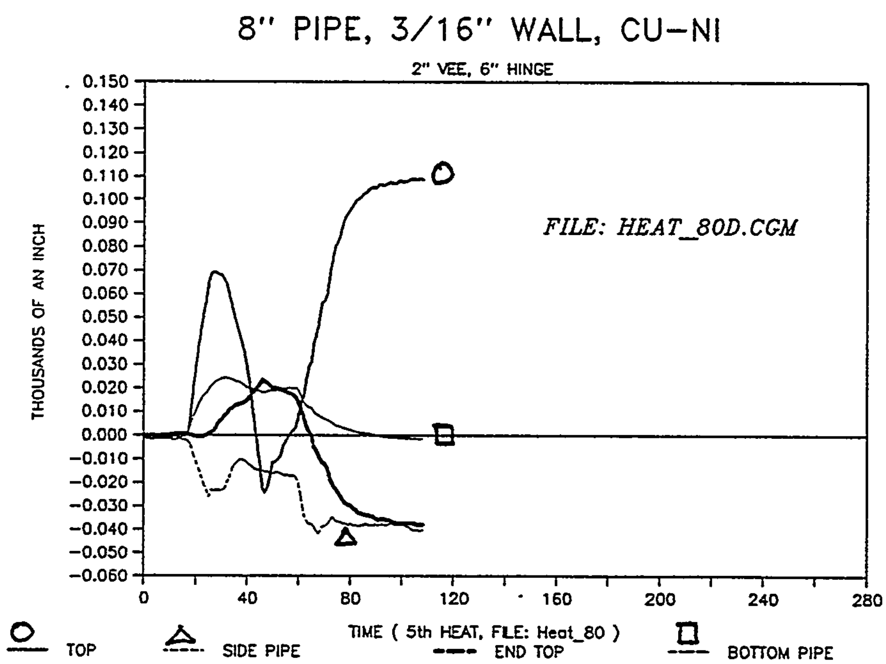
8" PIPE, 3/16" WALL, CU-NI

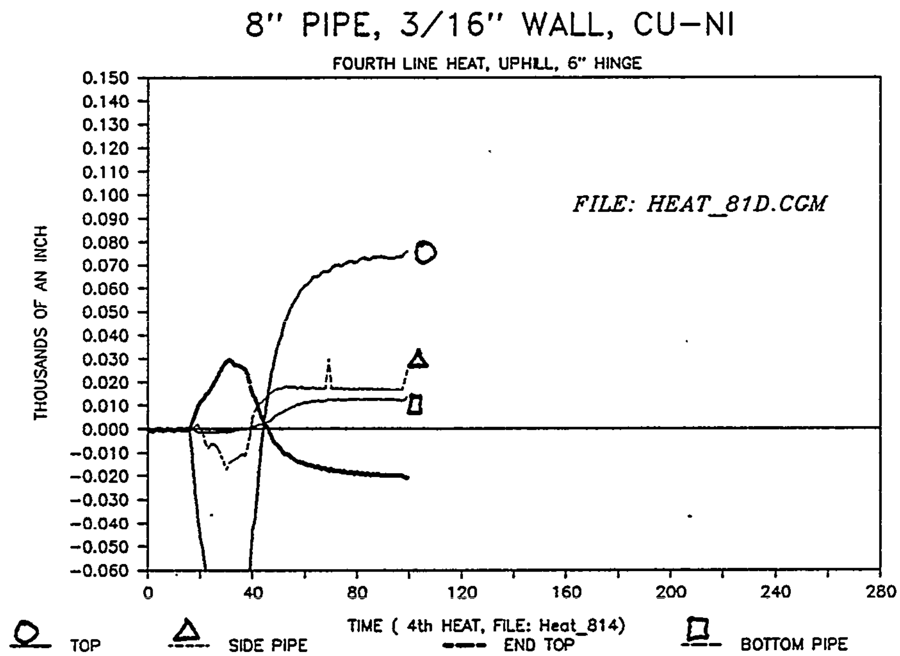


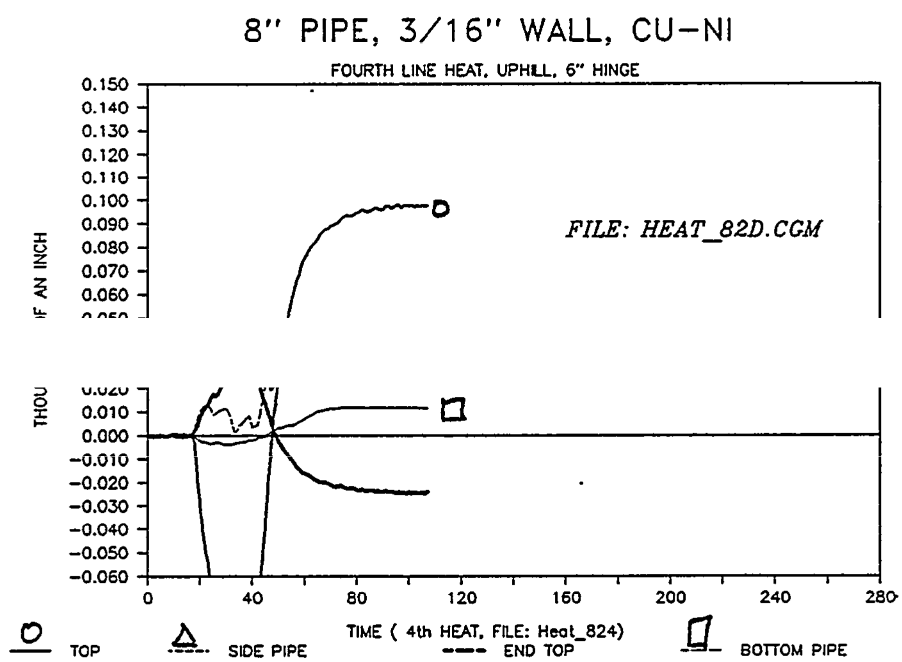
8" PIPE, 3/16" WALL, CU-NI

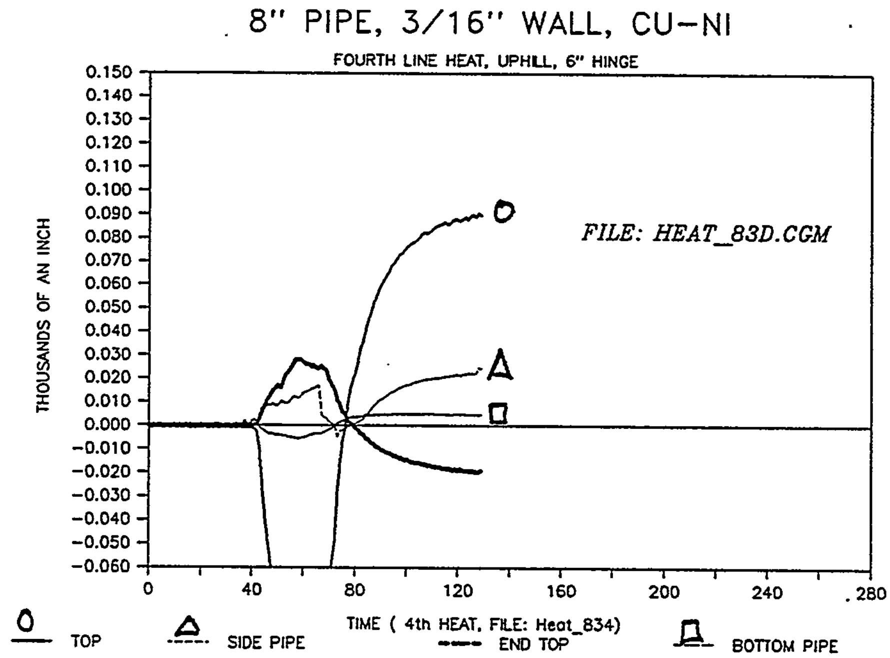


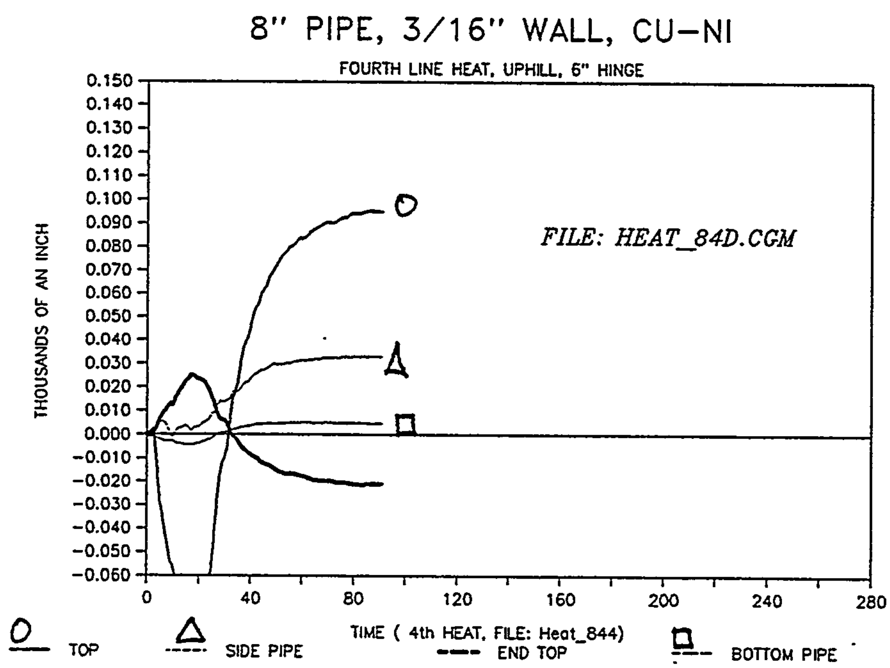

8" PIPE, 3/16" WALL, CU-NI
2" VEE, 6" HINGE
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
FILE: HEAT_79D.CGM
TIME (4th HEAT, FILE: Heat_79)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

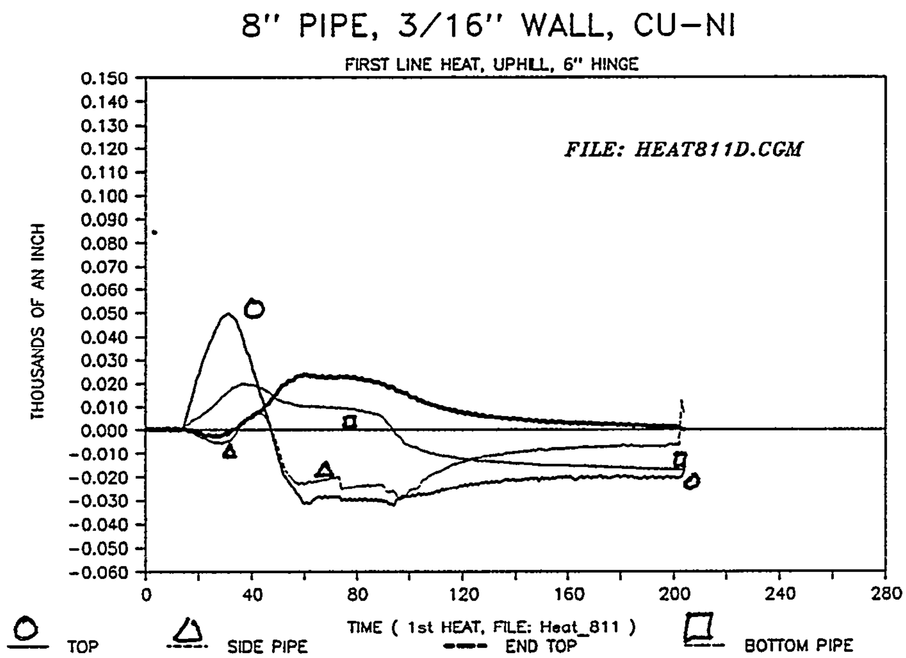

8" PIPE, 3/16" WALL, CU-NI
2" VEE, 6" HINGE
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
FILE: HEAT_80D.CGM
TIME (5th HEAT, FILE: Heat_80)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

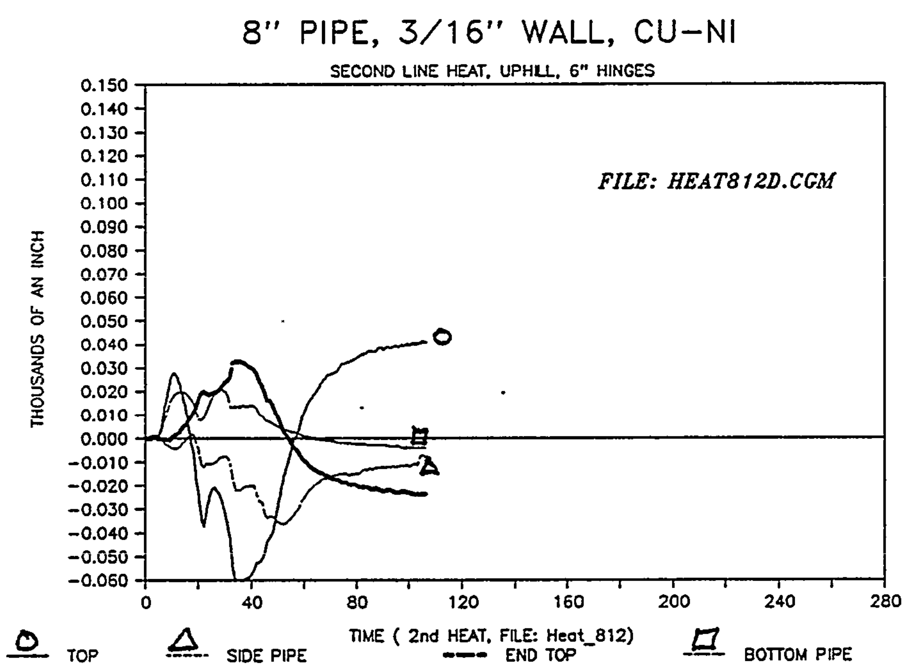

8" PIPE, 3/16" WALL, CU-NI
FOURTH LINE HEAT, UPHILL, 6" HINGE
THOUSANDS OF AN INCH
FILE: HEAT_81D.CGM
TIME (4th HEAT, FILE: Heat_814)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

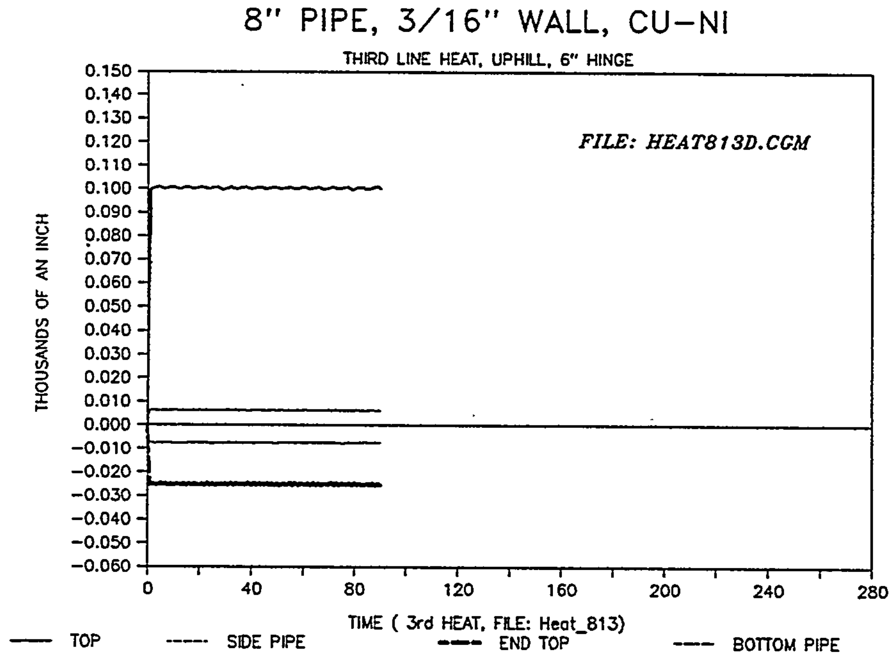

8" PIPE, 3/16" WALL, CU-NI
FOURTH LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT_82D.CGM
TIME (4th HEAT, FILE: Heat_824)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

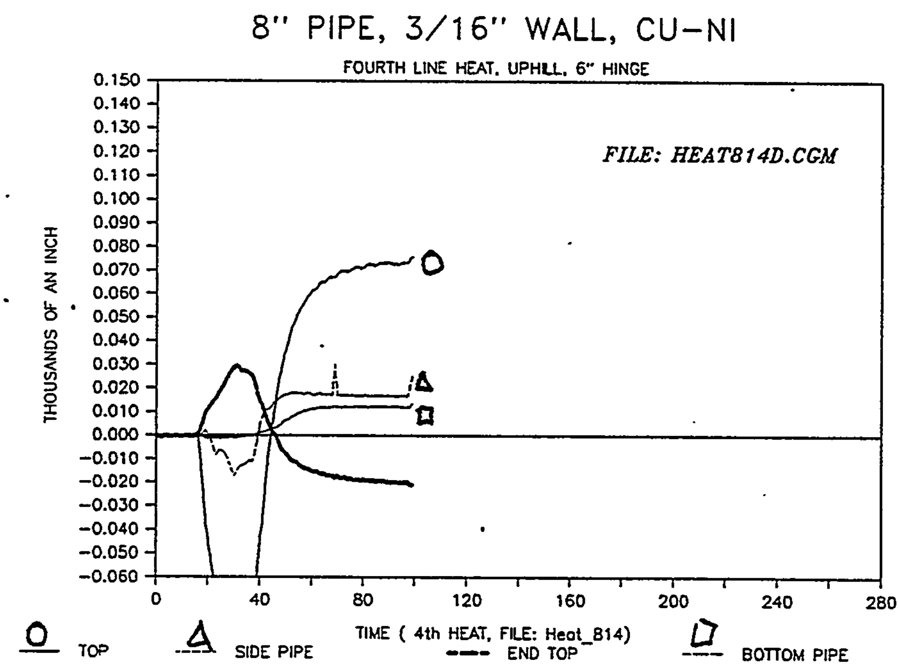

8" PIPE, 3/16" WALL, CU-NI
FOURTH LINE HEAT, UPHILL, 6" HINGE
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
FILE: HEAT_83D.CGM
TIME (4th HEAT, FILE: Heat_834)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

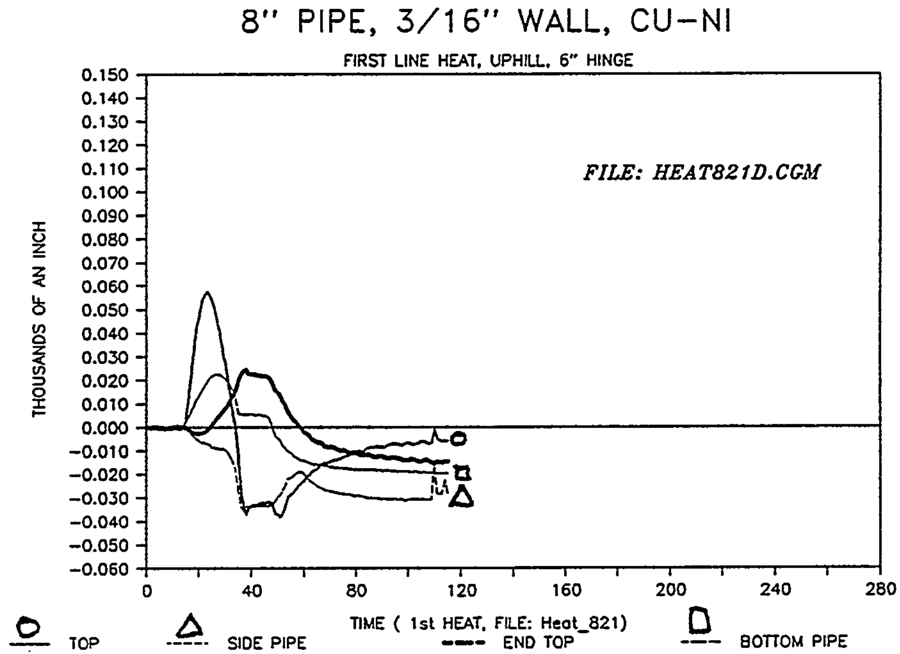

8" PIPE, 3/16" WALL, CU-NI
FOURTH LINE HEAT, UPHILL, 6" HINGE
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
FILE: HEAT_84D.CGM
TIME (4th HEAT, FILE: Heat_844)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

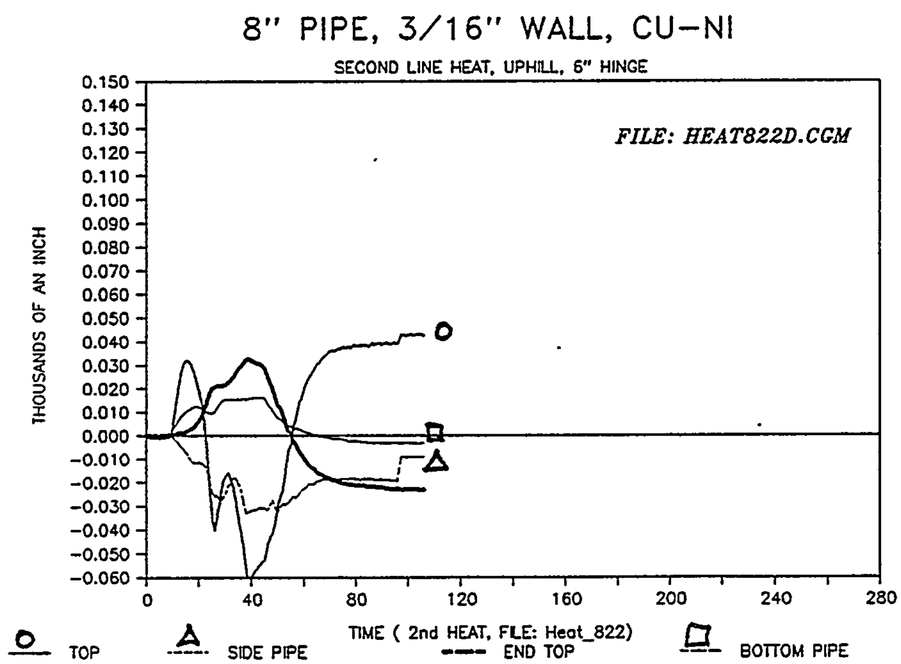

8" PIPE, 3/16" WALL, CU-NI
FIRST LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT811D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_811)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

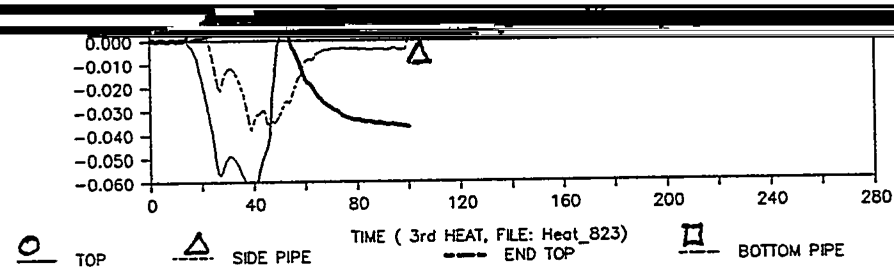

8" PIPE, 3/16" WALL, CU-NI
SECOND LINE HEAT, UPHILL, 6" HINGES
FILE: HEAT812D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_812)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

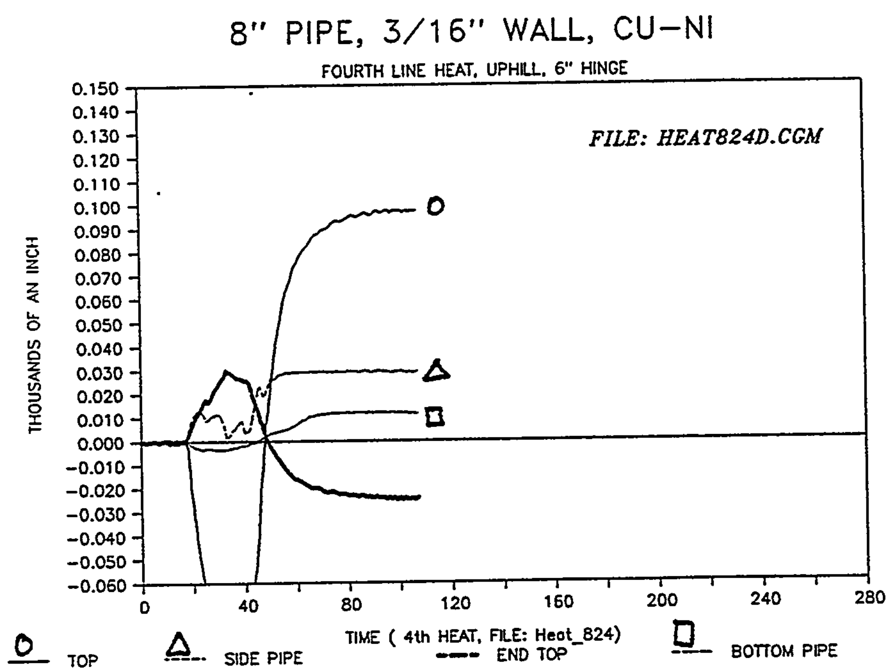

8" PIPE, 3/16" WALL, CU-NI
THIRD LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT813D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
−0.010
−0.020
−0.030
−0.040
−0.050
−0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_813)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

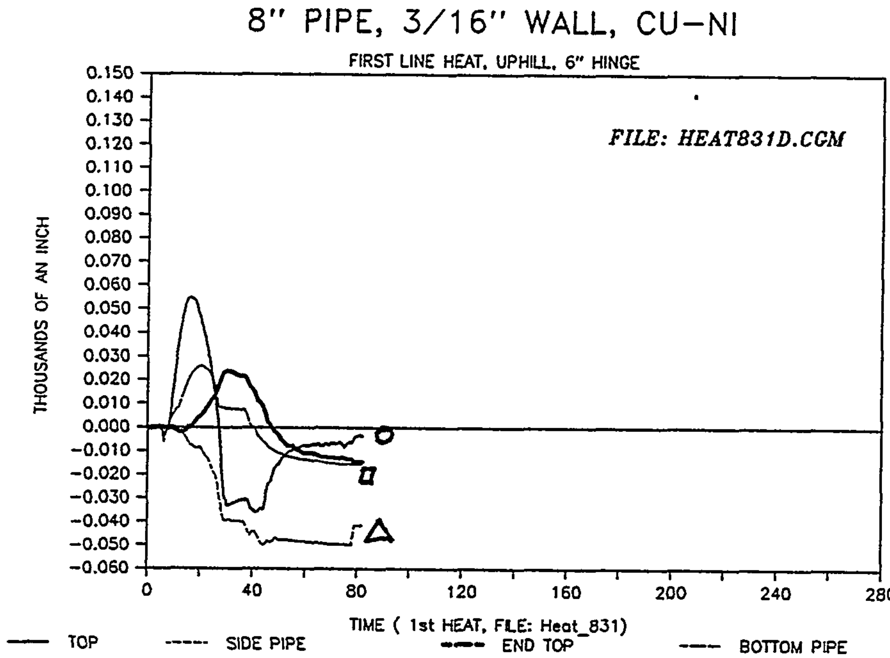

8" PIPE, 3/16" WALL, CU-NI
FOURTH LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT814D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
−0.010
−0.020
−0.030
−0.040
−0.050
−0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: Heat_814)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

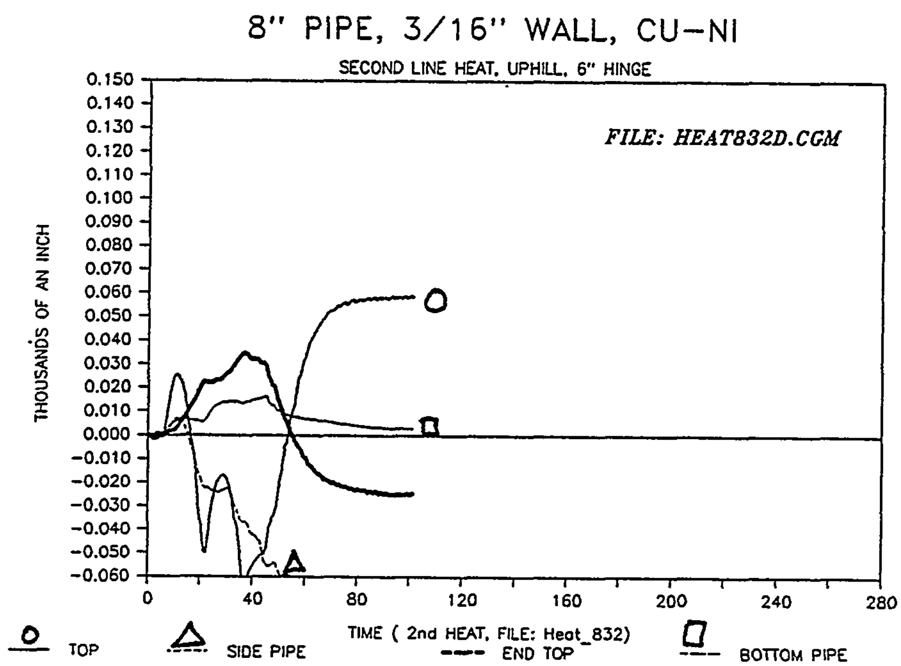

8" PIPE, 3/16" WALL, CU-NI
FIRST LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT821D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_821)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, CU-NI
SECOND LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT822D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_822)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_823)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

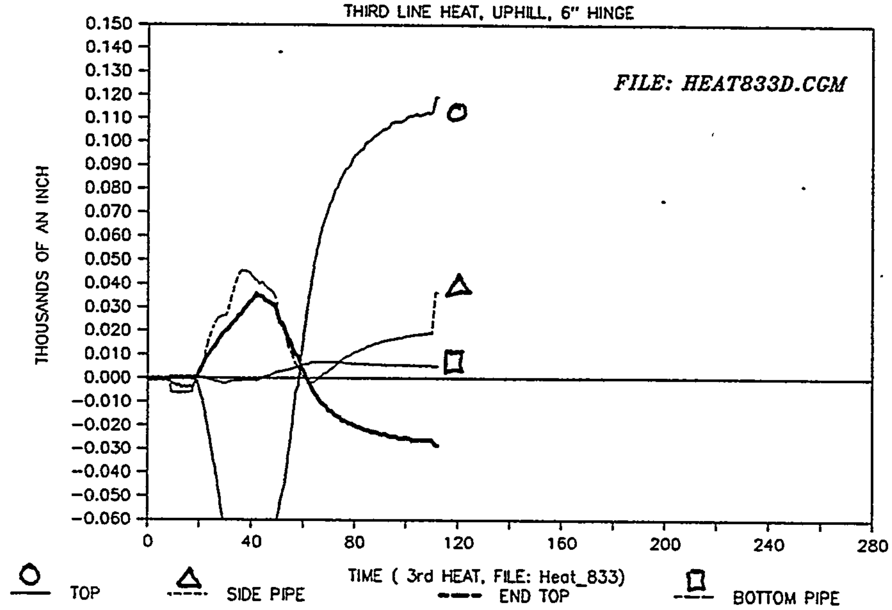

8" PIPE, 3/16" WALL, CU-NI
FOURTH LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT824D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: Heat_824)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, CU-NI
FIRST LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT831D.CGM
THOUSANDS OF AN INCH
TIME (1st HEAT, FILE: Heat_831)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, CU-NI
SECOND LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT832D.CGM
THOUSANDS OF AN INCH
TIME (2nd HEAT, FILE: Heat_832)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

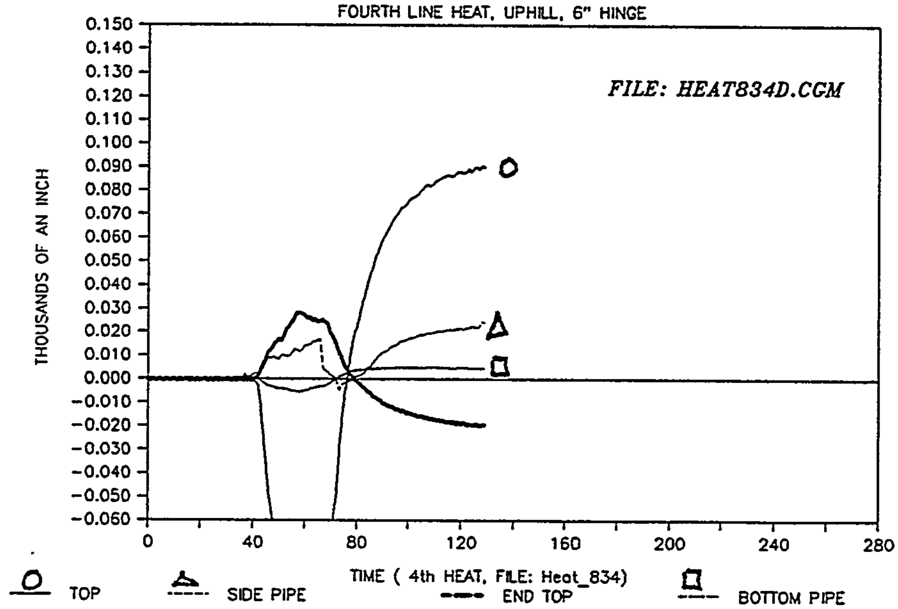
8" PIPE, 3/16" WALL, CU-NI

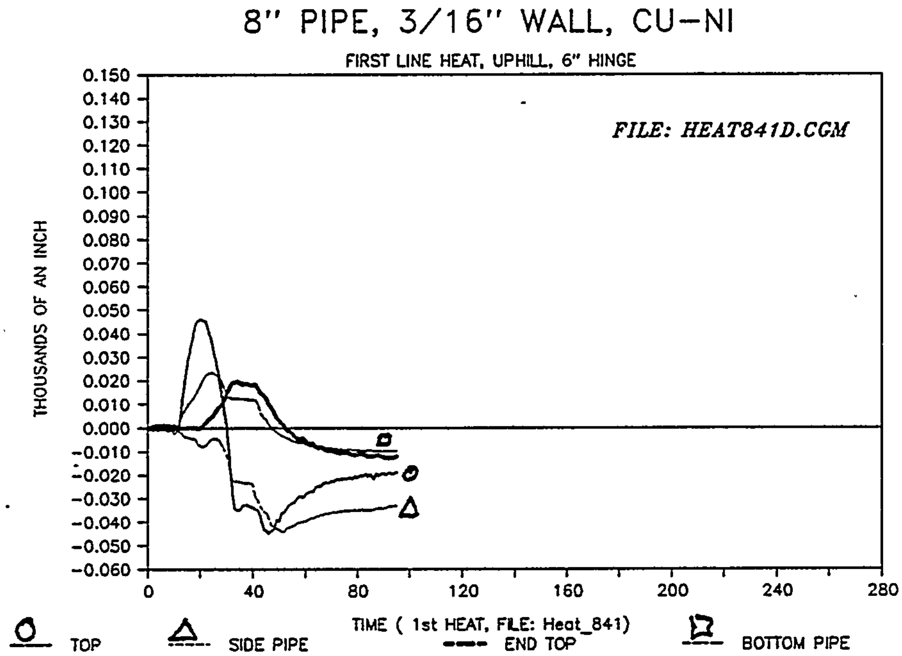
THIRD LINE HEAT, UPHILL, 6" HINGE

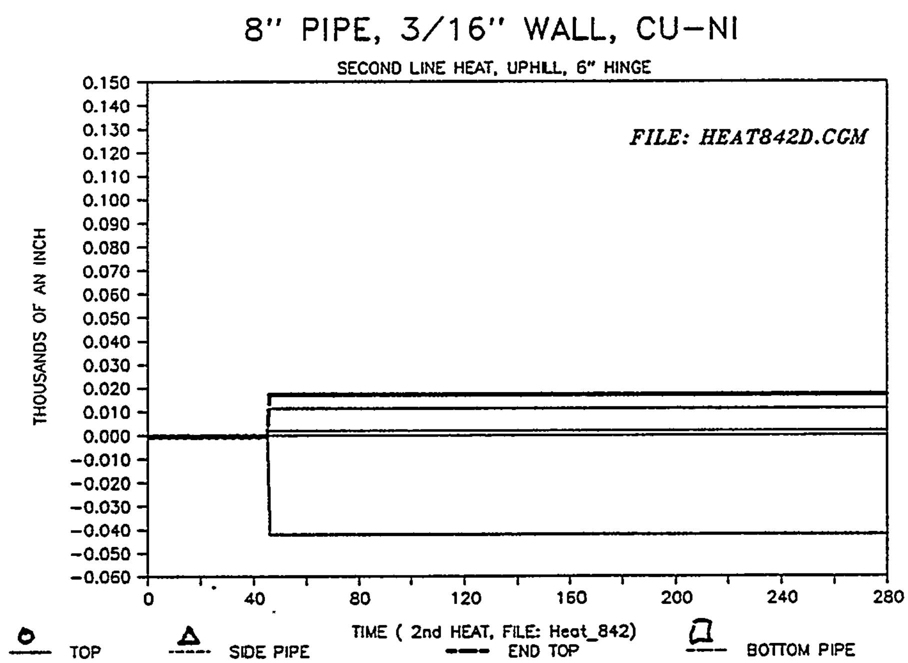


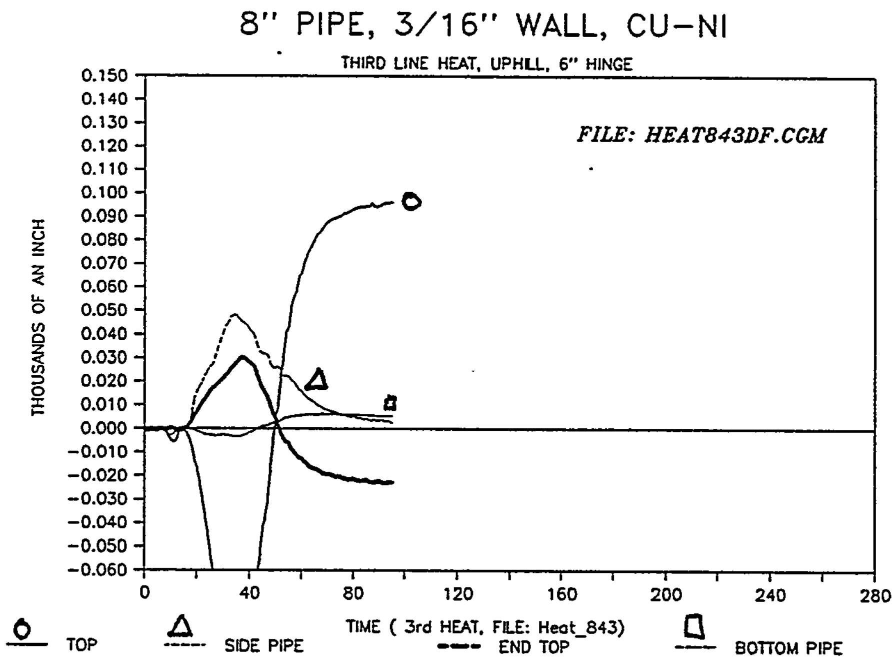
8" PIPE, 3/16" WALL, CU-NI

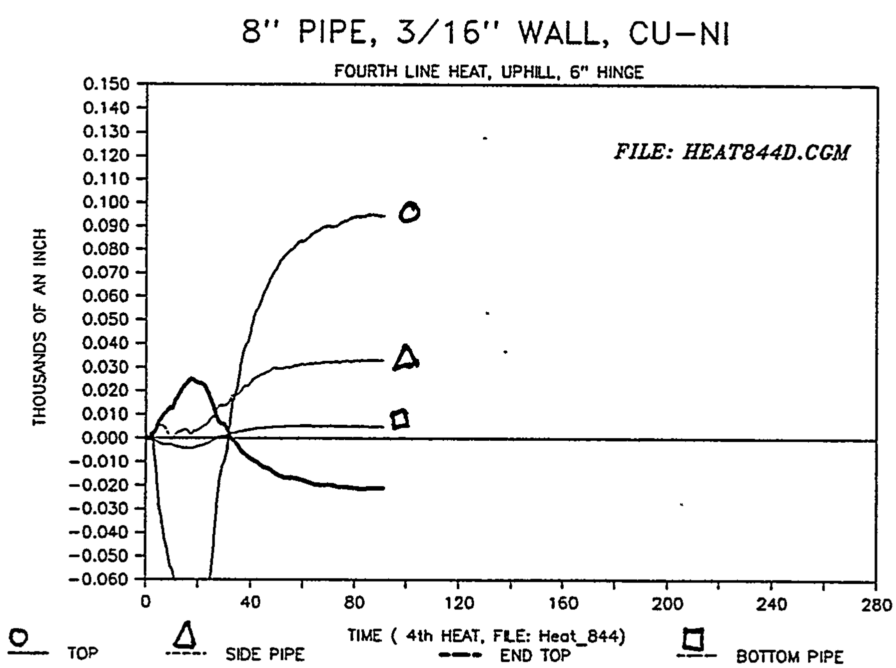
FOURTH LINE HEAT, UPHILL, 6" HINGE



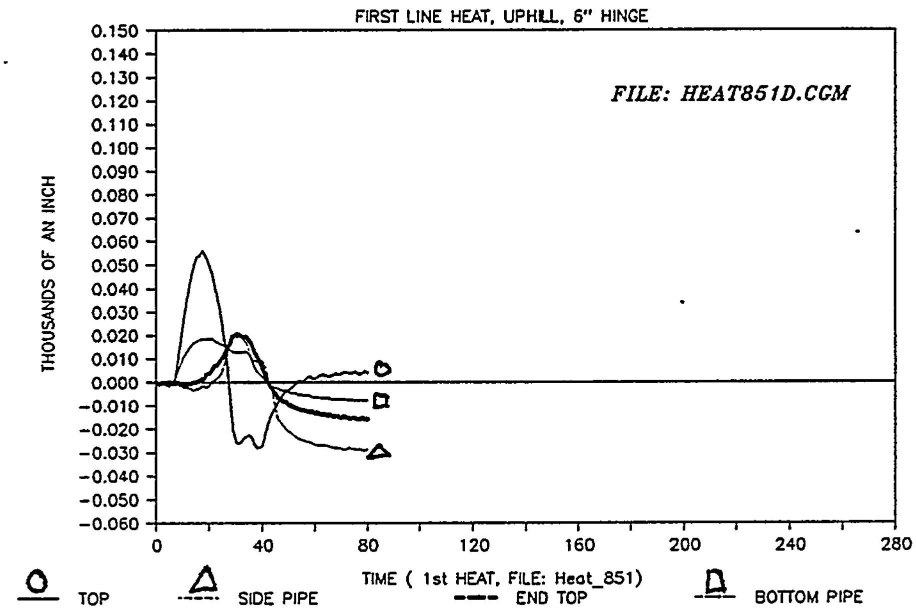

8" PIPE, 3/16" WALL, CU-NI
FIRST LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT841D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_841)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, CU-NI
SECOND LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT842D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_842)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

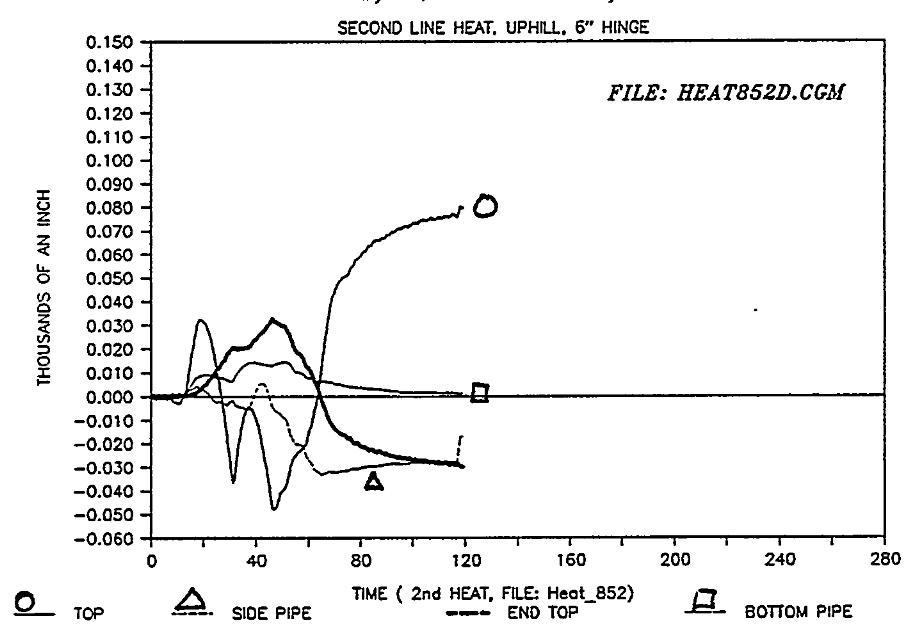

8" PIPE, 3/16" WALL, CU-NI
THIRD LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT843DF.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_843)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, CU-NI
FOURTH LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT844D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: Heat_844)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

8" PIPE, 3/16" WALL, CU-NI

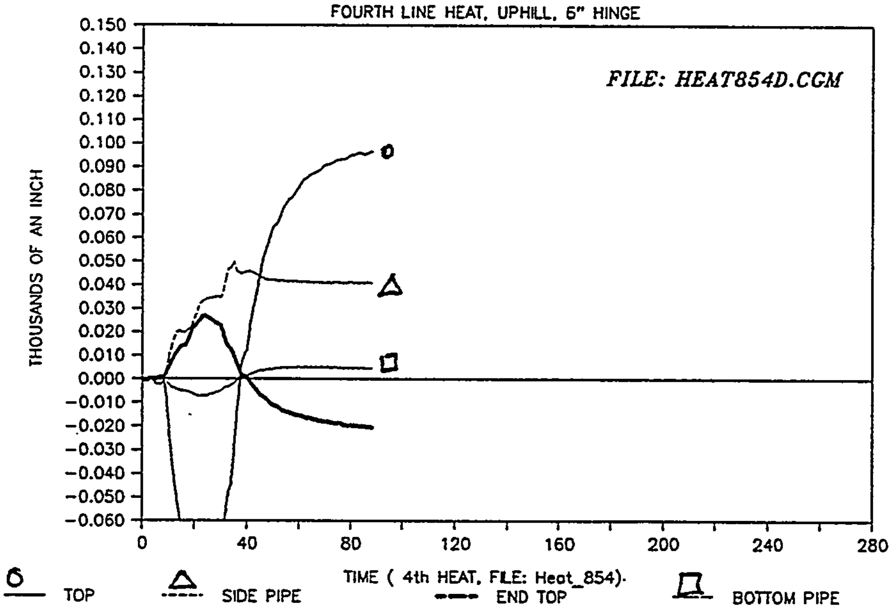


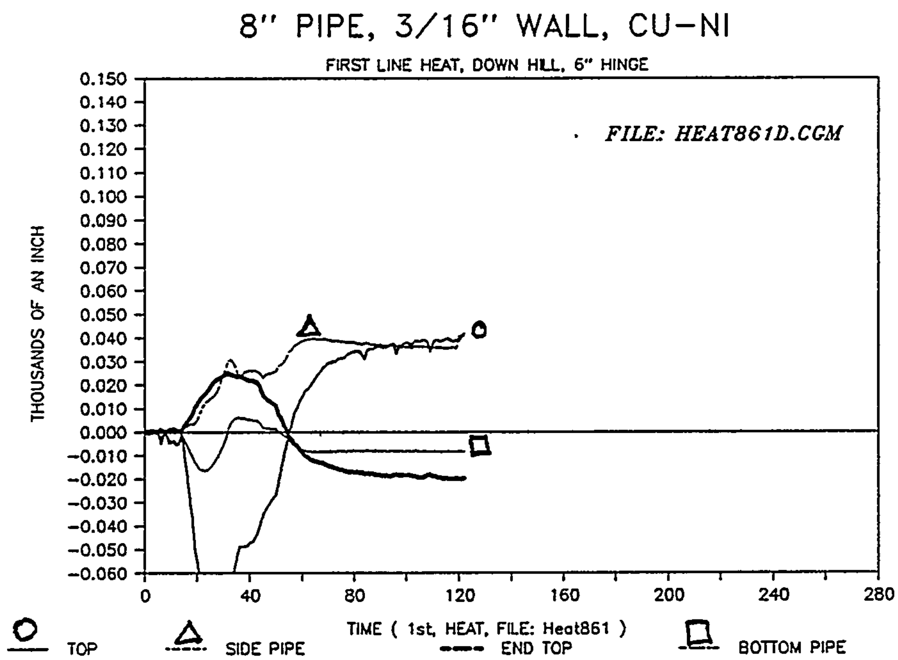
8" PIPE, 3/16" WALL, CU-NI

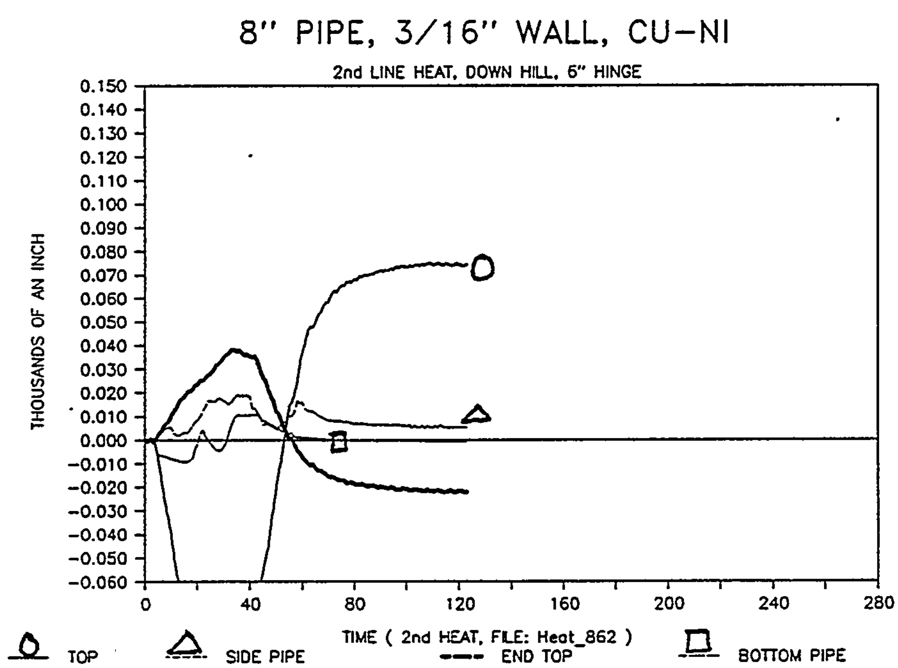


8" PIPE, 3/16" WALL, CU-NI

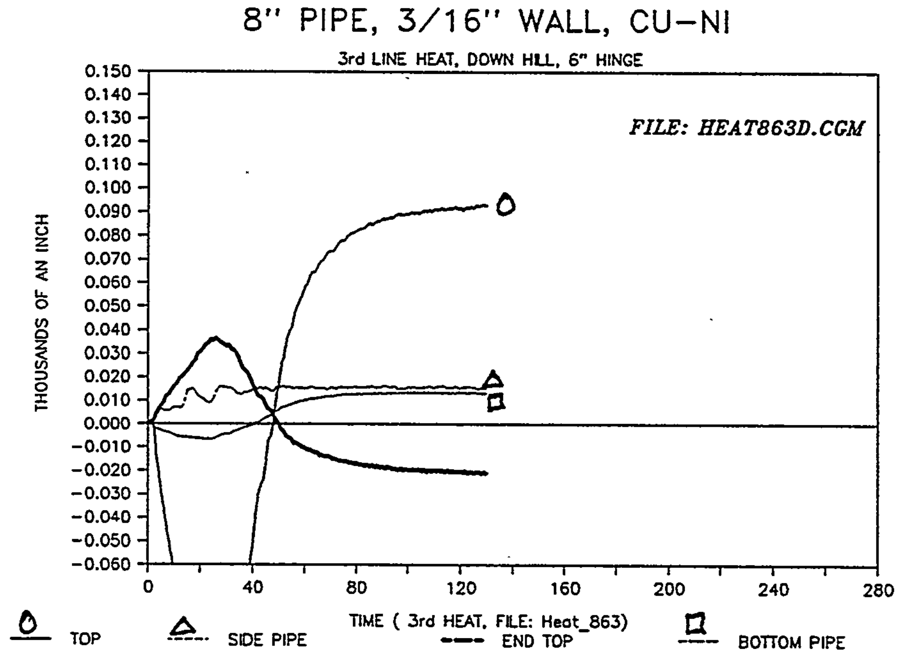
FOURTH LINE HEAT, UPHILL, 6" HINGE

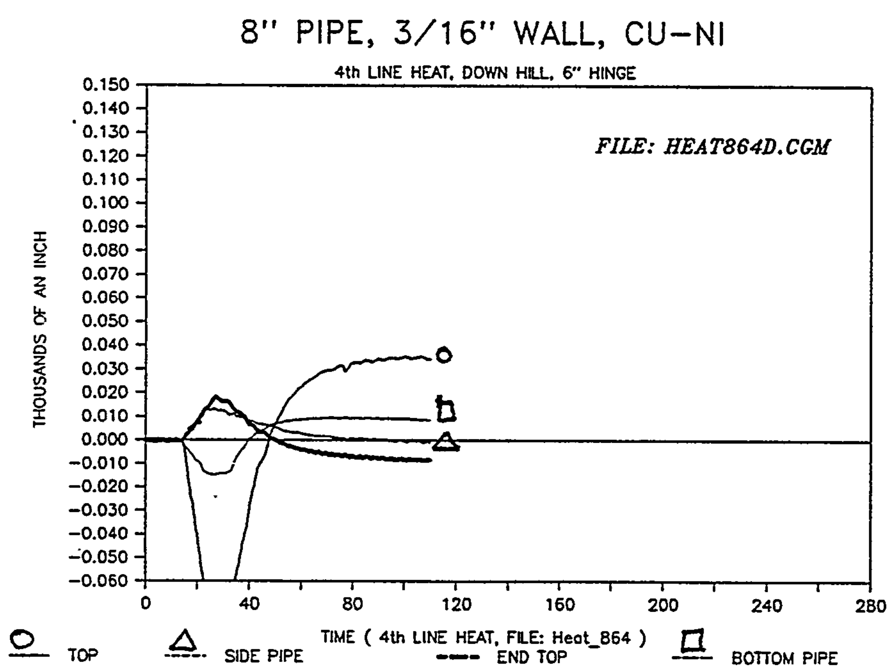



8" PIPE, 3/16" WALL, CU-NI
FIRST LINE HEAT, DOWN HILL, 6" HINGE
FILE: HEAT861D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st, HEAT, FILE: Heat861)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

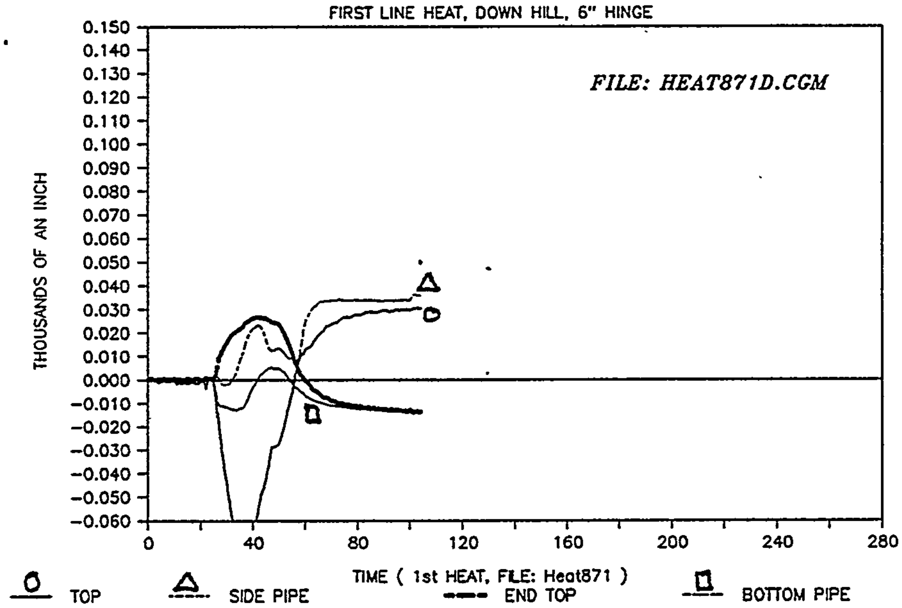

8" PIPE, 3/16" WALL, CU-NI
2nd LINE HEAT, DOWN HILL, 6" HINGE
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_862)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

APPENDIX C
FLAME BENDING GRAPHS

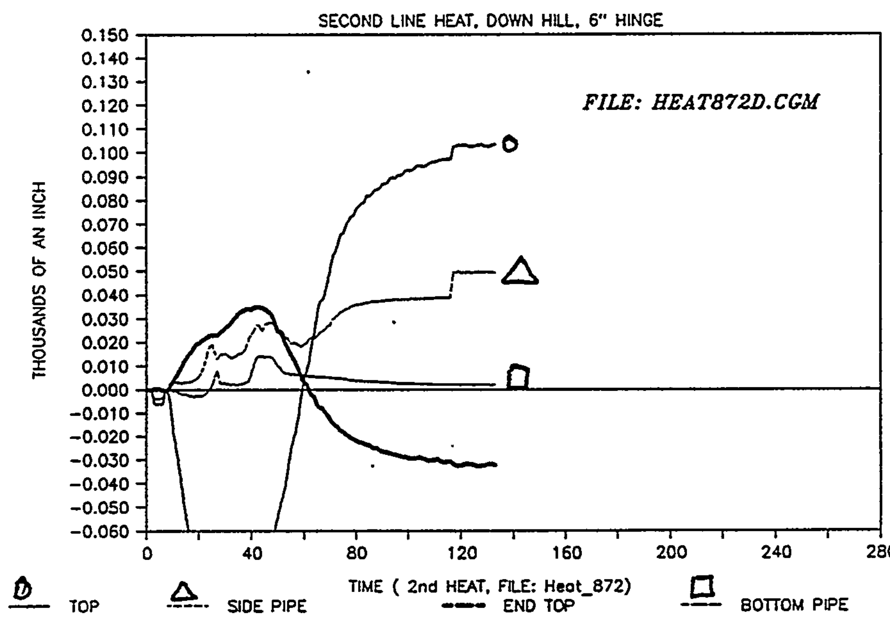


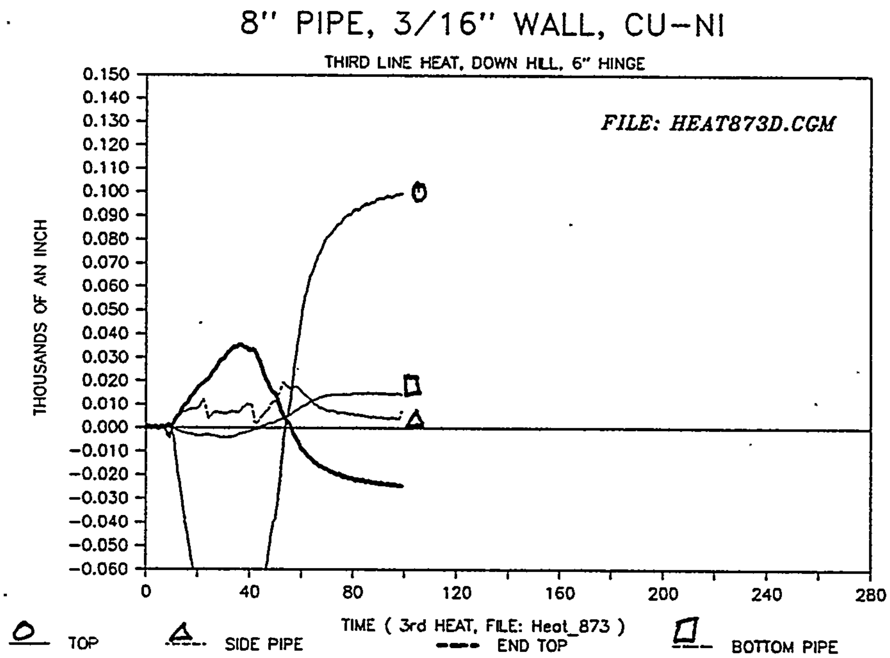


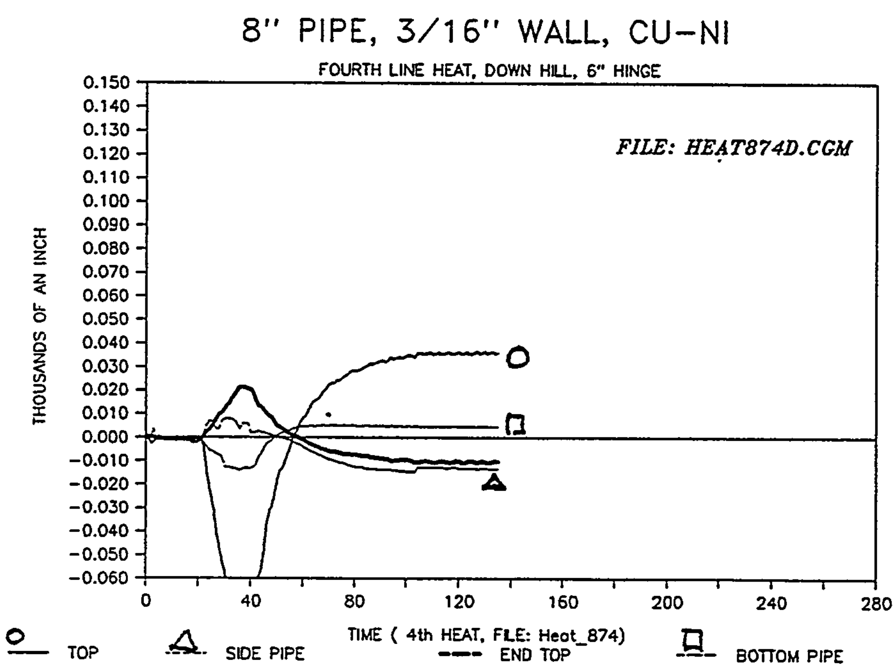
8" PIPE, 3/16" WALL, CU-NI

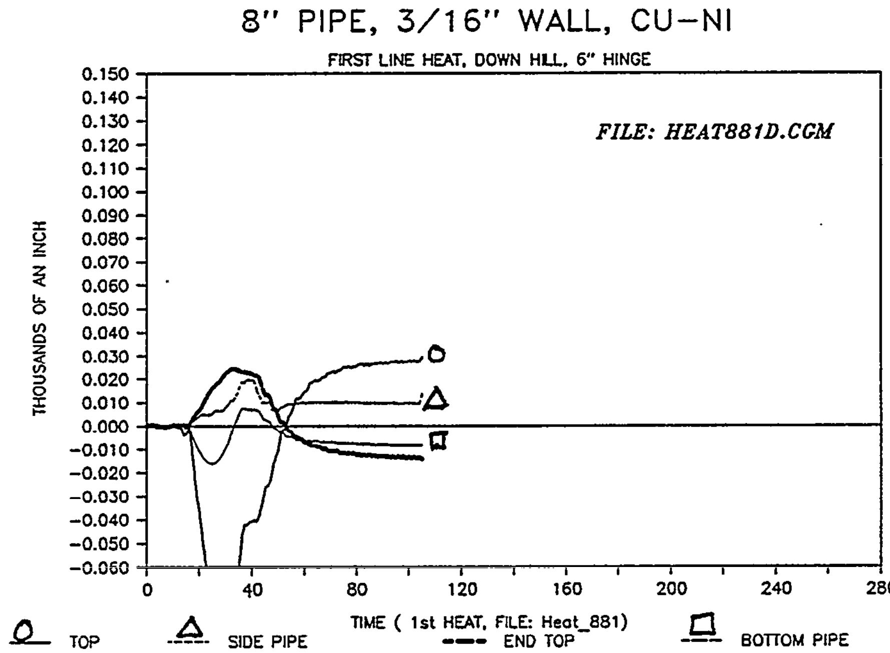


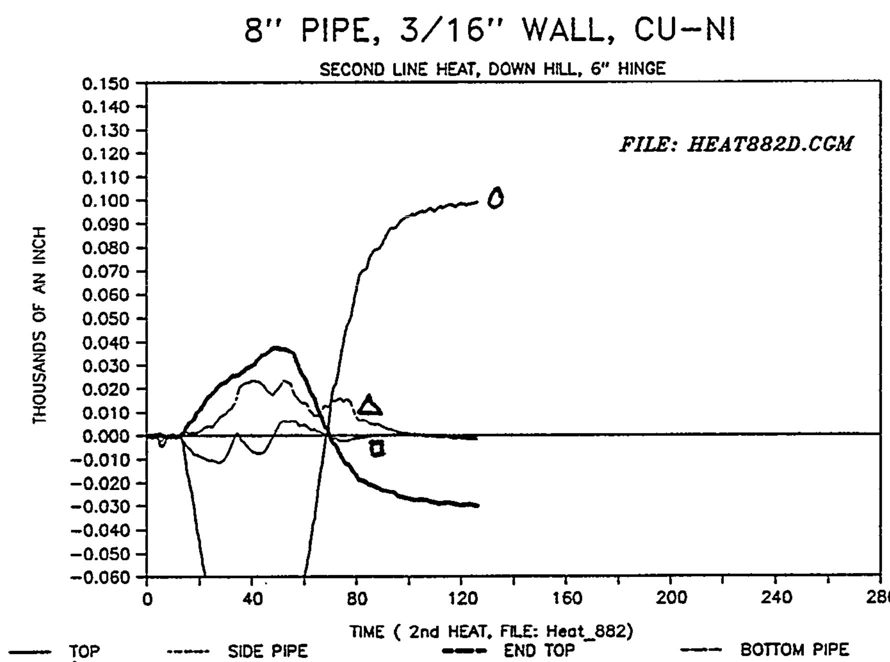
8" PIPE, 3/16" WALL, CU-NI

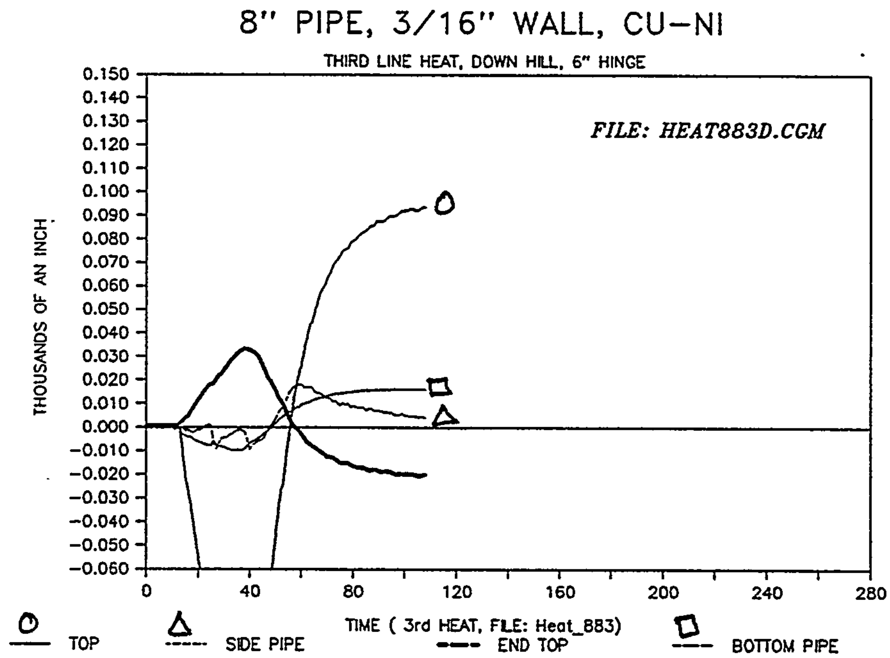


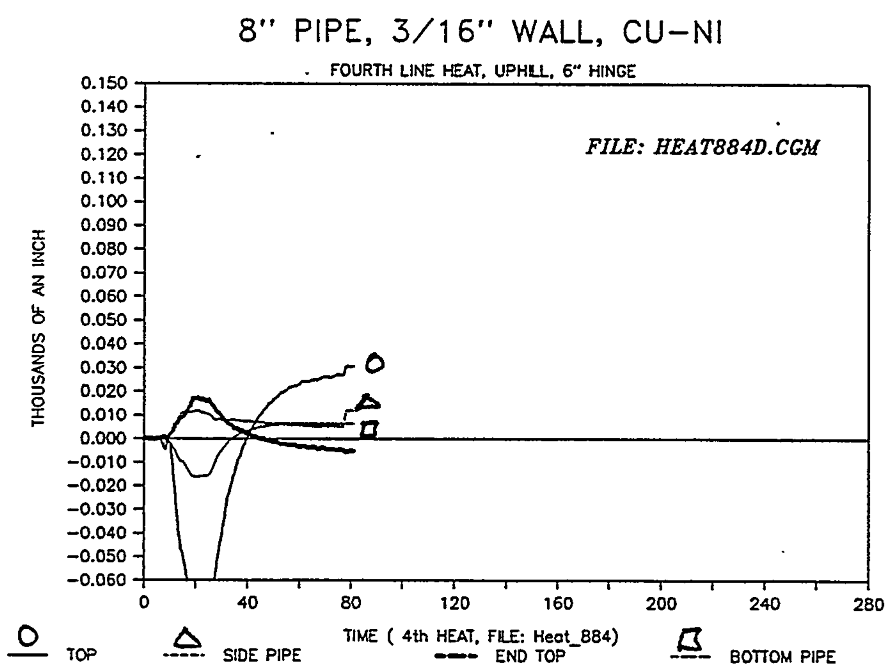

8" PIPE, 3/16" WALL, CU-NI
THIRD LINE HEAT, DOWN HILL, 6" HINGE
FILE: HEAT873D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_873)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, CU-NI
FOURTH LINE HEAT, DOWN HILL, 6" HINGE
FILE: HEAT874D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: Heat_874)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, CU-NI
FIRST LINE HEAT, DOWN HILL, 6" HINGE
FILE: HEAT881D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_881)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

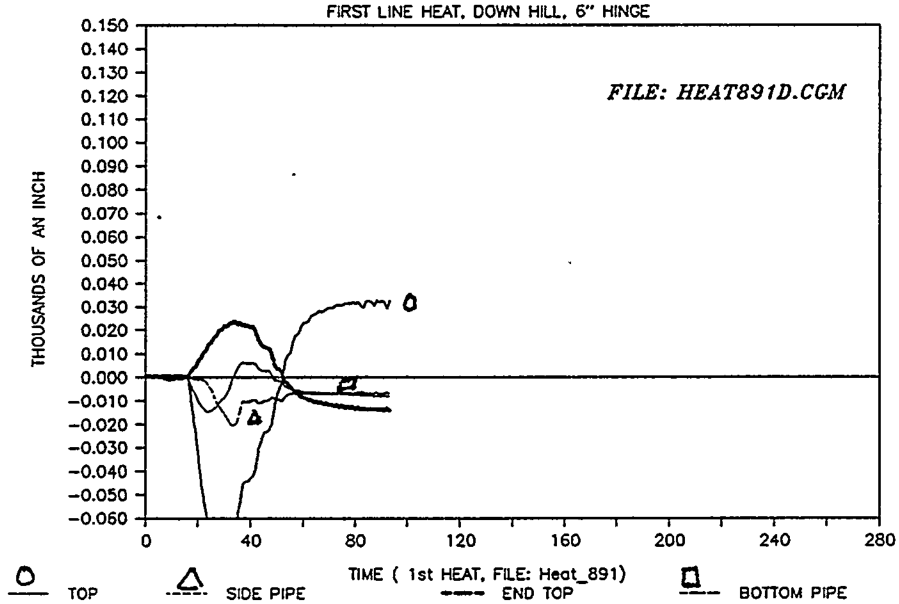

8" PIPE, 3/16" WALL, CU-NI
SECOND LINE HEAT, DOWN HILL, 6" HINGE
FILE: HEAT882D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_882)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, CU-NI
THIRD LINE HEAT, DOWN HILL, 6" HINGE
FILE: HEAT883D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_883)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, CU-NI
FOURTH LINE HEAT, UPHILL, 6" HINGE
FILE: HEAT884D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: Heat_884)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

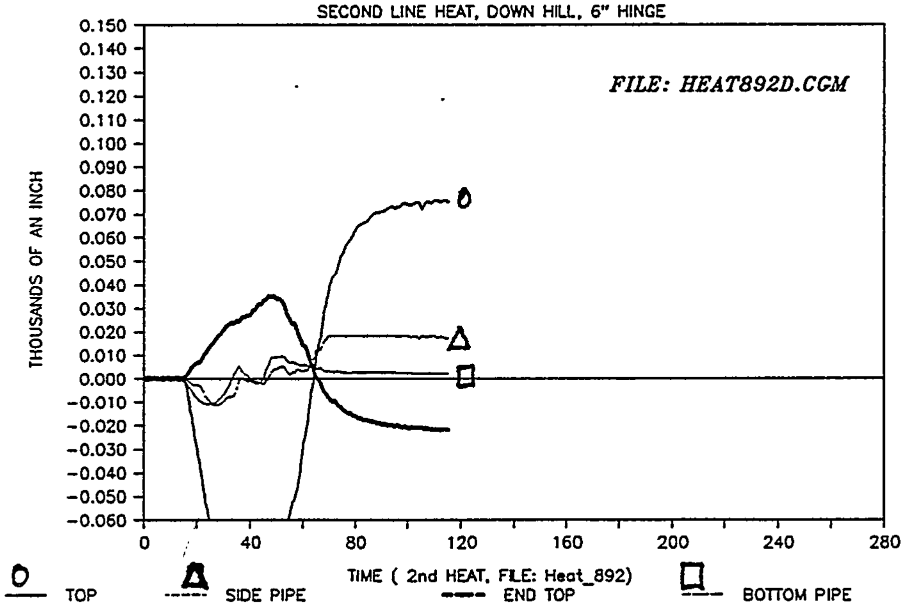
8" PIPE, 3/16" WALL, CU-NI

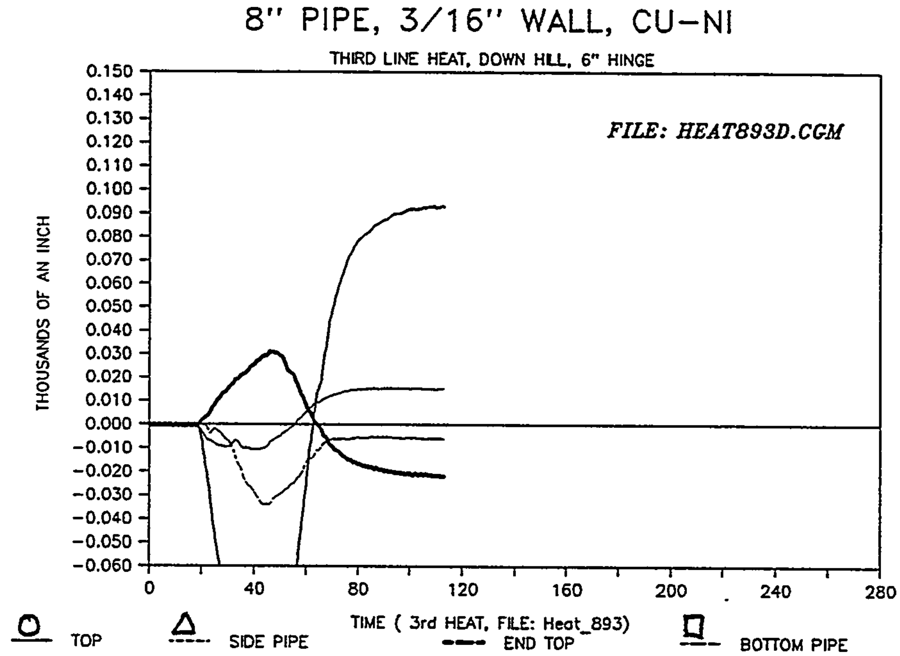
FIRST LINE HEAT, DOWN HILL, 6" HINGE

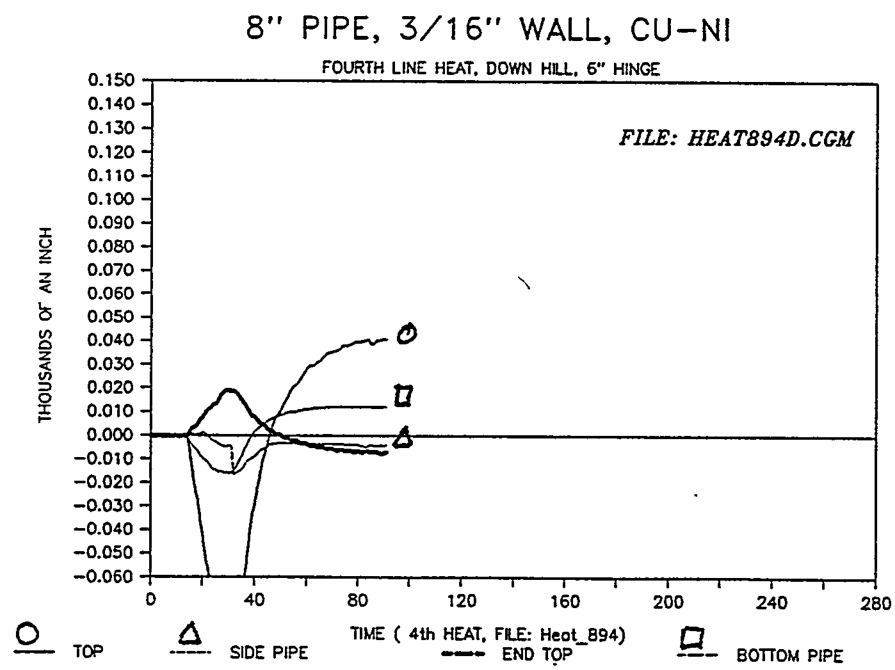


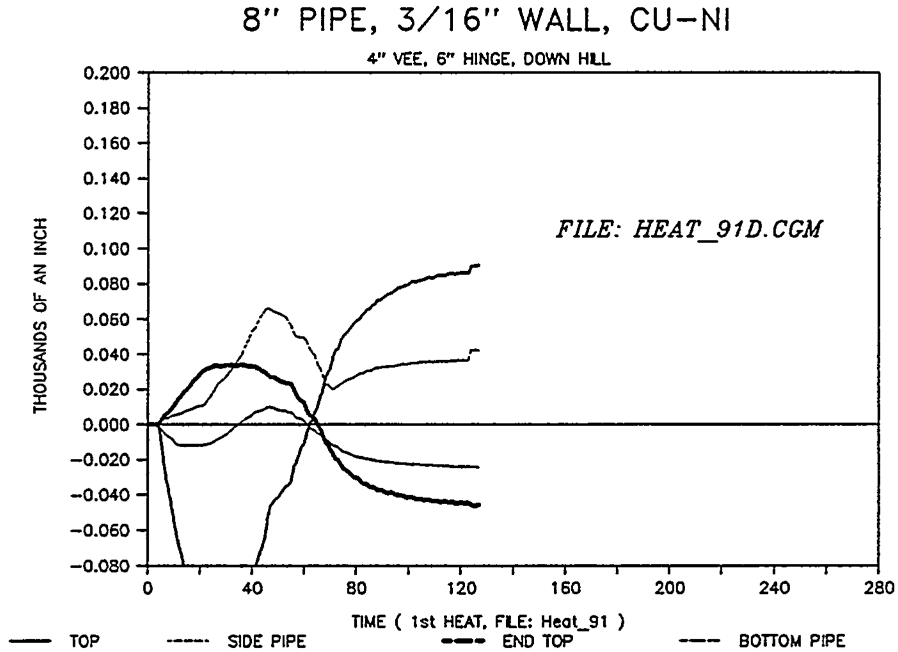
8" PIPE, 3/16" WALL, CU-NI

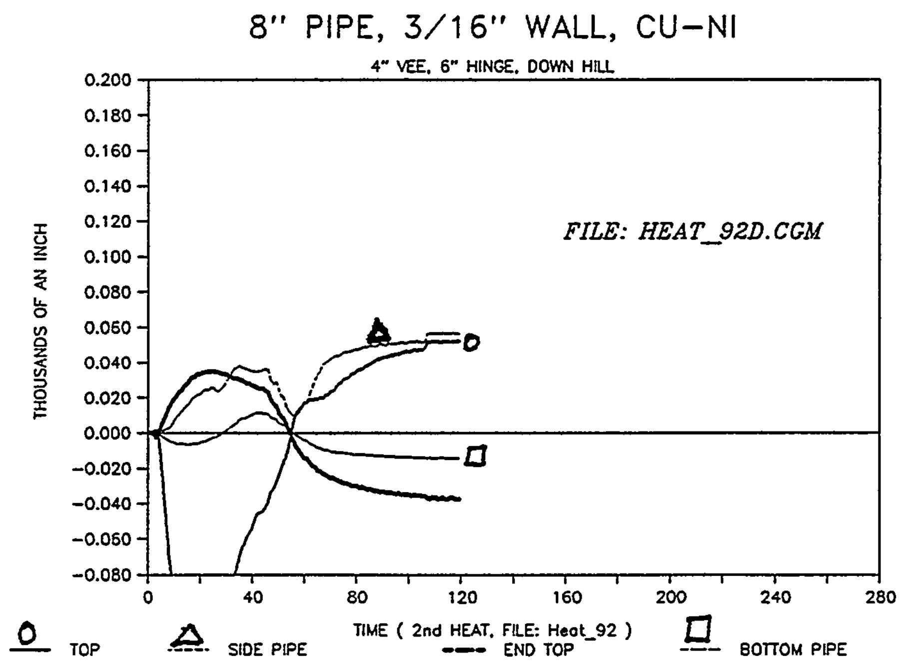
SECOND LINE HEAT, DOWN HILL, 6" HINGE

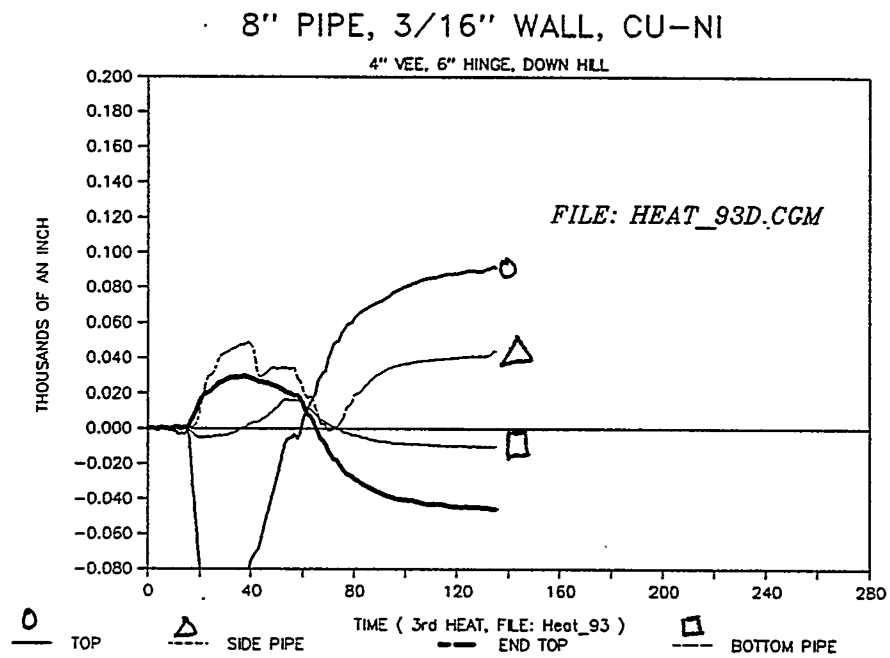


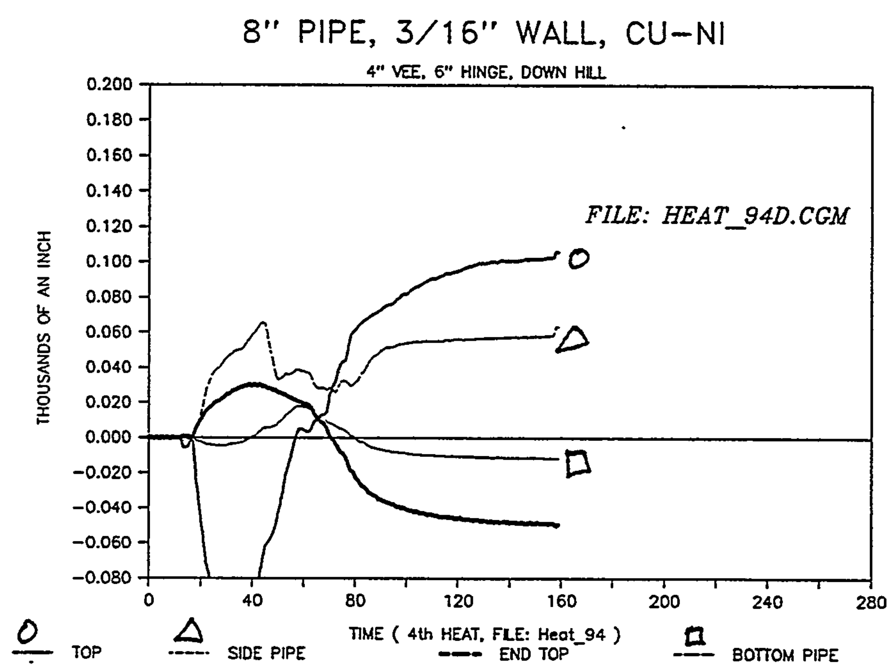

8" PIPE, 3/16" WALL, CU-NI
THIRD LINE HEAT, DOWN HILL, 6" HINGE
FILE: HEAT893D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_893)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

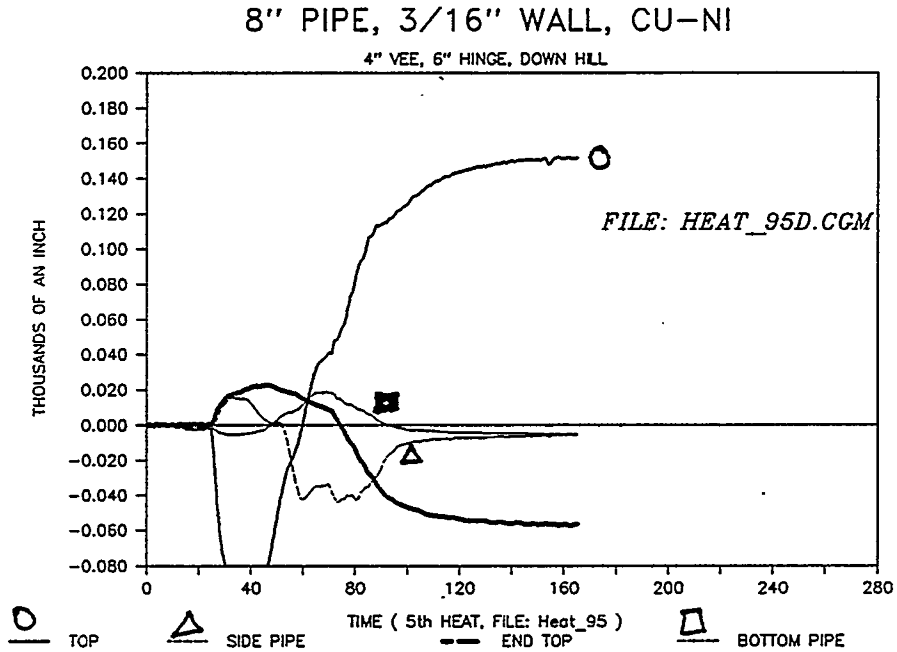

8" PIPE, 3/16" WALL, CU-NI
FOURTH LINE HEAT, DOWN HILL, 6" HINGE
FILE: HEAT894D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: Heat_894)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

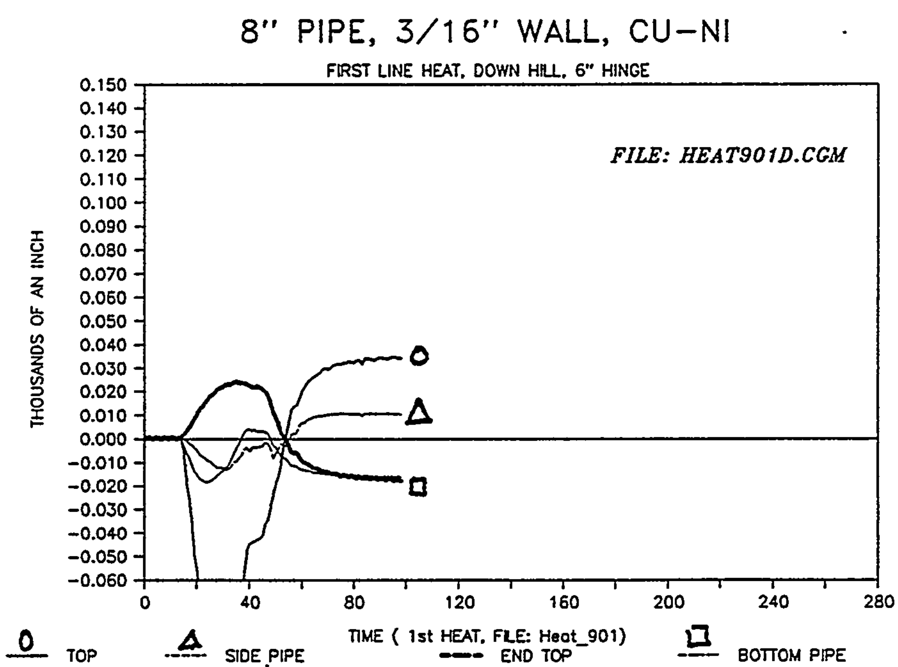

8" PIPE, 3/16" WALL, CU-NI
4" VEE, 6" HINGE, DOWN HILL
FILE: HEAT_91D.CGM
THOUSANDS OF AN INCH
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_91)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, CU-NI
4" VEE, 6" HINGE, DOWN HILL
FILE: HEAT_92D.CGM
THOUSANDS OF AN INCH
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_92)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

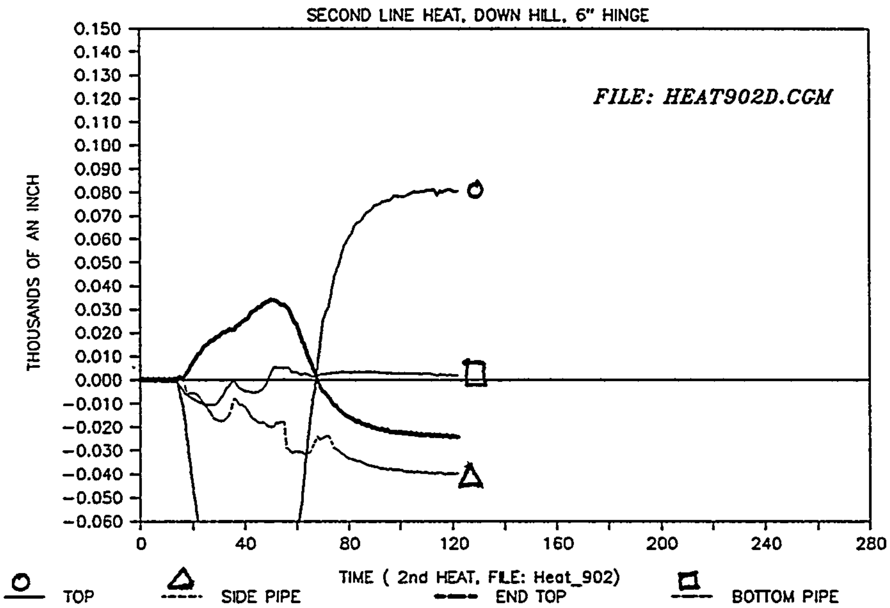

8" PIPE, 3/16" WALL, CU-NI
4" VEE, 6" HINGE, DOWN HILL
FILE: HEAT_93D.CGM
THOUSANDS OF AN INCH
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_93)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, CU-NI
4" VEE, 6" HINGE, DOWN HILL
FILE: HEAT_94D.CGM
THOUSANDS OF AN INCH
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: Heat_94)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

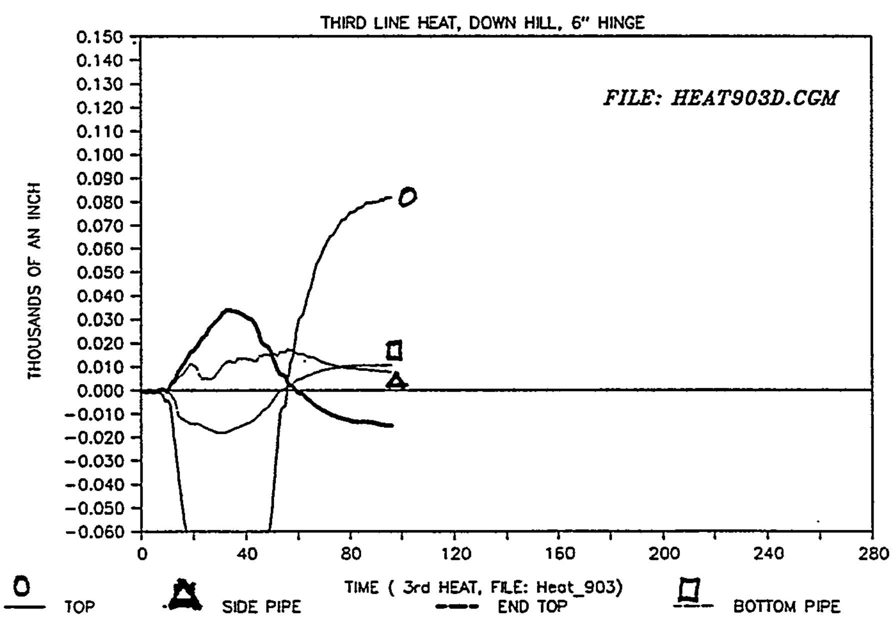

8" PIPE, 3/16" WALL, CU-NI
4" VEE, 6" HINGE, DOWN HILL
THOUSANDS OF AN INCH
FILE: HEAT_95D.CGM
TIME (5th HEAT, FILE: Heat_95)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

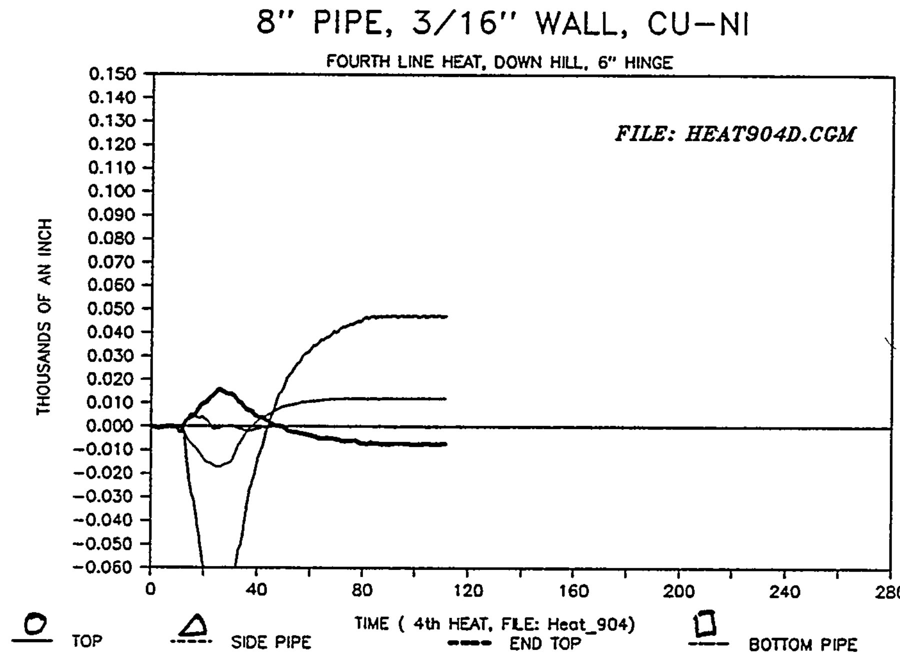

8" PIPE, 3/16" WALL, CU-NI
FIRST LINE HEAT, DOWN HILL, 6" HINGE
THOUSANDS OF AN INCH
FILE: HEAT901D.CGM
TIME (1st HEAT, FILE: Heat_901)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

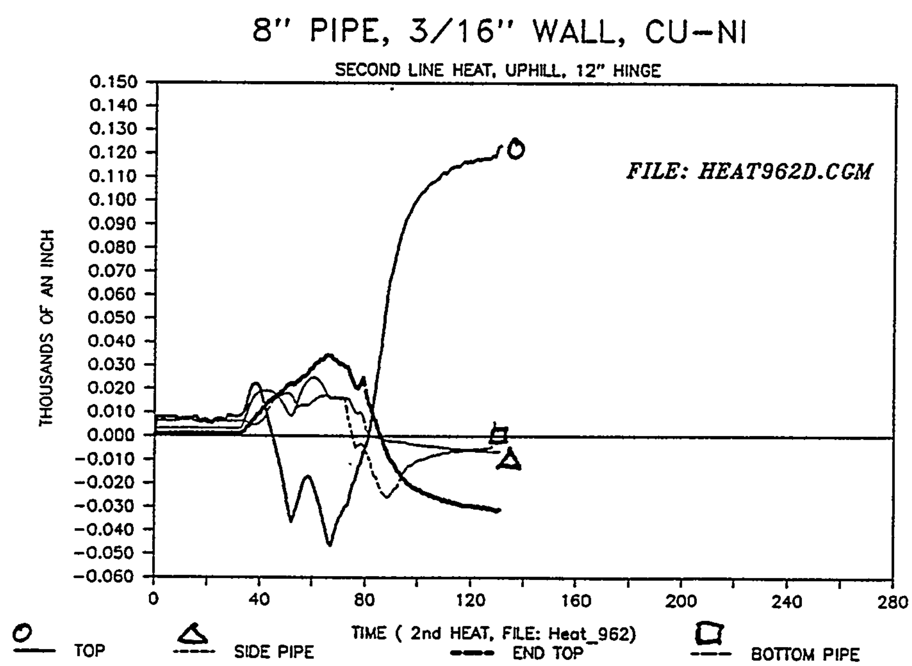
8" PIPE, 3/16" WALL, CU-NI

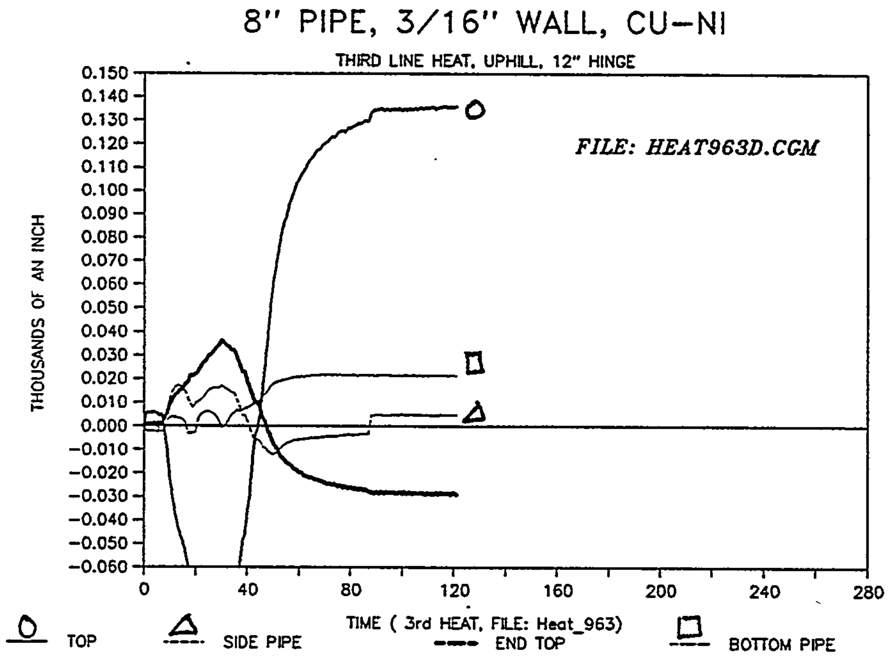


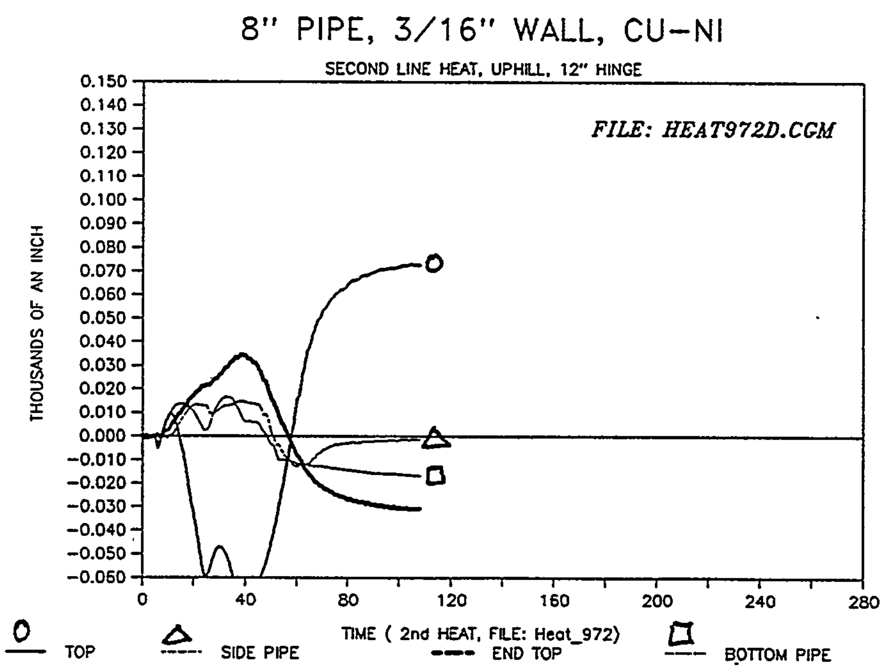
8" PIPE, 3/16" WALL, CU-NI

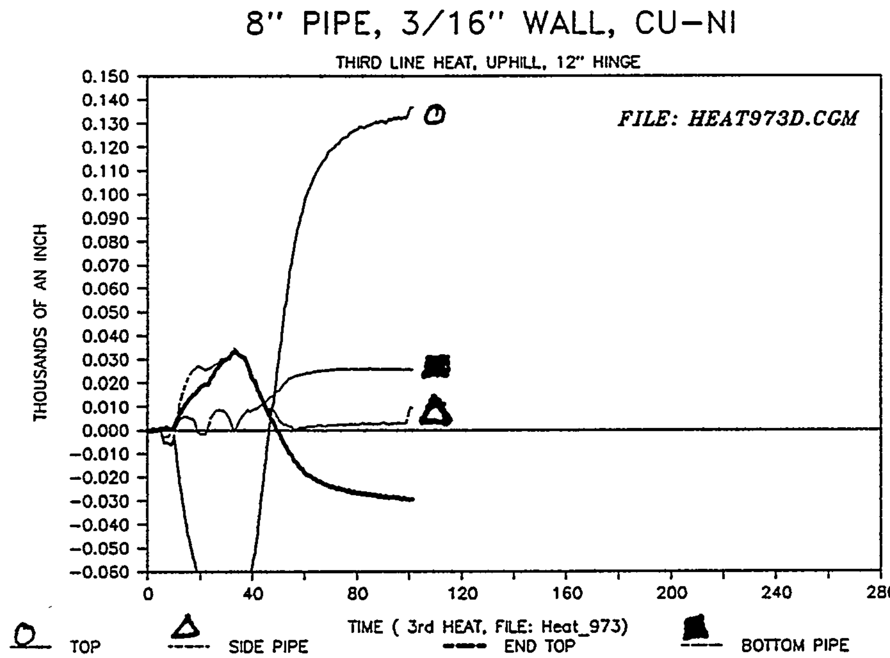


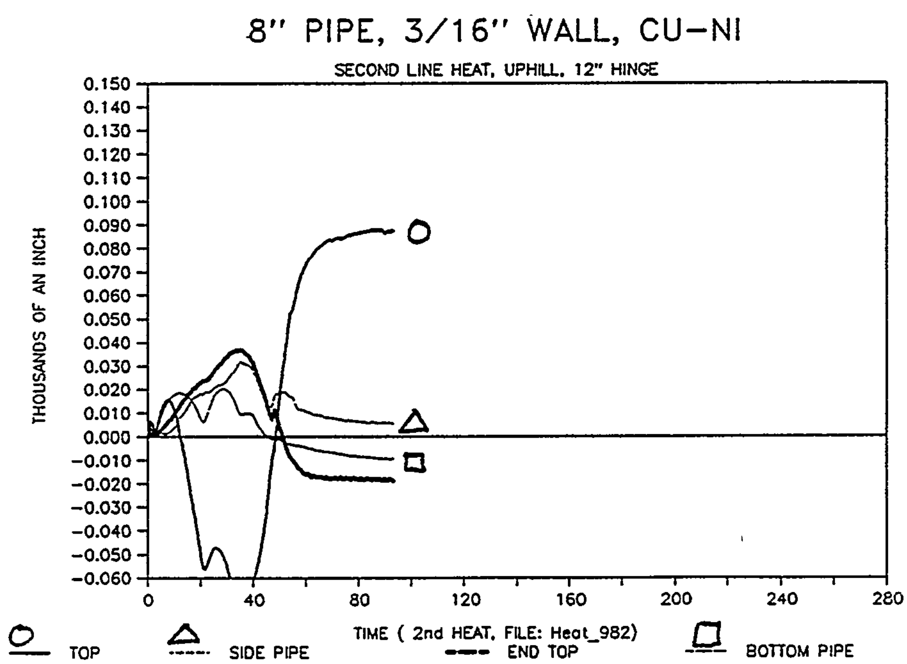

8" PIPE, 3/16" WALL, CU-NI
FOURTH LINE HEAT, DOWN HILL, 6" HINGE
FILE: HEAT904D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: Heat_904)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

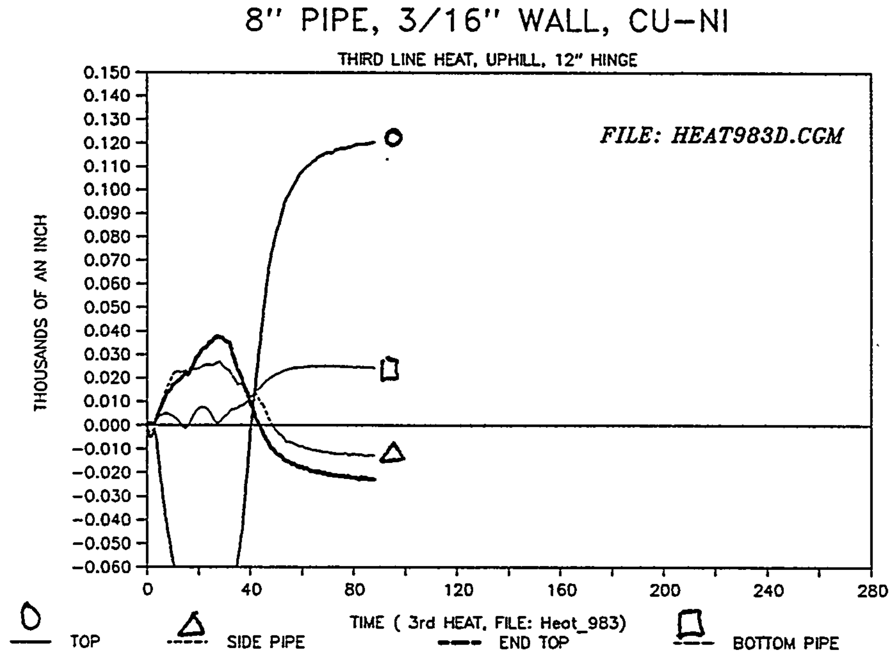

8" PIPE, 3/16" WALL, CU-NI
SECOND LINE HEAT, UPHILL, 12" HINGE
FILE: HEAT962D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_962)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

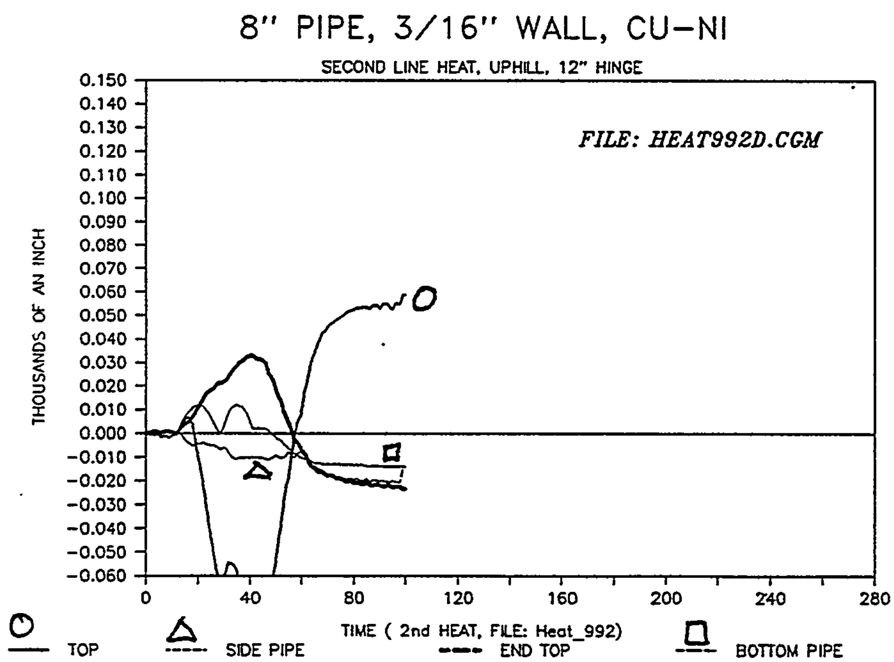

8" PIPE, 3/16" WALL, CU-NI
THIRD LINE HEAT, UPHILL, 12" HINGE
FILE: HEAT963D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_963)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

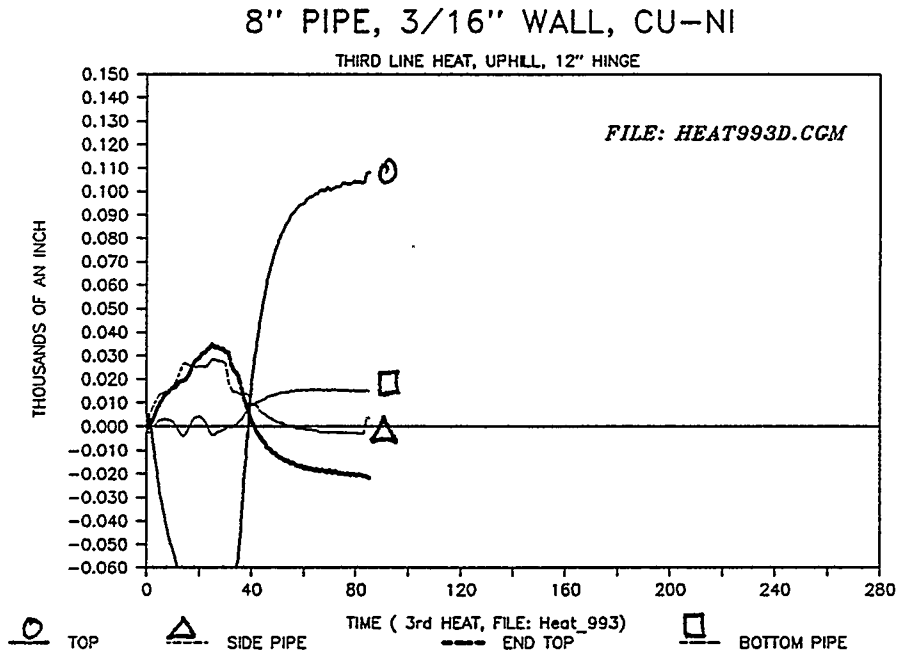

8" PIPE, 3/16" WALL, CU-NI
SECOND LINE HEAT, UPHILL, 12" HINGE
FILE: HEAT972D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_972)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

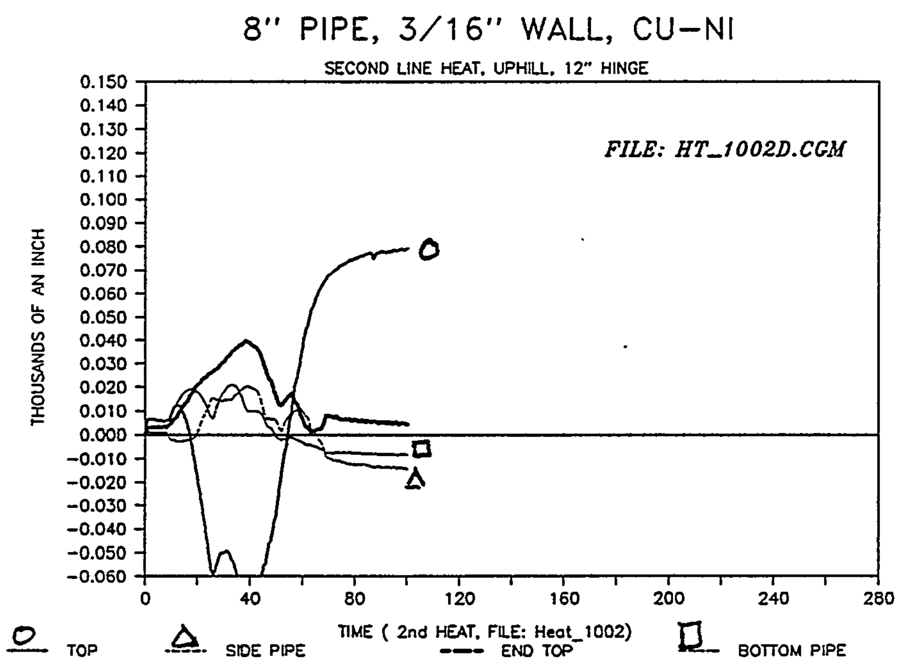

8" PIPE, 3/16" WALL, CU-NI
THIRD LINE HEAT, UPHILL, 12" HINGE
FILE: HEAT973D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_973)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

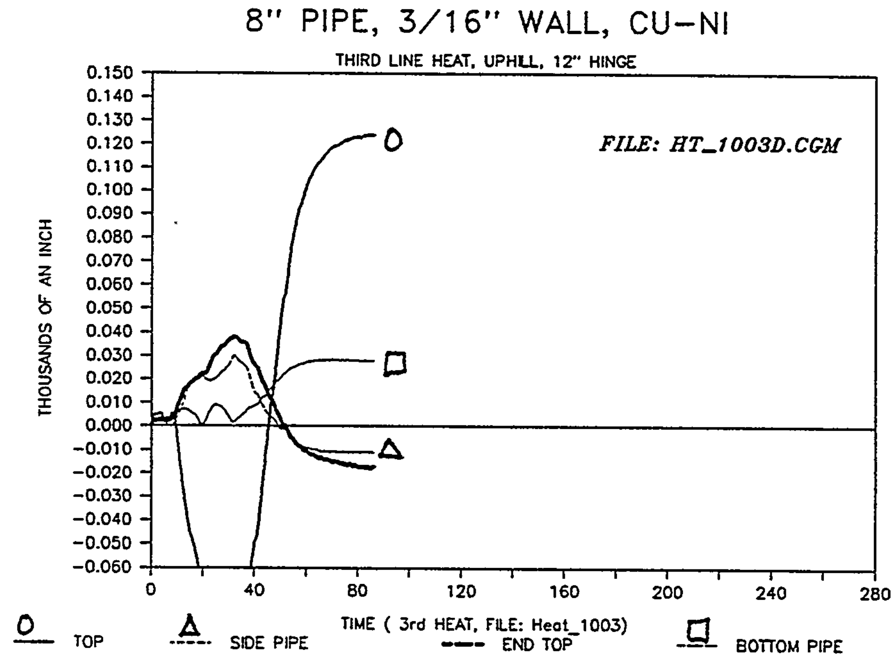

8" PIPE, 3/16" WALL, CU-NI
SECOND LINE HEAT, UPHILL, 12" HINGE
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_982)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

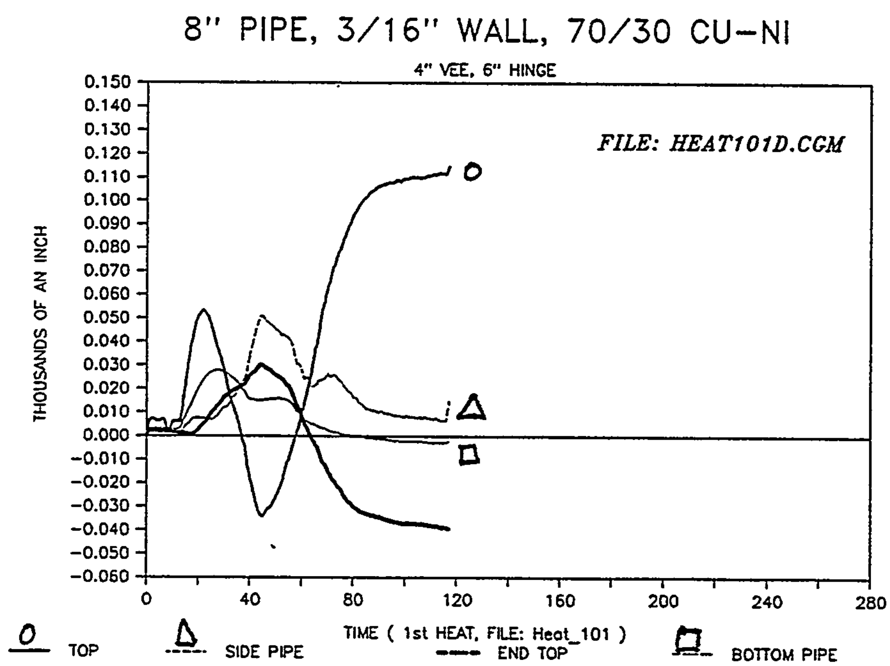

8" PIPE, 3/16" WALL, CU-NI
THIRD LINE HEAT, UPHILL, 12" HINGE
FILE: HEAT983D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_983)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

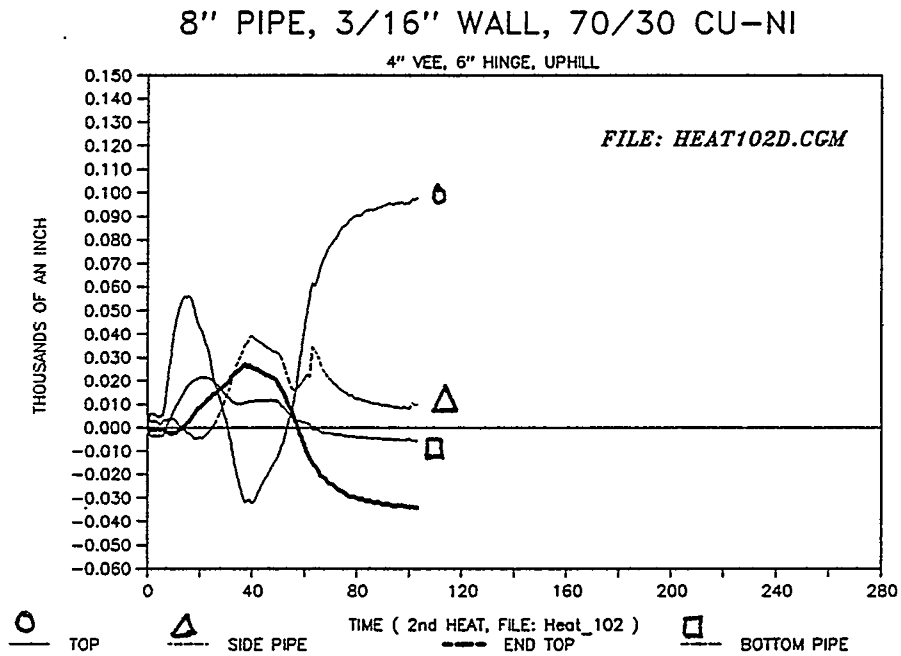

8" PIPE, 3/16" WALL, CU-NI
SECOND LINE HEAT, UPHILL, 12" HINGE
FILE: HEAT992D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_992)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

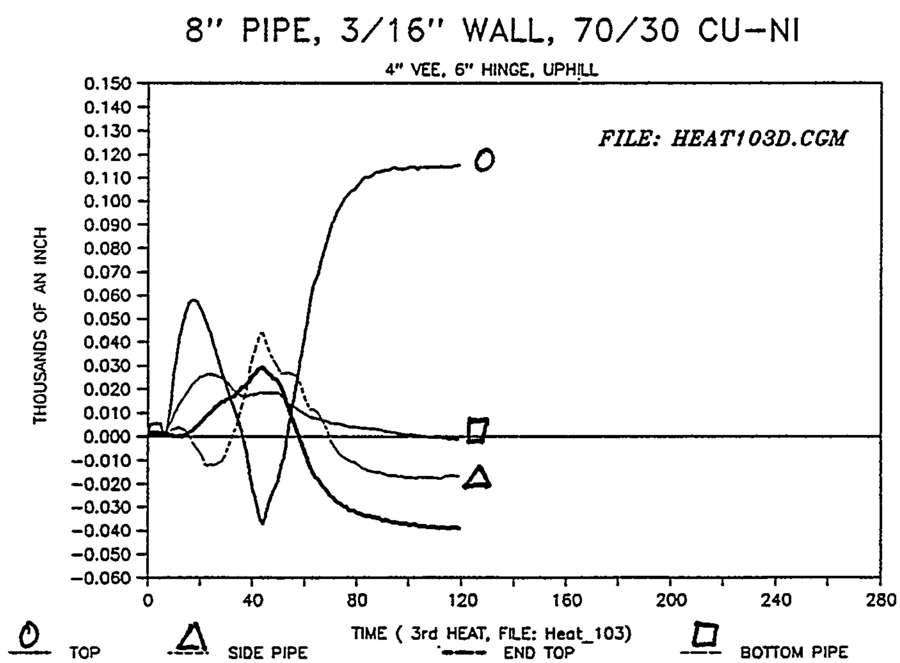

8" PIPE, 3/16" WALL, CU-NI
THIRD LINE HEAT, UPHILL, 12" HINGE
FILE: HEAT993D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_993)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

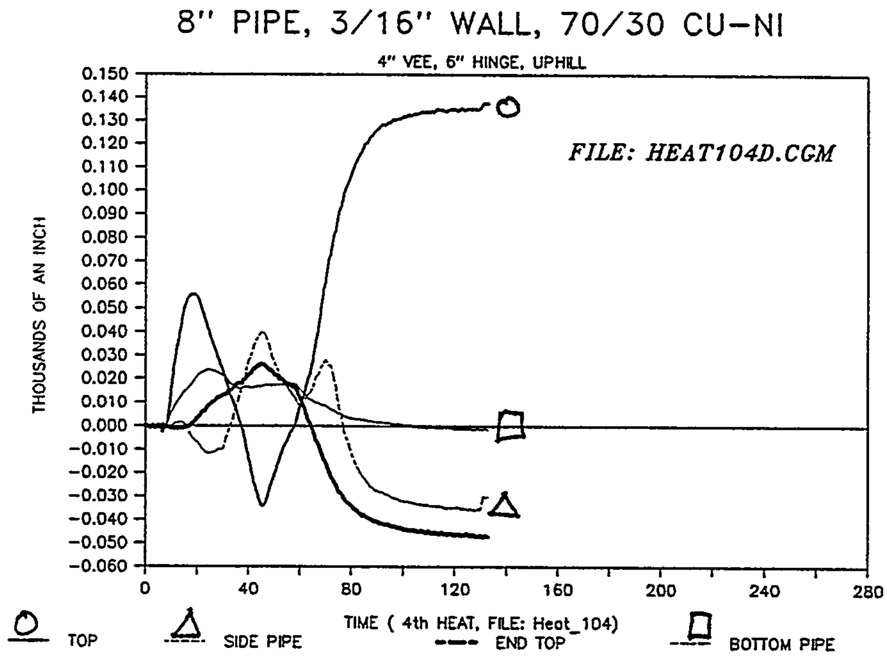

8" PIPE, 3/16" WALL, CU-NI
SECOND LINE HEAT, UPHILL, 12" HINGE
FILE: HT_1002D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_1002)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

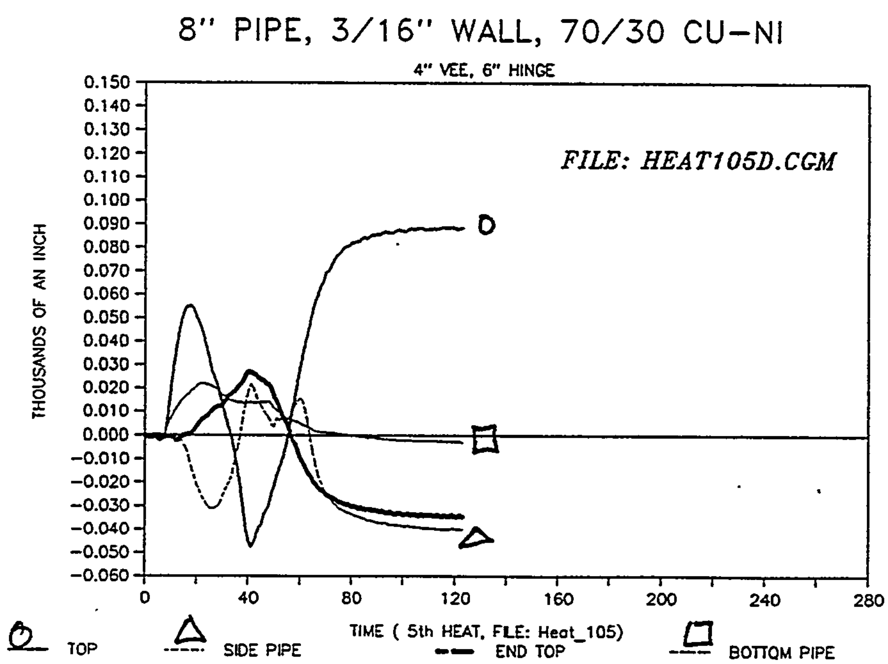

8" PIPE, 3/16" WALL, CU-NI
THIRD LINE HEAT, UPHILL, 12" HINGE
FILE: HT_1003D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_1003)
O TOP
Δ SIDE PIPE
END TOP
□ BOTTOM PIPE

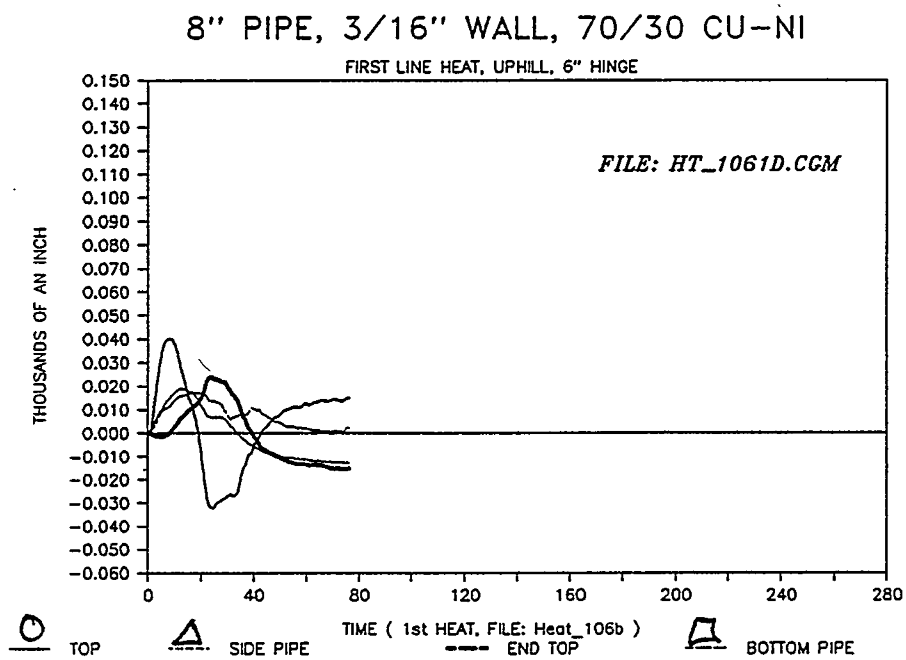

8" PIPE, 3/16" WALL, 70/30 CU-NI
4" VEE, 6" HINGE
FILE: HEAT101D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_101)
O TOP
Δ SIDE PIPE
END TOP
□ BOTTOM PIPE

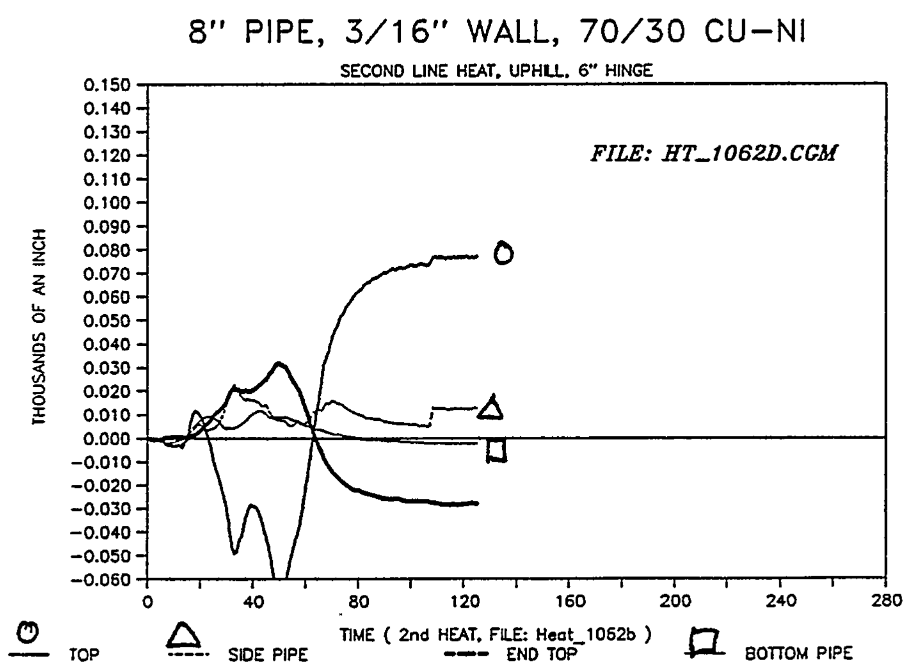

8" PIPE, 3/16" WALL, 70/30 CU-NI
4" VEE, 6" HINGE, UPHILL
FILE: HEAT102D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_102)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

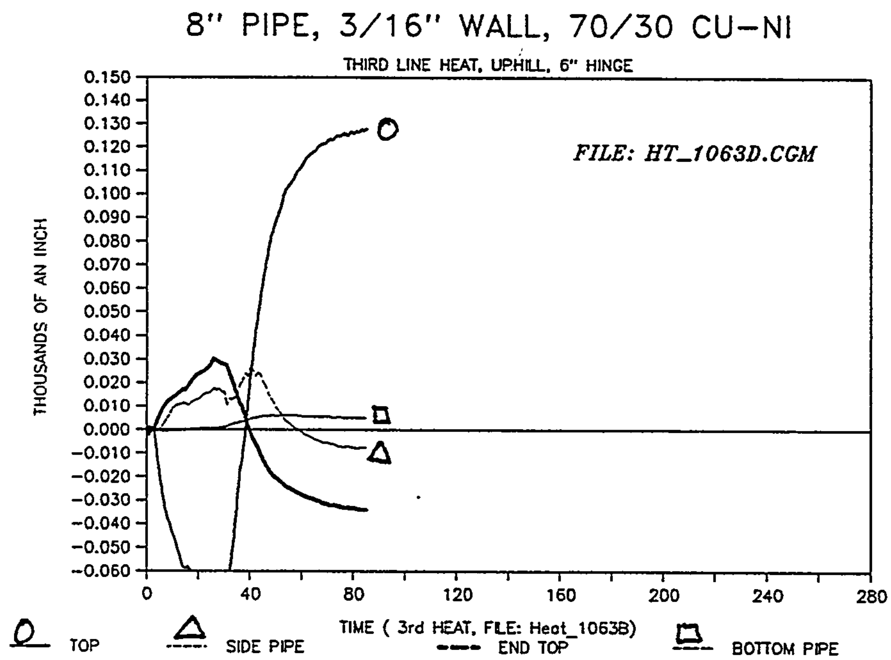

8" PIPE, 3/16" WALL, 70/30 CU-NI
4" VEE, 6" HINGE, UPHILL
FILE: HEAT103D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_103)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

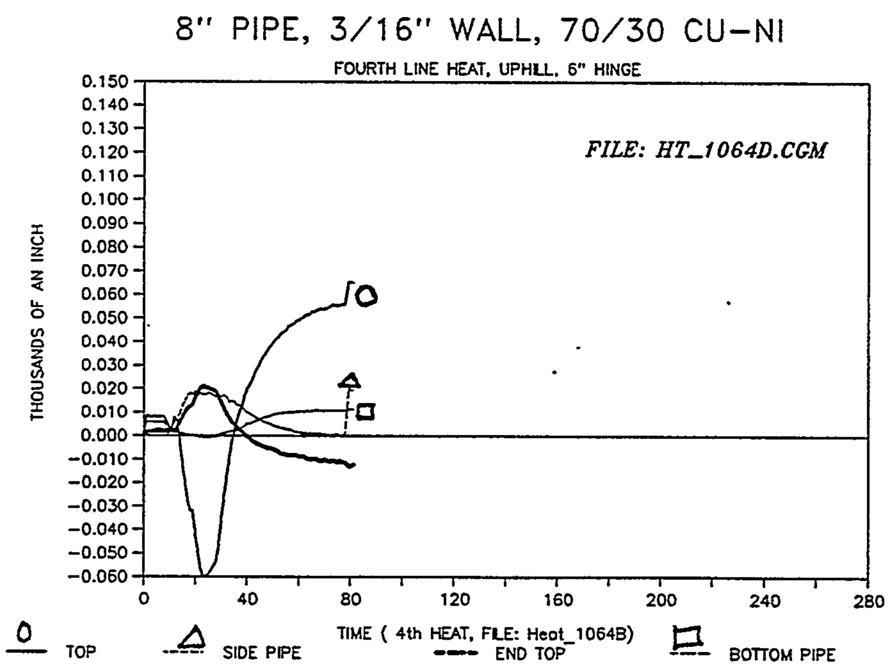

8" PIPE, 3/16" WALL, 70/30 CU-NI
4" VEE, 6" HINGE, UPHILL
FILE: HEAT104D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: Heat_104)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

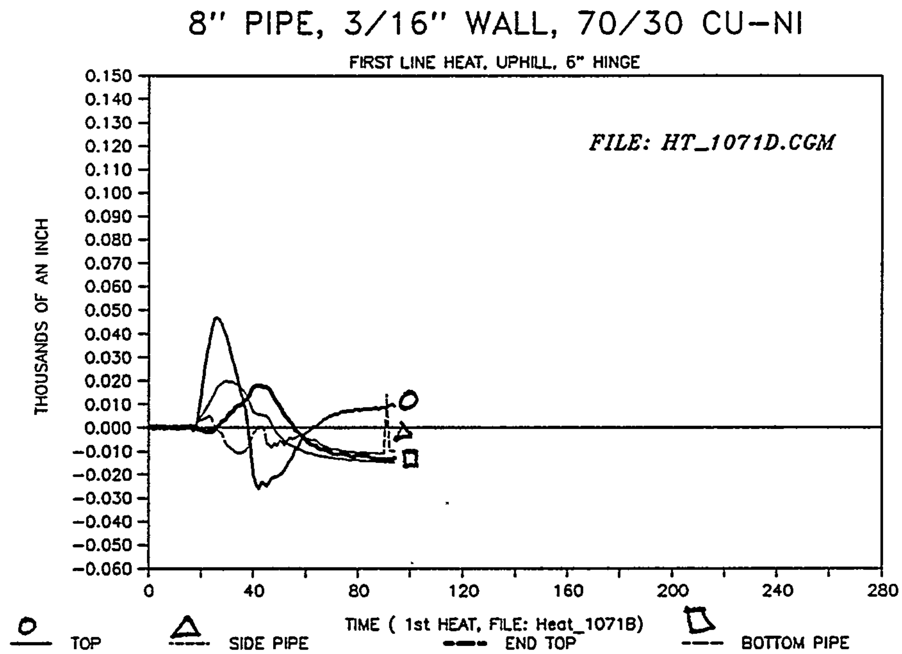

8" PIPE, 3/16" WALL, 70/30 CU-NI
4" VEE, 6" HINGE
FILE: HEAT105D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (5th HEAT, FILE: Heat_105)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

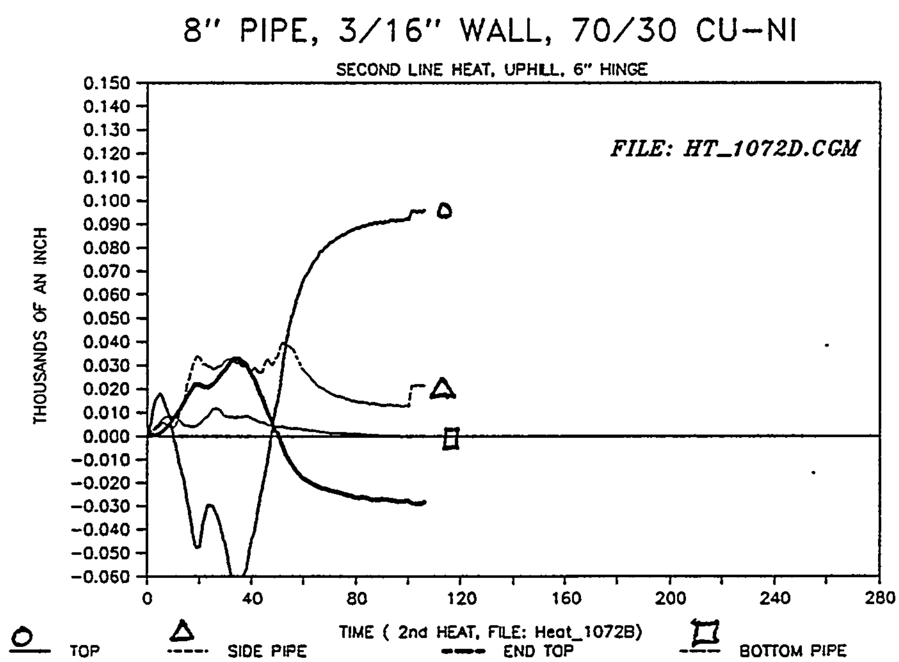

8" PIPE, 3/16" WALL, 70/30 CU-NI
FIRST LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1061D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
−0.010
−0.020
−0.030
−0.040
−0.050
−0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_106b)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

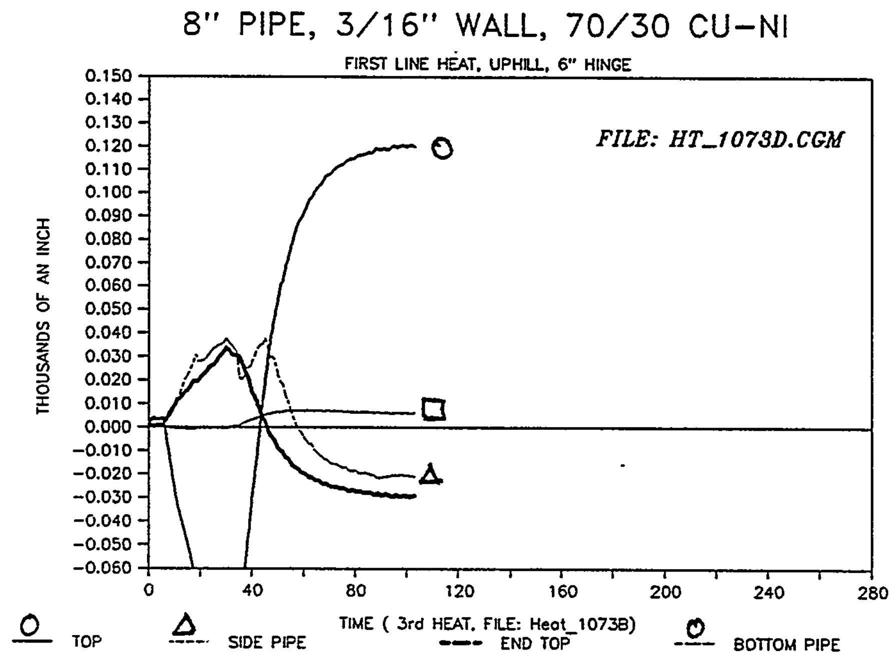

8" PIPE, 3/16" WALL, 70/30 CU-NI
SECOND LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1062D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
−0.010
−0.020
−0.030
−0.040
−0.050
−0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_1062b)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

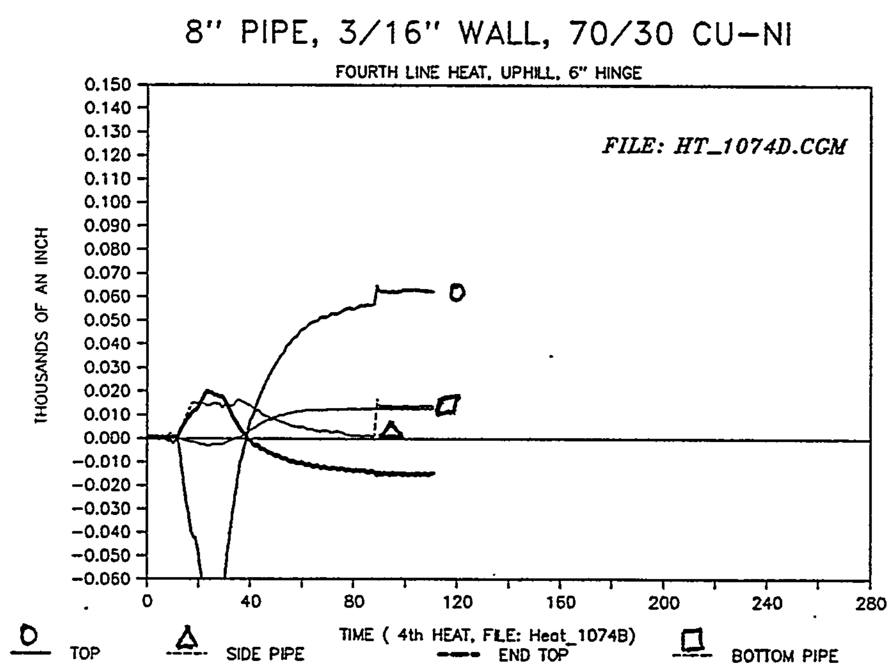

8" PIPE, 3/16" WALL, 70/30 CU-NI
THIRD LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1063D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_1063B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

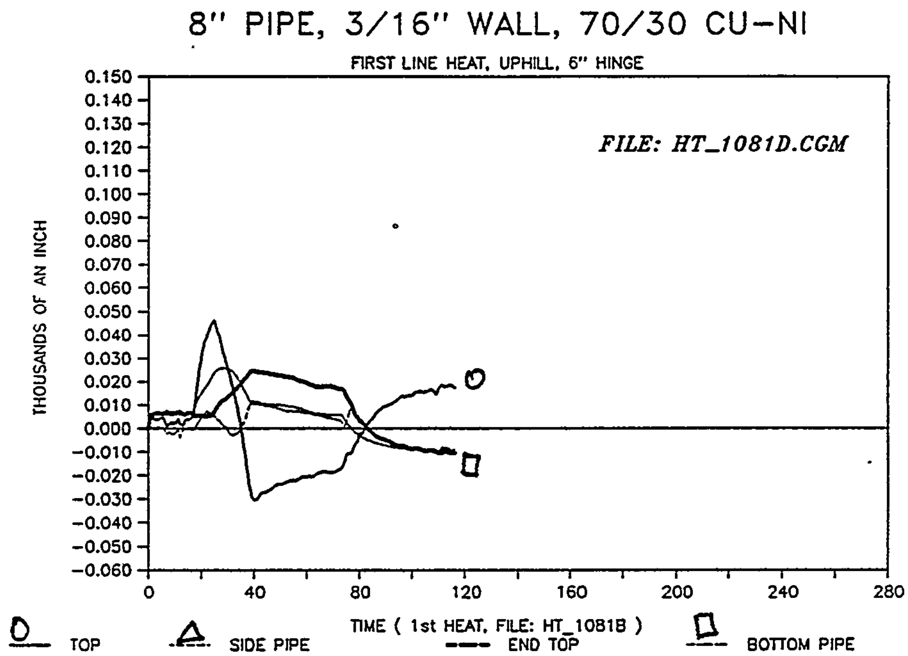

8" PIPE, 3/16" WALL, 70/30 CU-NI
FOURTH LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1064D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: Heat_1064B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

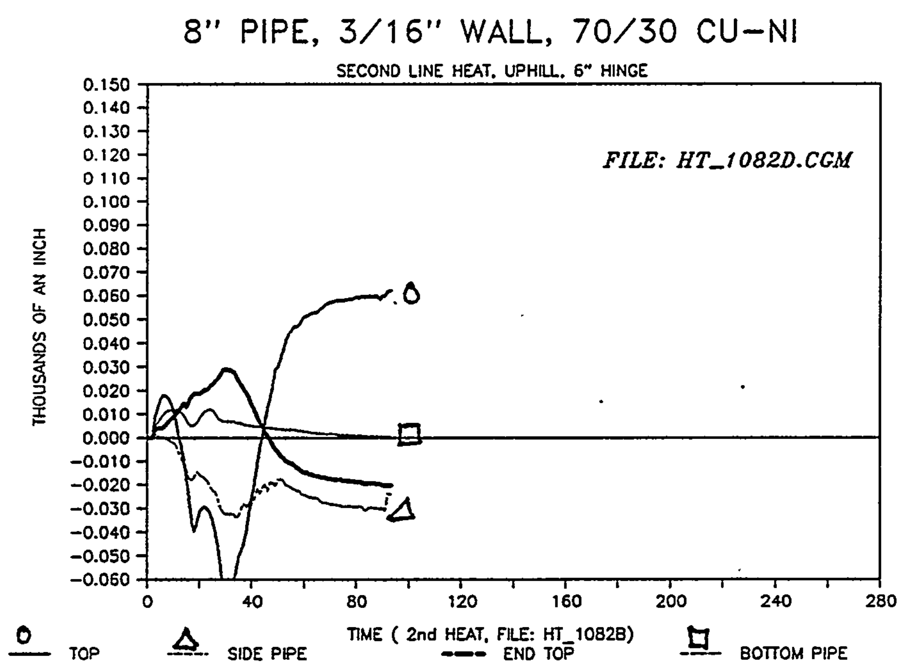

8" PIPE, 3/16" WALL, 70/30 CU-NI
FIRST LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1071D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_1071B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

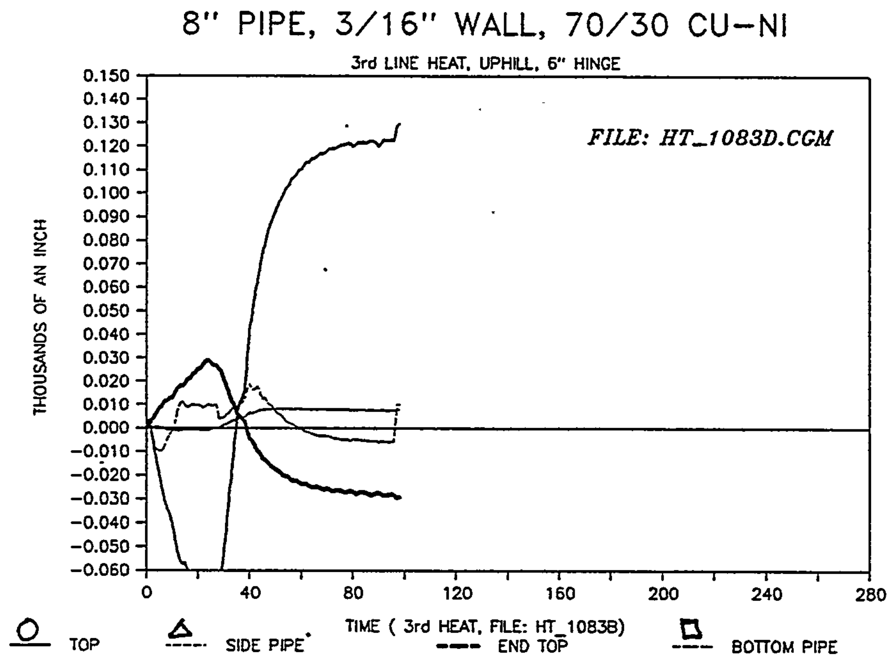

8" PIPE, 3/16" WALL, 70/30 CU-NI
SECOND LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1072D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_1072B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

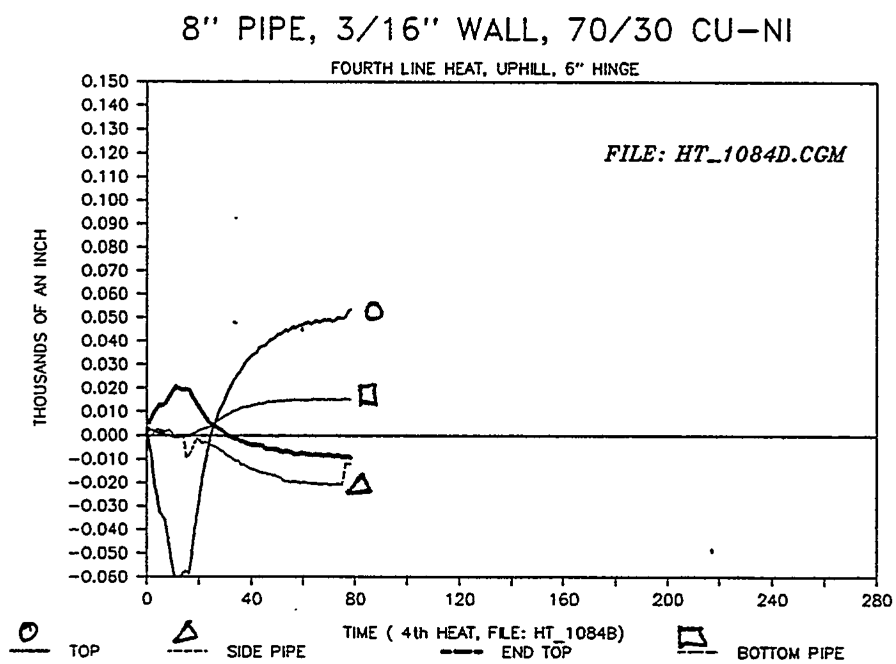

8" PIPE, 3/16" WALL, 70/30 CU-NI
FIRST LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1073D.CGM
THOUSANDS OF AN INCH
TIME (3rd HEAT, FILE: Heat_1073B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

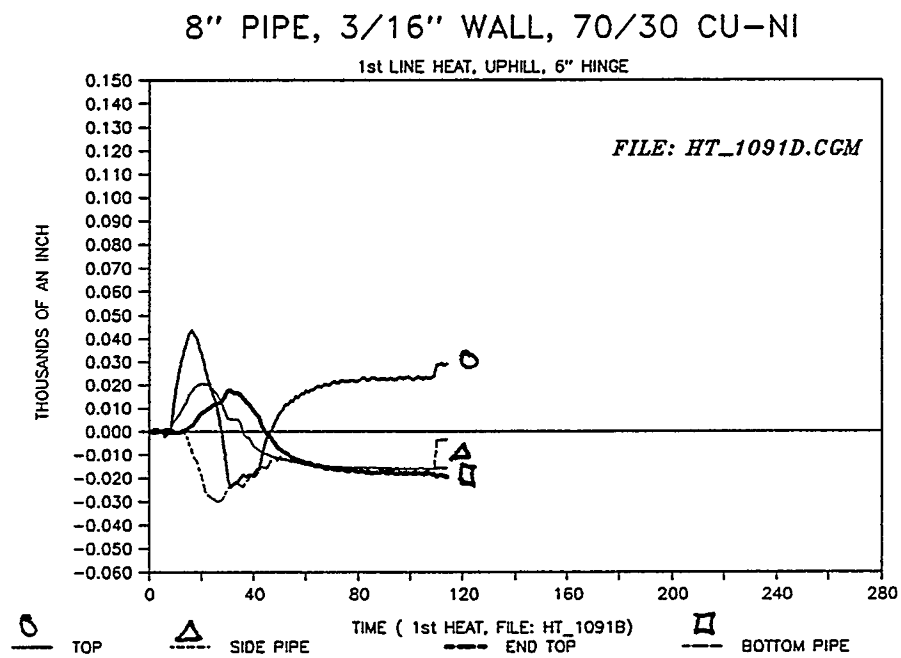

8" PIPE, 3/16" WALL, 70/30 CU-NI
FOURTH LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1074D.CGM
THOUSANDS OF AN INCH
TIME (4th HEAT, FILE: Heat_1074B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

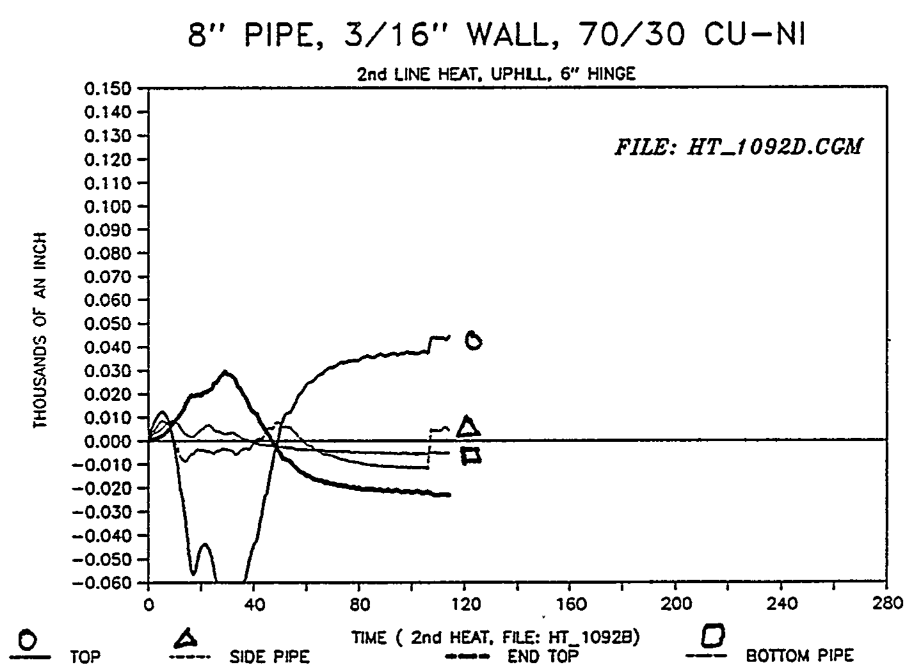

8" PIPE, 3/16" WALL, 70/30 CU-NI
FIRST LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1081D.CGM
THOUSANDS OF AN INCH
TIME (1st HEAT, FILE: HT_1081B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

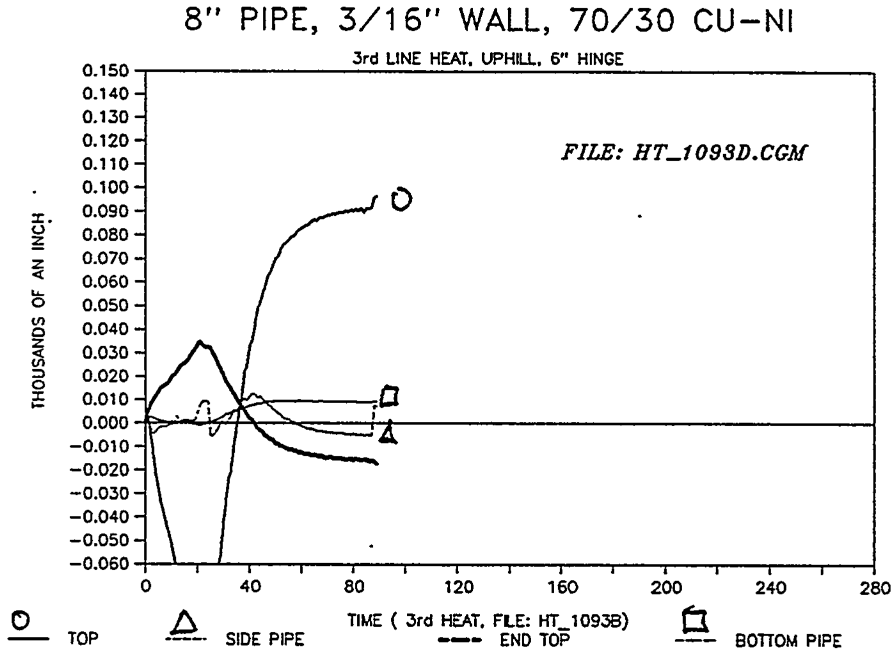

8" PIPE, 3/16" WALL, 70/30 CU-NI
SECOND LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1082D.CGM
THOUSANDS OF AN INCH
TIME (2nd HEAT, FILE: HT_1082B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

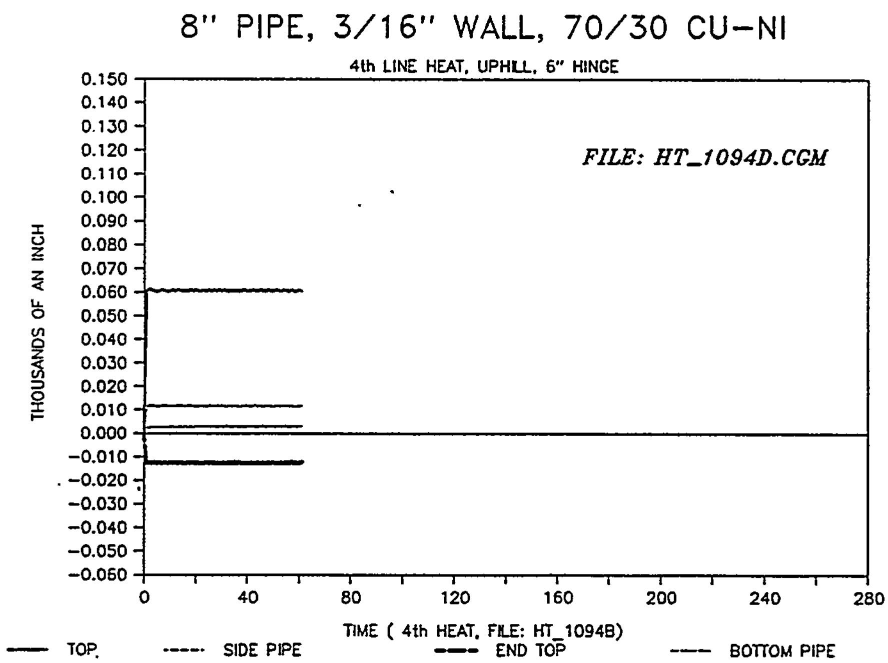

8" PIPE, 3/16" WALL, 70/30 CU-NI
3rd LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1083D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: HT_1083B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

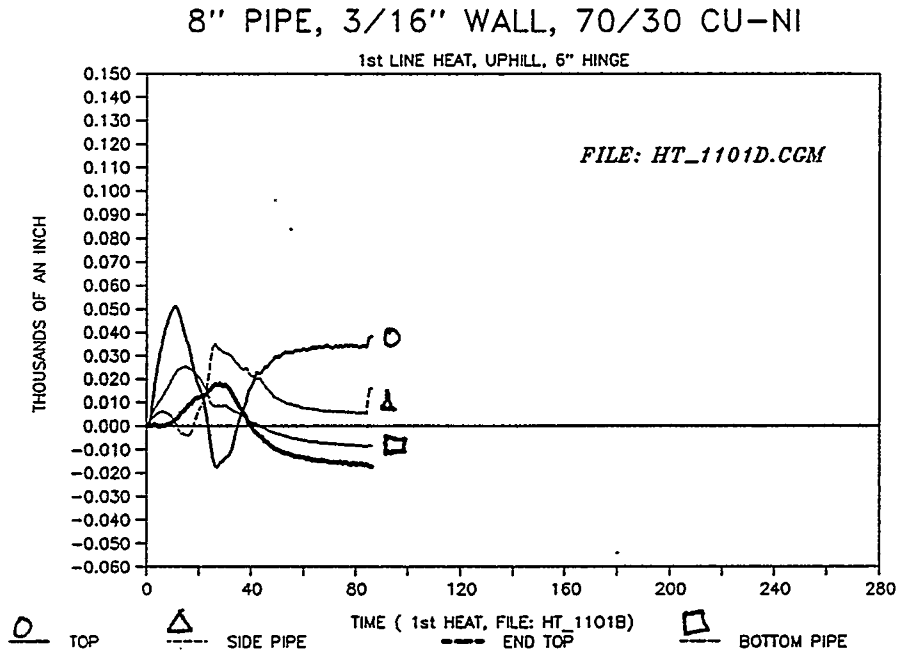

8" PIPE, 3/16" WALL, 70/30 CU-NI
FOURTH LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1084D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: HT_1084B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

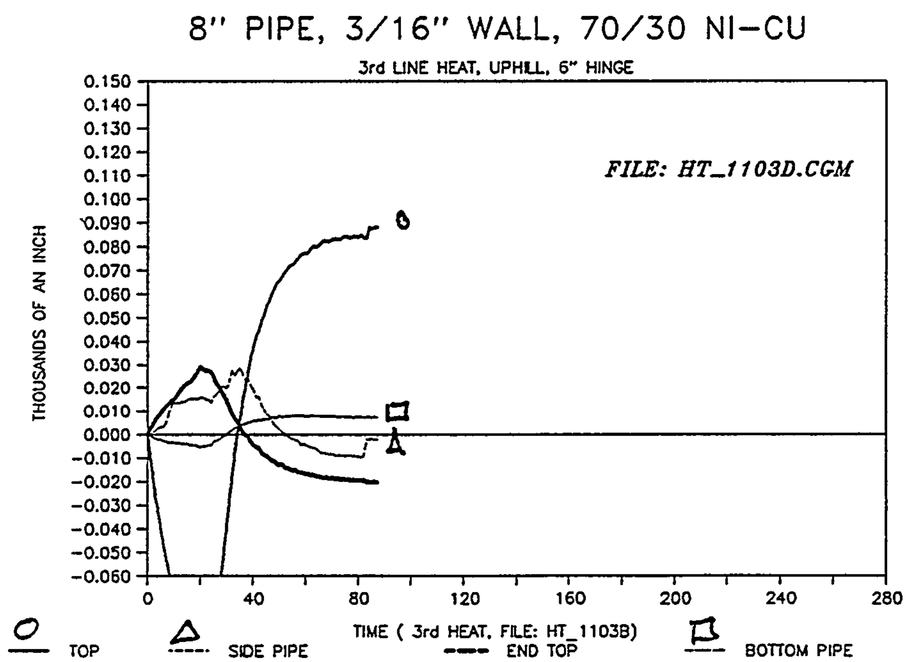

8" PIPE, 3/16" WALL, 70/30 CU-NI
1st LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1091D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: HT_1091B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

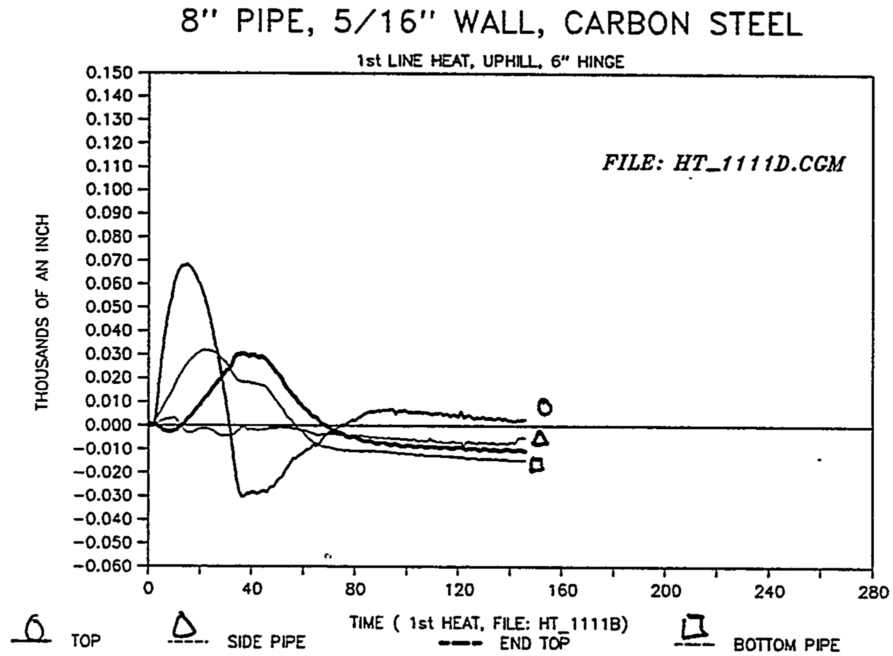

8" PIPE, 3/16" WALL, 70/30 CU-NI
2nd LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1092D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: HT_1092B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

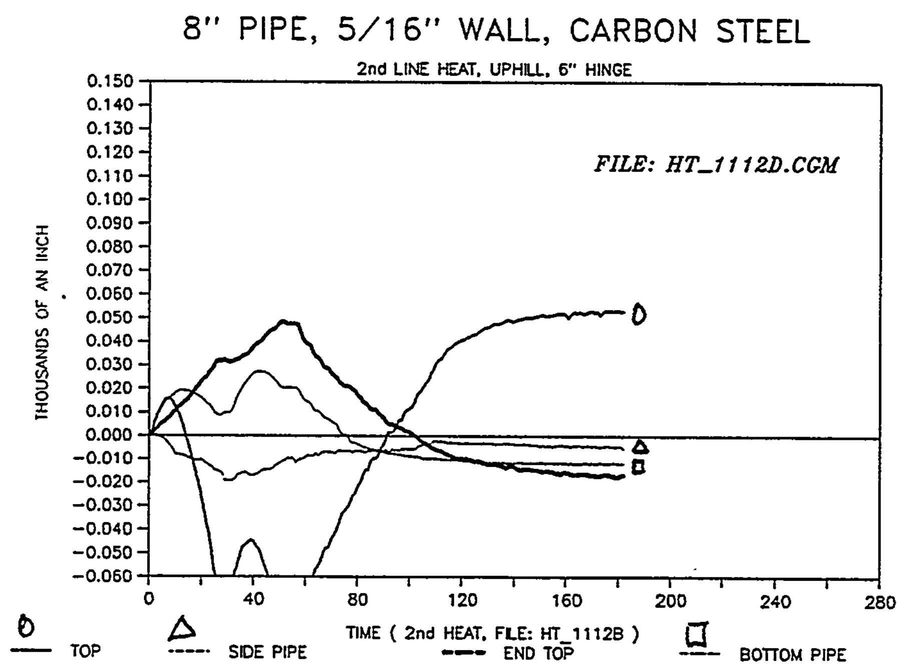

8" PIPE, 3/16" WALL, 70/30 CU-NI
3rd LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1093D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: HT_1093B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, 70/30 CU-NI
4th LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1094D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: HT_1094B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

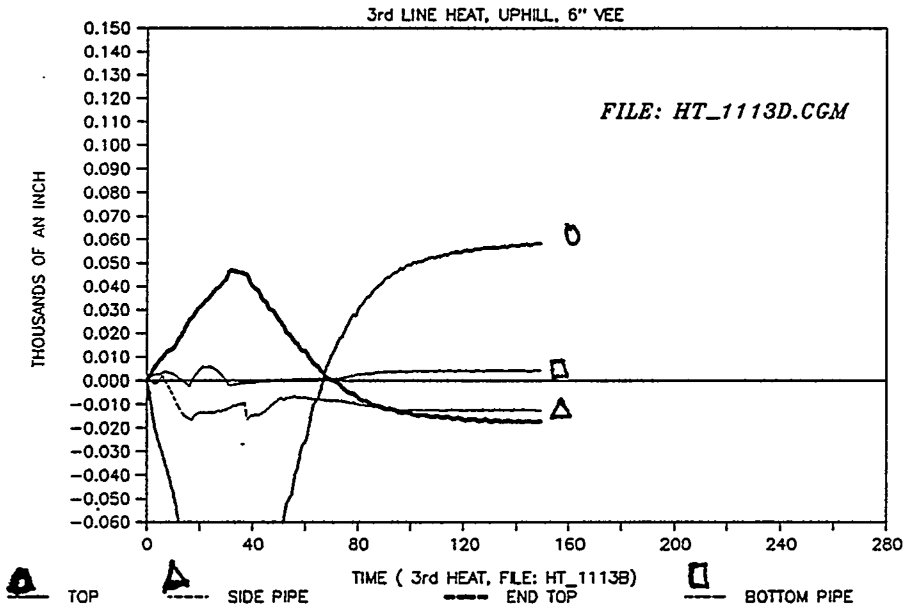

8" PIPE, 3/16" WALL, 70/30 CU-NI
1st LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1101D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: HT_1101B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 3/16" WALL, 70/30 NI-CU
3rd LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1103D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: HT_1103B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

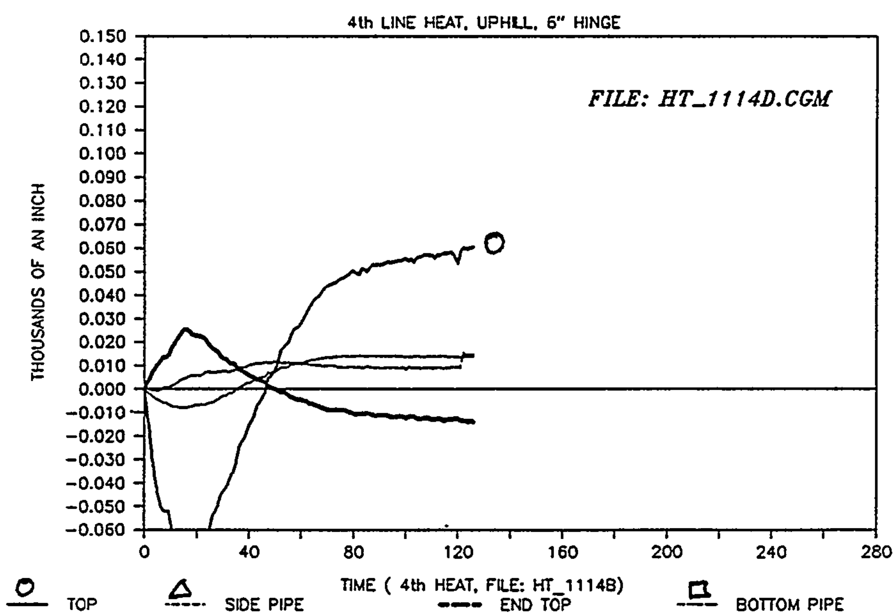

8" PIPE, 5/16" WALL, CARBON STEEL
1st LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1111D.CGM
THOUSANDS OF AN INCH
TIME (1st HEAT, FILE: HT_1111B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

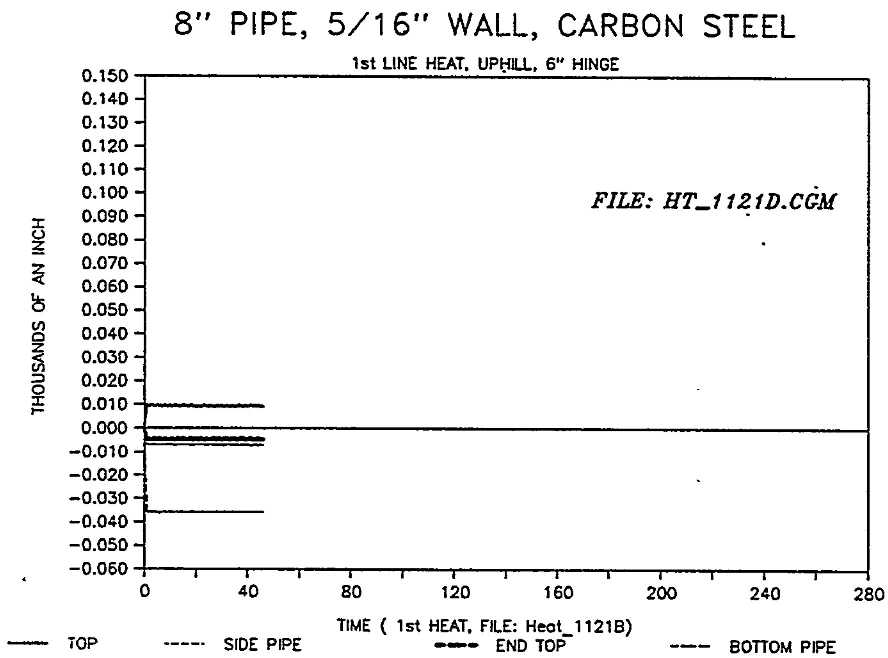

8" PIPE, 5/16" WALL, CARBON STEEL
2nd LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1112D.CGM
THOUSANDS OF AN INCH
TIME (2nd HEAT, FILE: HT_1112B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

8" PIPE, 5/16" WALL, CARBON STEEL

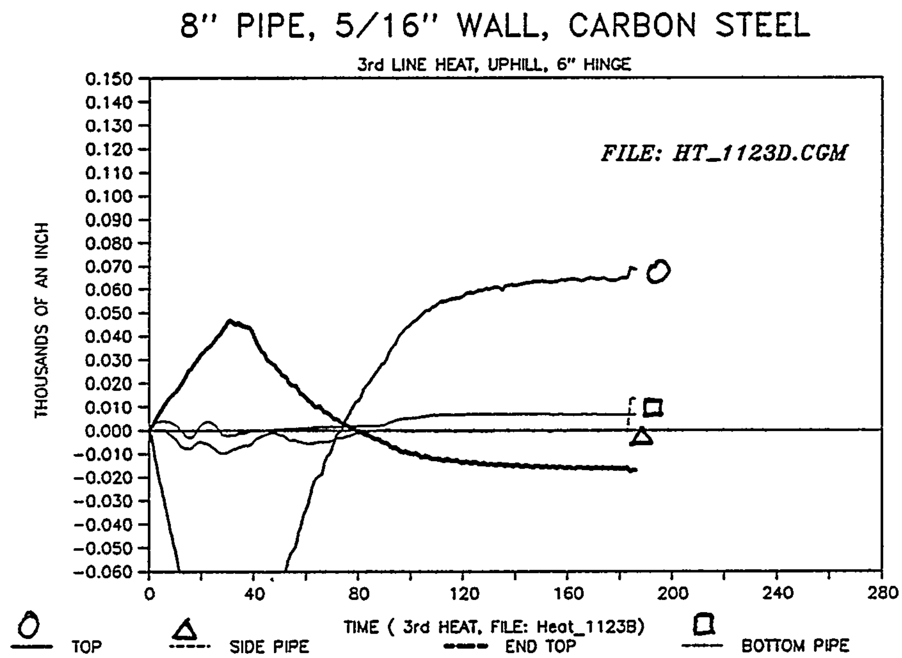


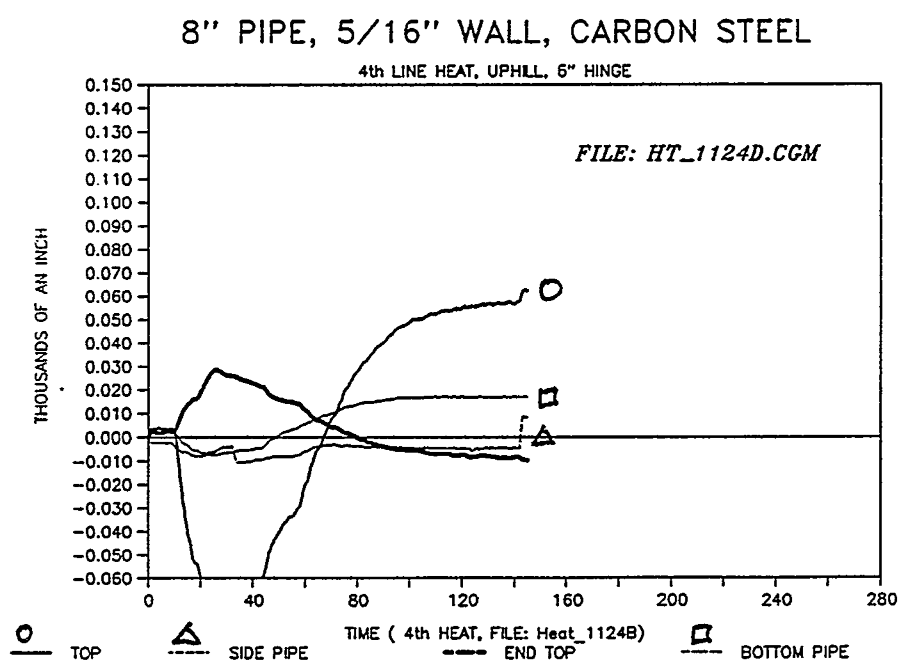
8" PIPE, 5/16" WALL, CARBON STEEL

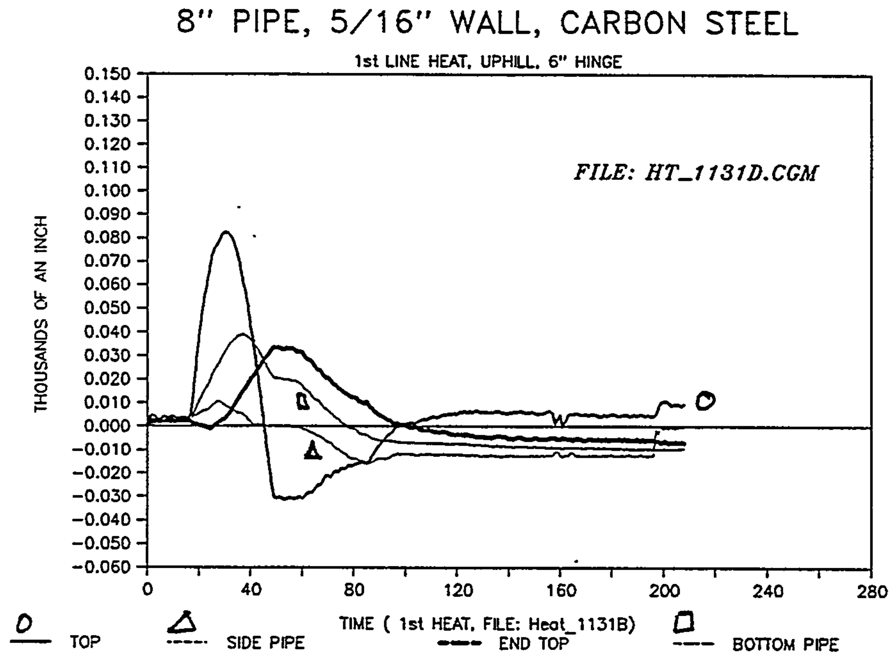


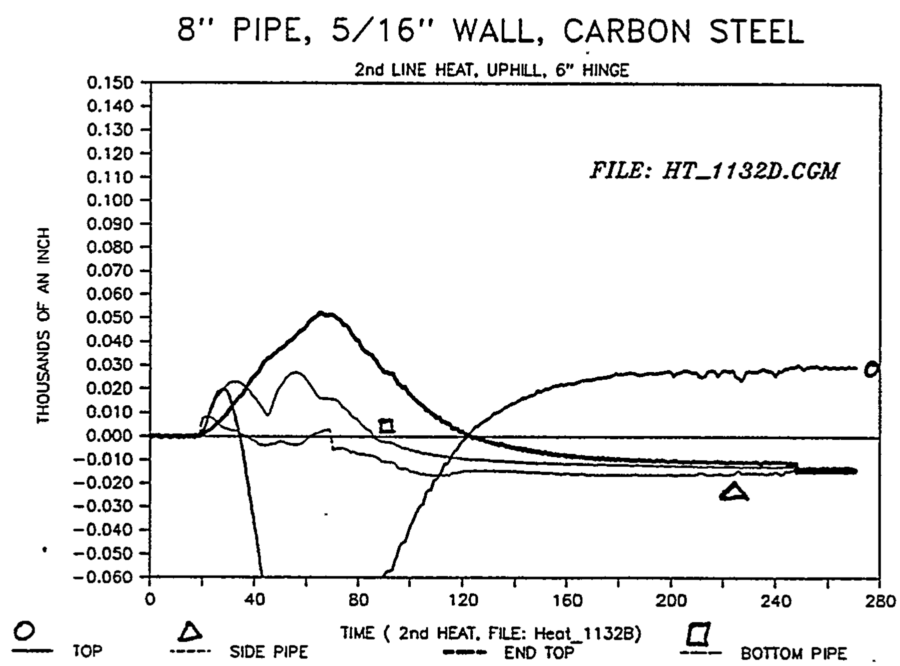

8" PIPE, 5/16" WALL, CARBON STEEL
1st LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1121D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_1121B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

[PICTURE]

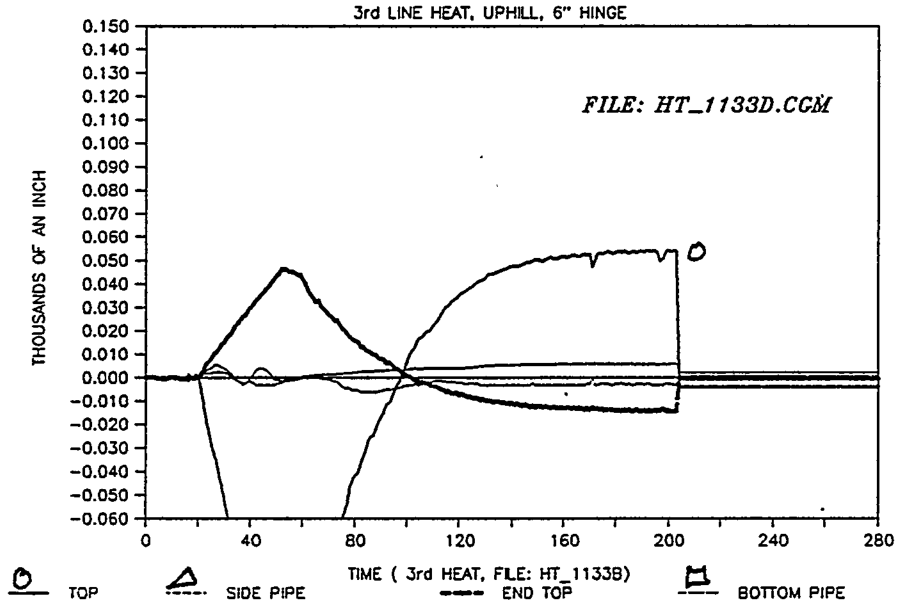

8" PIPE, 5/16" WALL, CARBON STEEL
3rd LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1123D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_1123B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 5/16" WALL, CARBON STEEL
4th LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1124D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: Heat_1124B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

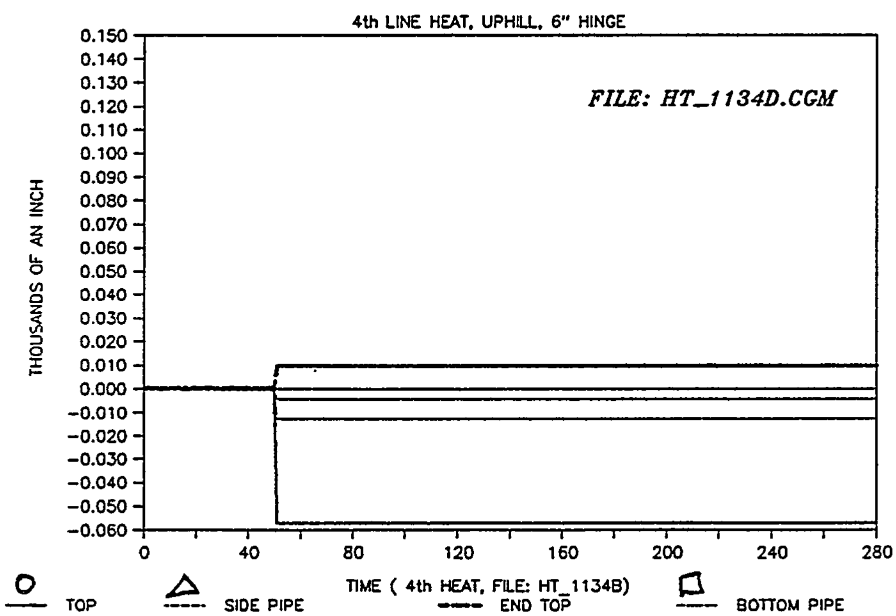

8" PIPE, 5/16" WALL, CARBON STEEL
1st LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1131D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0 40 80 120 160 200 240 280
TIME (1st HEAT, FILE: Heat_1131B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

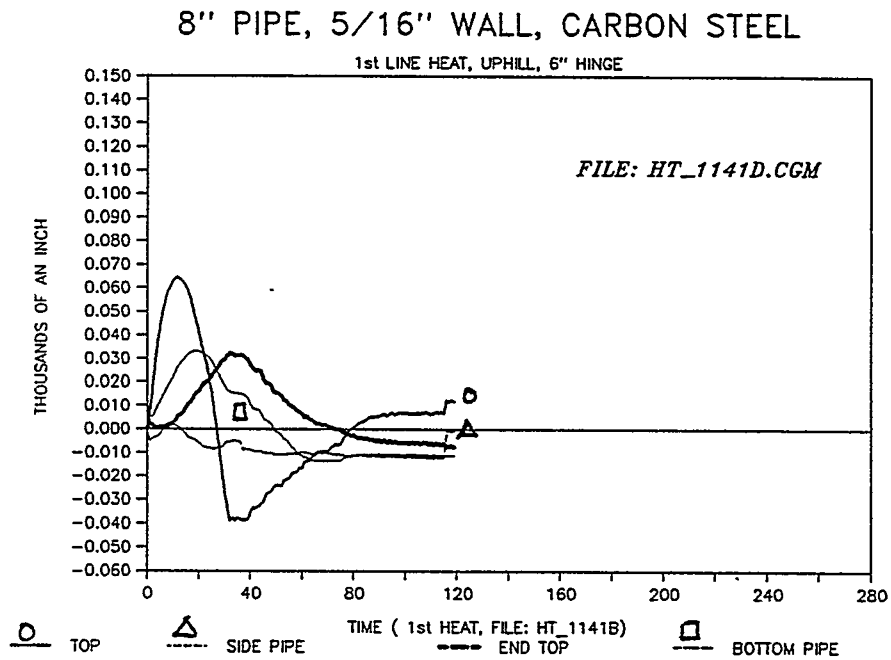

8" PIPE, 5/16" WALL, CARBON STEEL
2nd LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1132D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0 40 80 120 160 200 240 280
TIME (2nd HEAT, FILE: Heat_1132B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

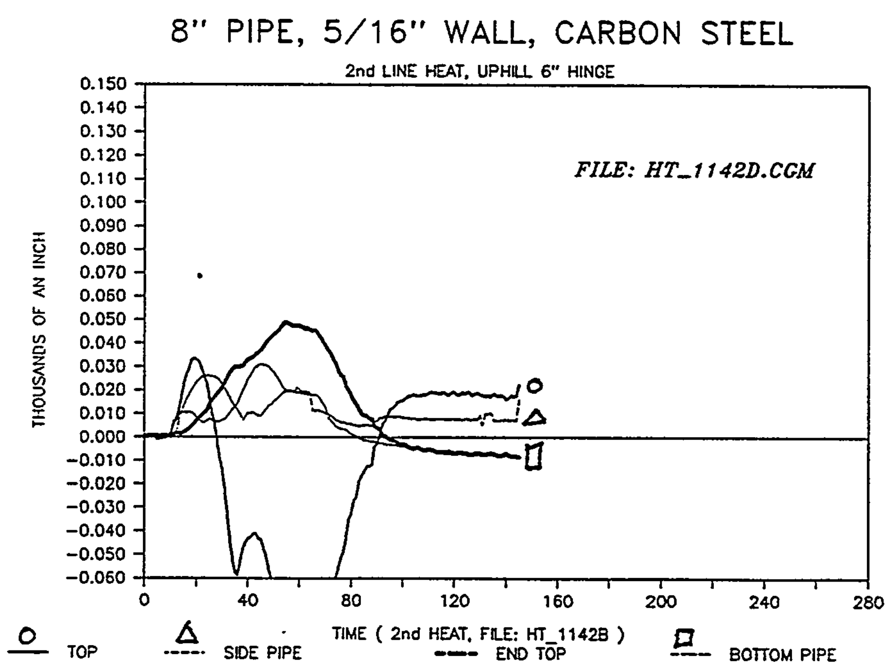
8" PIPE, 5/16" WALL, CARBON STEEL

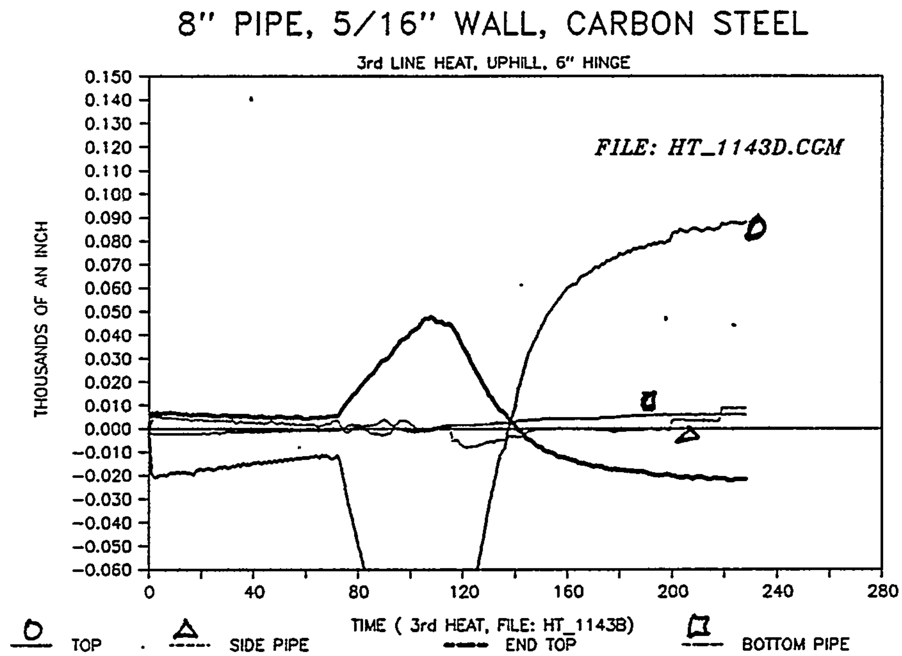


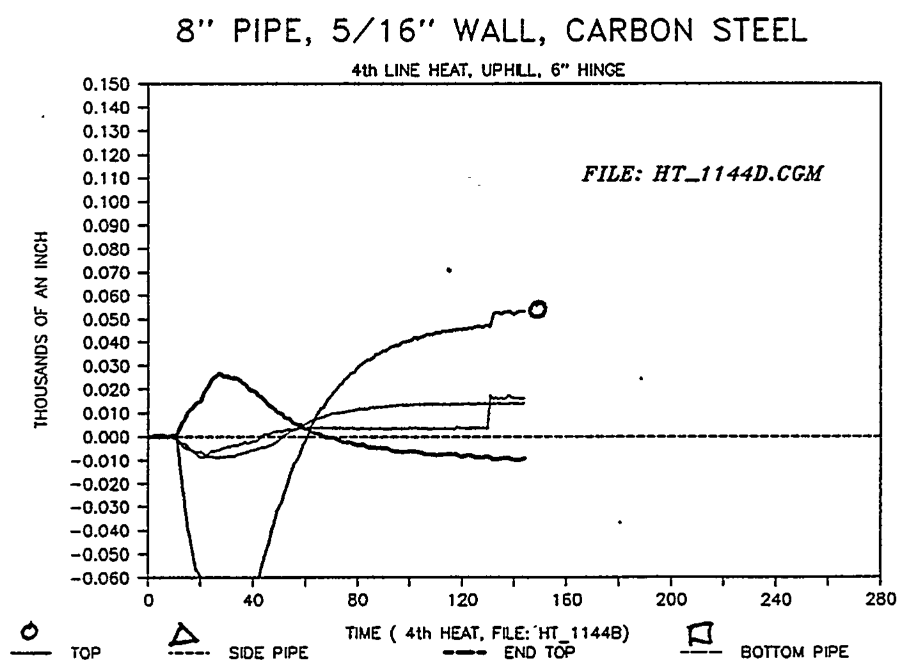
8" PIPE, 5/16" WALL, CARBON STEEL

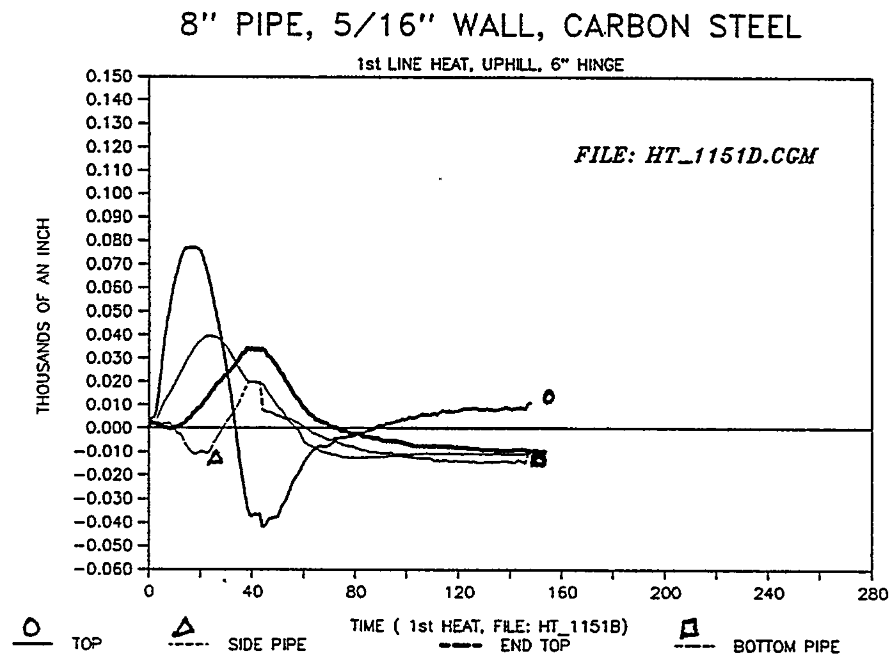


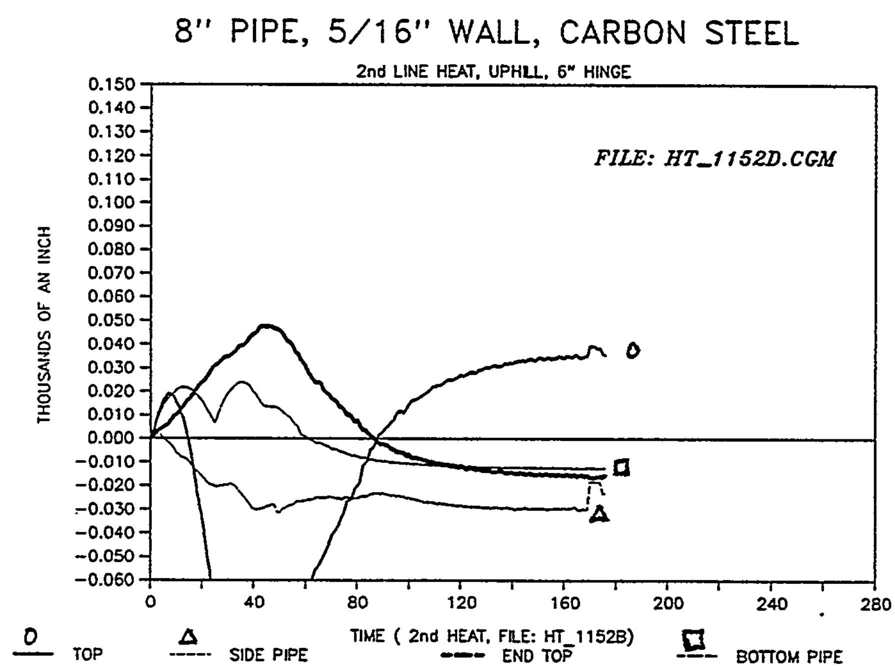

8" PIPE, 5/16" WALL, CARBON STEEL
1st LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1141D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: HT_1141B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

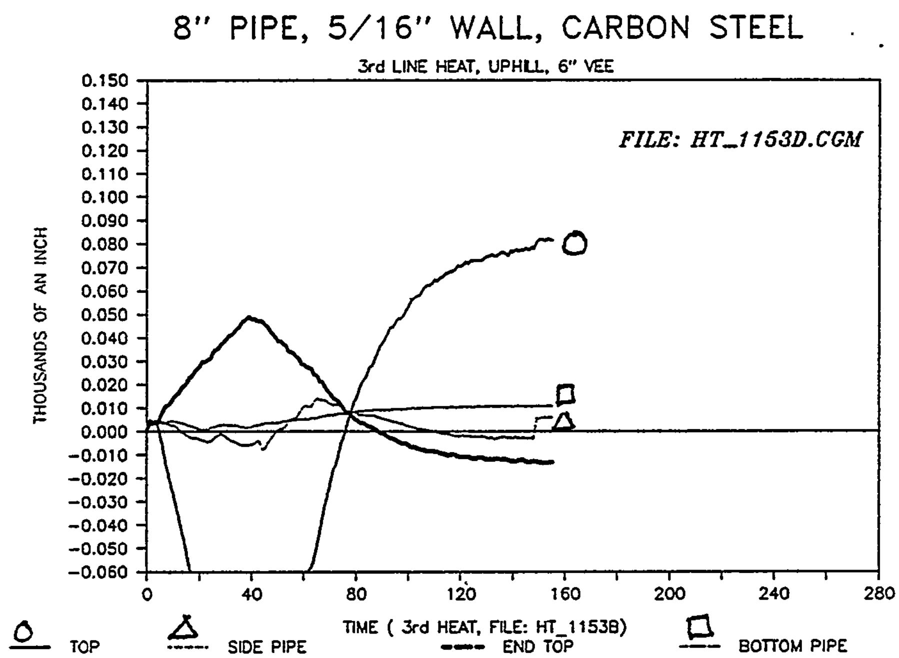

8" PIPE, 5/16" WALL, CARBON STEEL
2nd LINE HEAT, UPHILL 6" HINGE
FILE: HT_1142D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: HT_1142B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

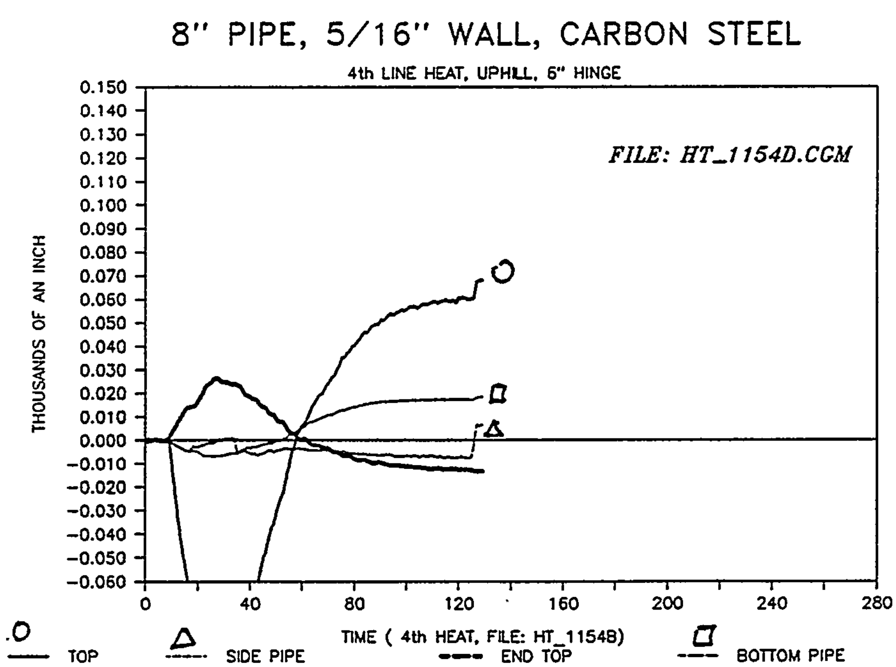

8" PIPE, 5/16" WALL, CARBON STEEL
3rd LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1143D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
−0.010
−0.020
−0.030
−0.040
−0.050
−0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: HT_1143B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 5/16" WALL, CARBON STEEL
4th LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1144D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
−0.010
−0.020
−0.030
−0.040
−0.050
−0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: HT_1144B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

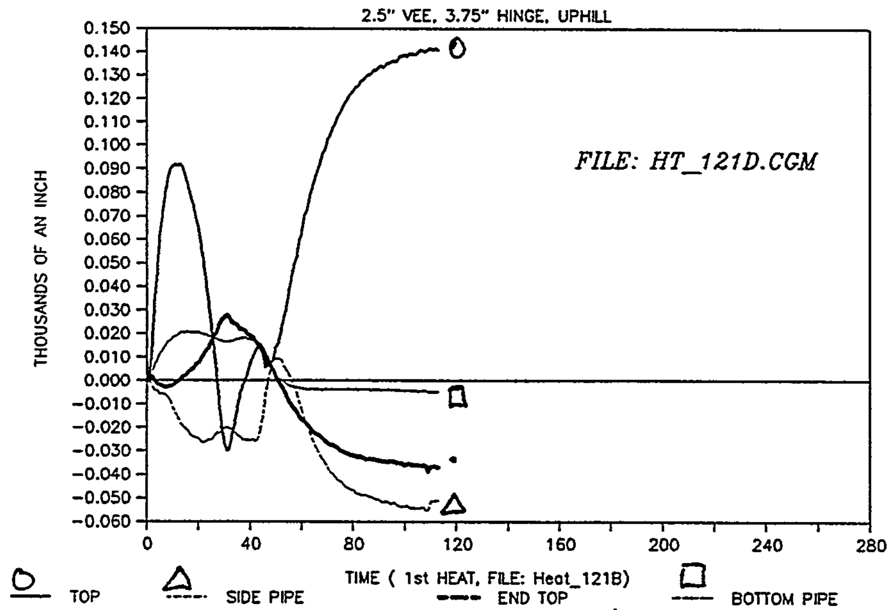

8" PIPE, 5/16" WALL, CARBON STEEL
1st LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1151D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: HT_1151B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


8" PIPE, 5/16" WALL, CARBON STEEL
2nd LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1152D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: HT_1152B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

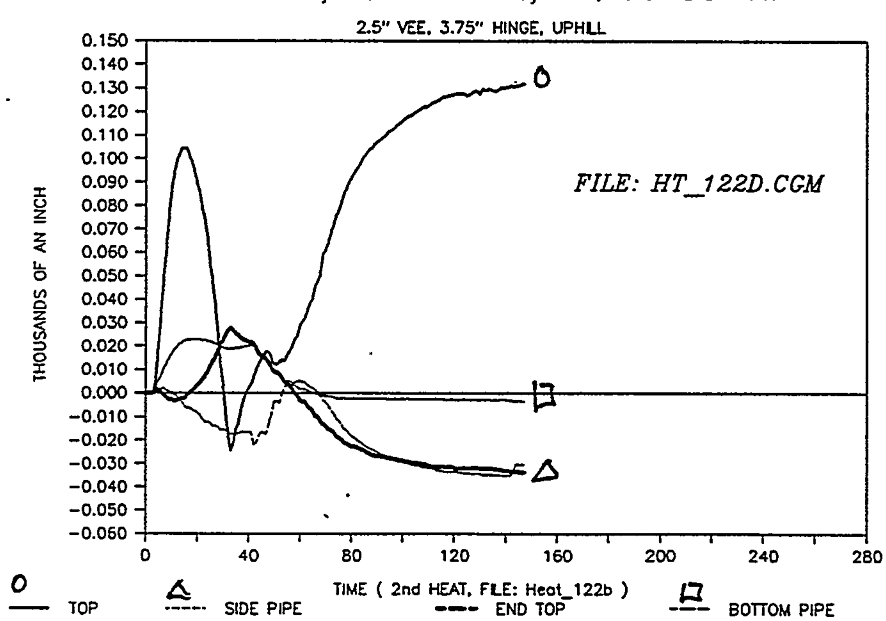

8" PIPE, 5/16" WALL, CARBON STEEL
3rd LINE HEAT, UPHILL, 6" VEE
FILE: HT_1153D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: HT_1153B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

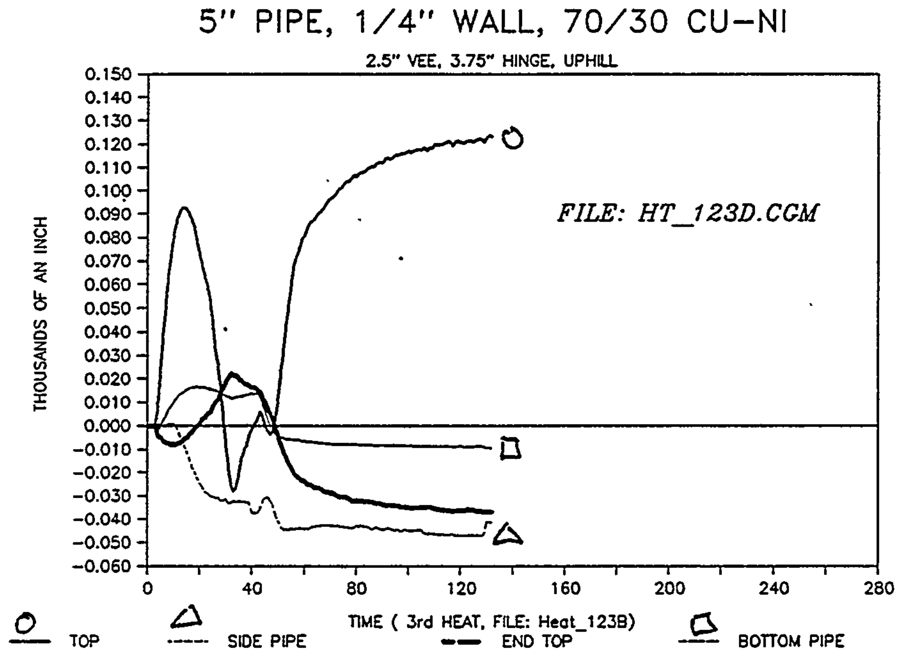

8" PIPE, 5/16" WALL, CARBON STEEL
4th LINE HEAT, UPHILL, 6" HINGE
FILE: HT_1154D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: HT_1154B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

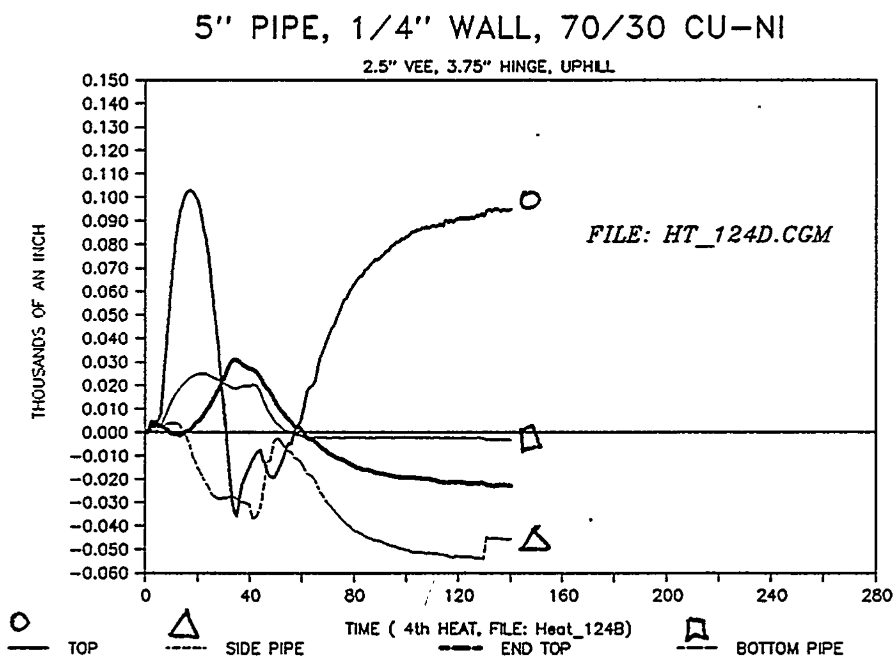
5" PIPE, 1/4" WALL, 70/30 CU-NI

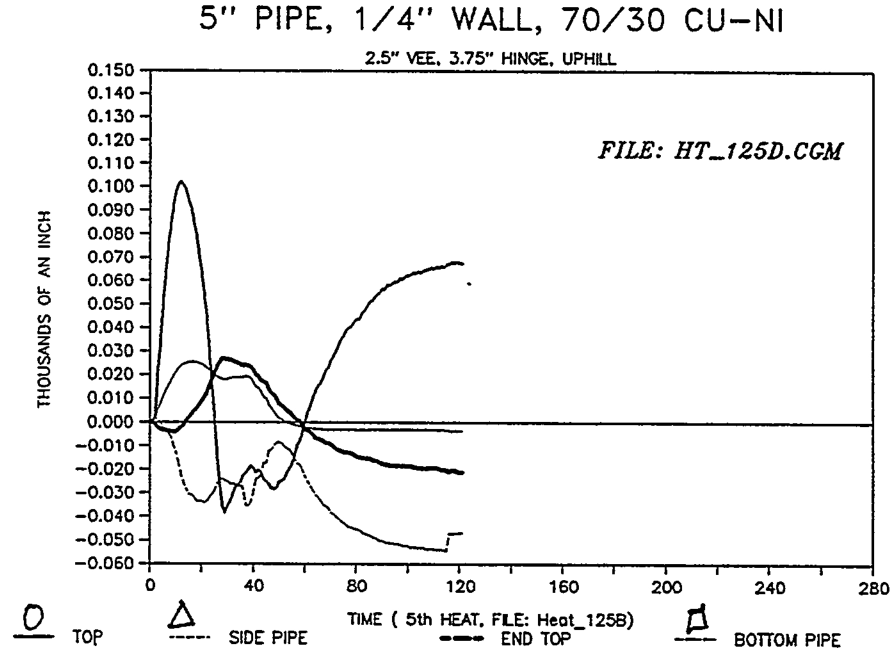


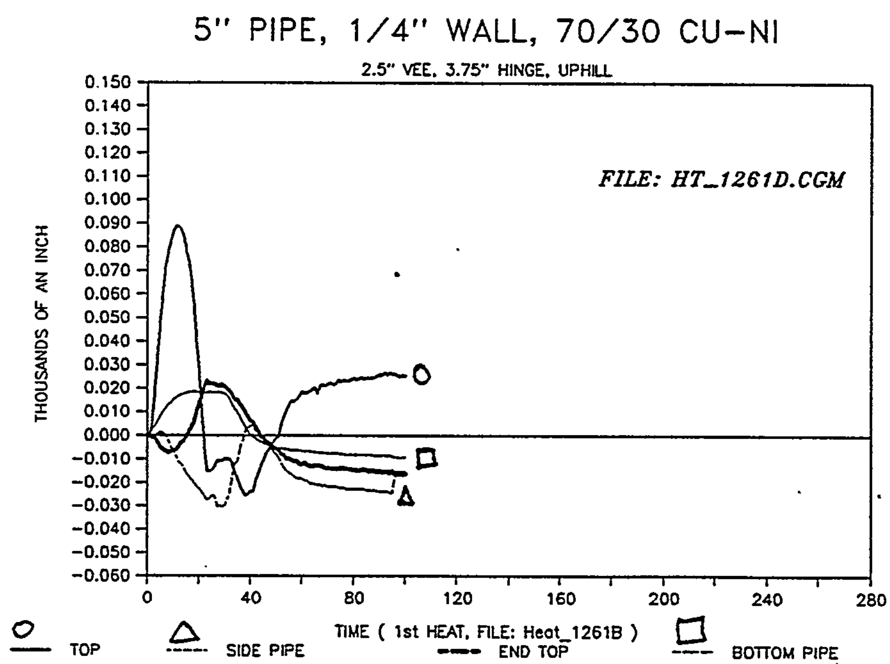
5" PIPE, 1/4" WALL, 70/30 CU-NI

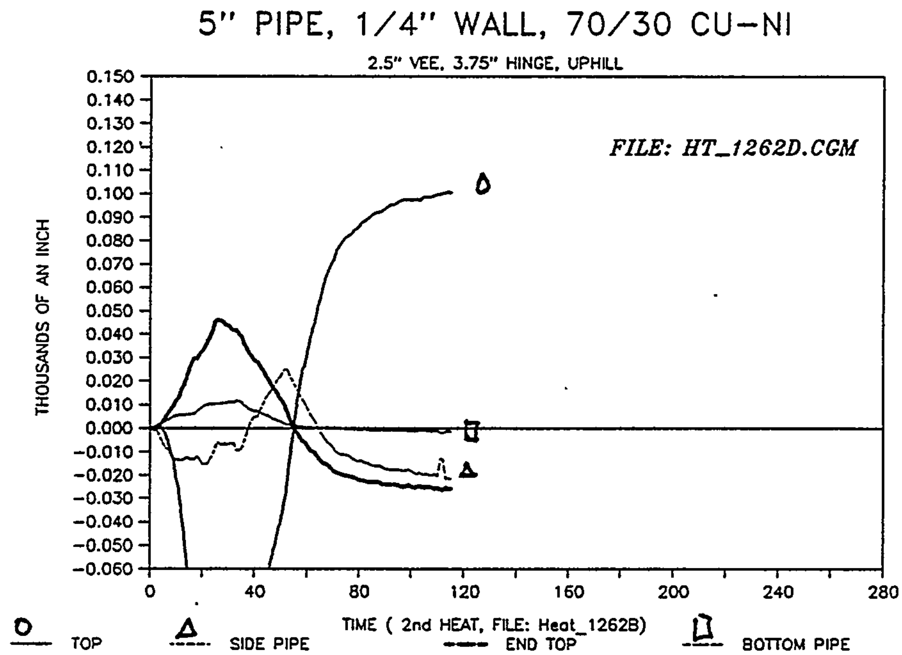


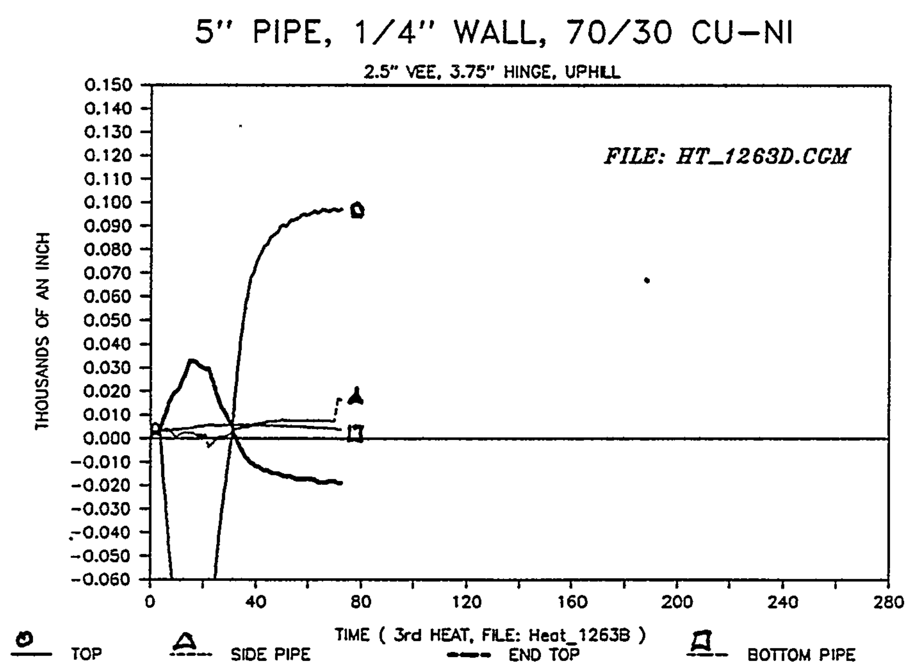

5" PIPE, 1/4" WALL, 70/30 CU-NI
2.5" VEE, 3.75" HINGE, UPHILL
THOUSANDS OF AN INCH
FILE: HT_123D.CGM
TIME (3rd HEAT, FILE: Heat_123B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

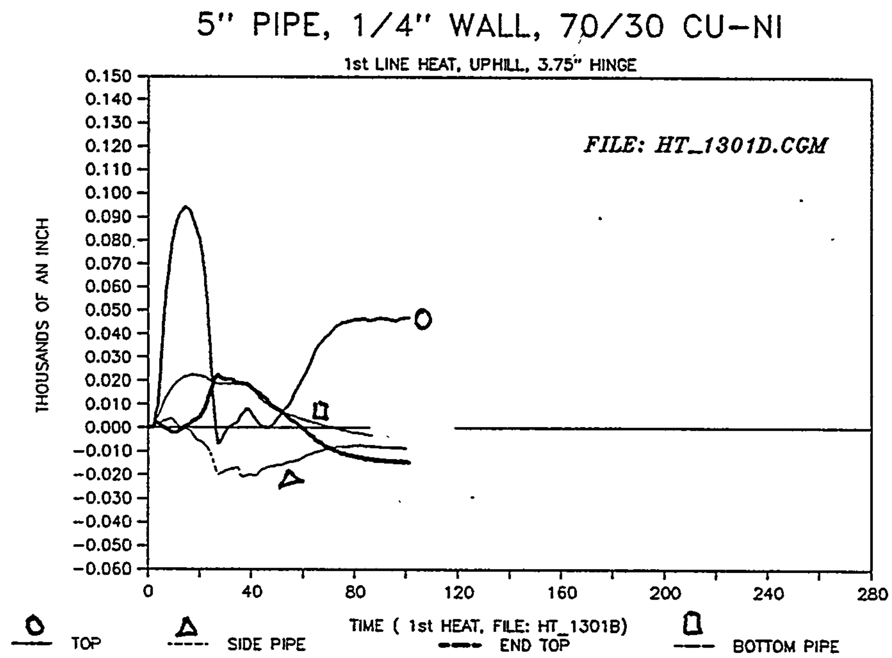

5" PIPE, 1/4" WALL, 70/30 CU-NI
2.5" VEE, 3.75" HINGE, UPHILL
THOUSANDS OF AN INCH
FILE: HT_124D.CGM
TIME (4th HEAT, FILE: Heat_124B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

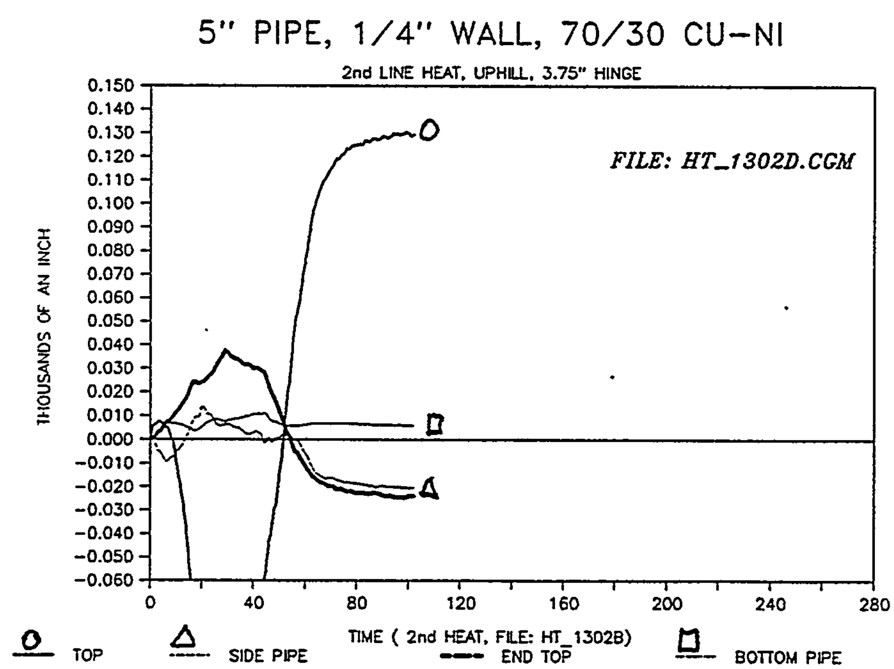

5" PIPE, 1/4" WALL, 70/30 CU-NI
2.5" VEE, 3.75" HINGE, UPHILL
FILE: HT_125D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (5th HEAT, FILE: Heat_125B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

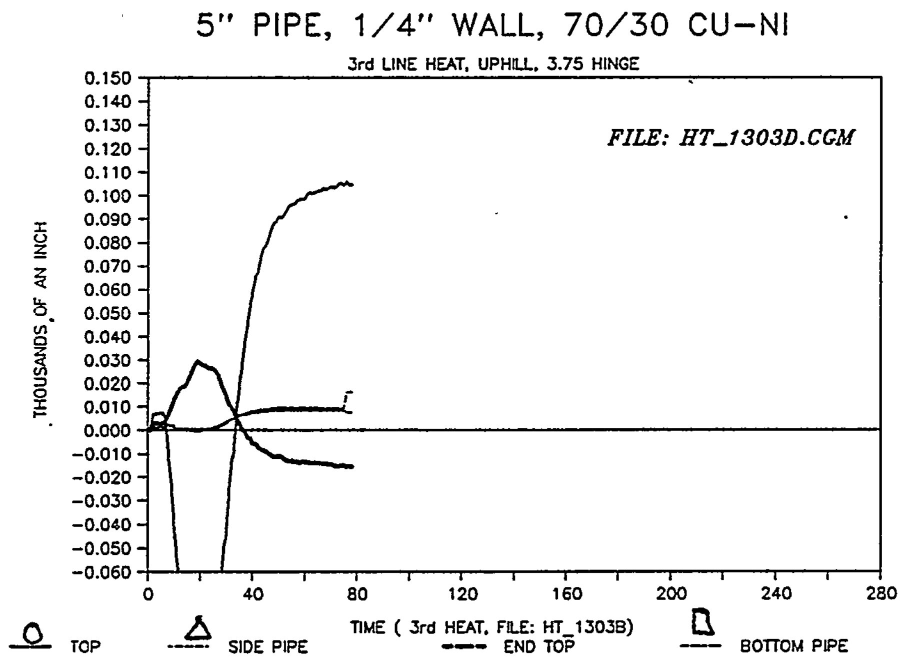

5" PIPE, 1/4" WALL, 70/30 CU-NI
2.5" VEE, 3.75" HINGE, UPHILL
FILE: HT_1261D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: Heat_1261B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

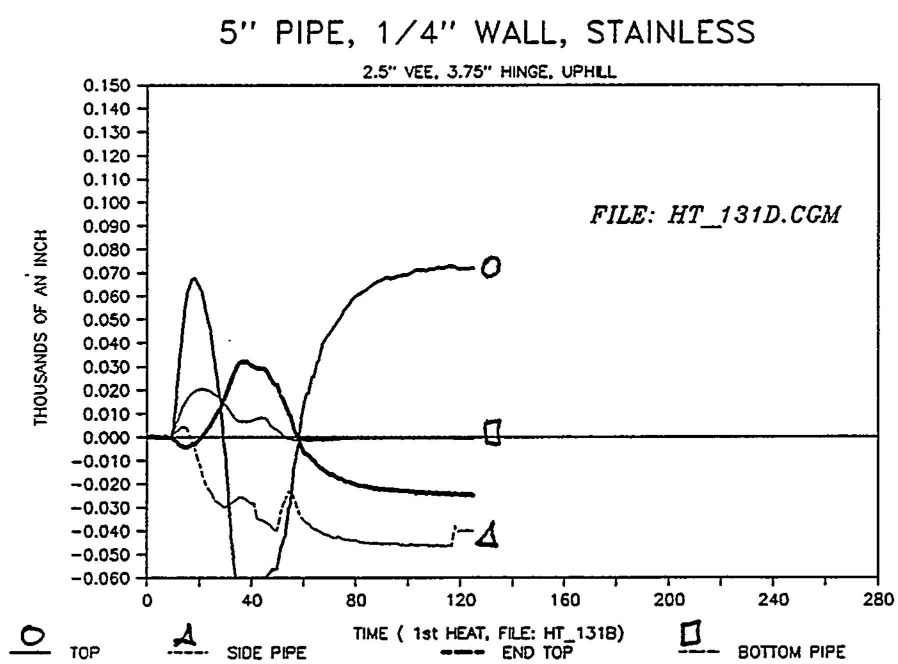

5" PIPE, 1/4" WALL, 70/30 CU-NI
2.5" VEE, 3.75" HINGE, UPHILL
FILE: HT_1262D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: Heat_1262B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

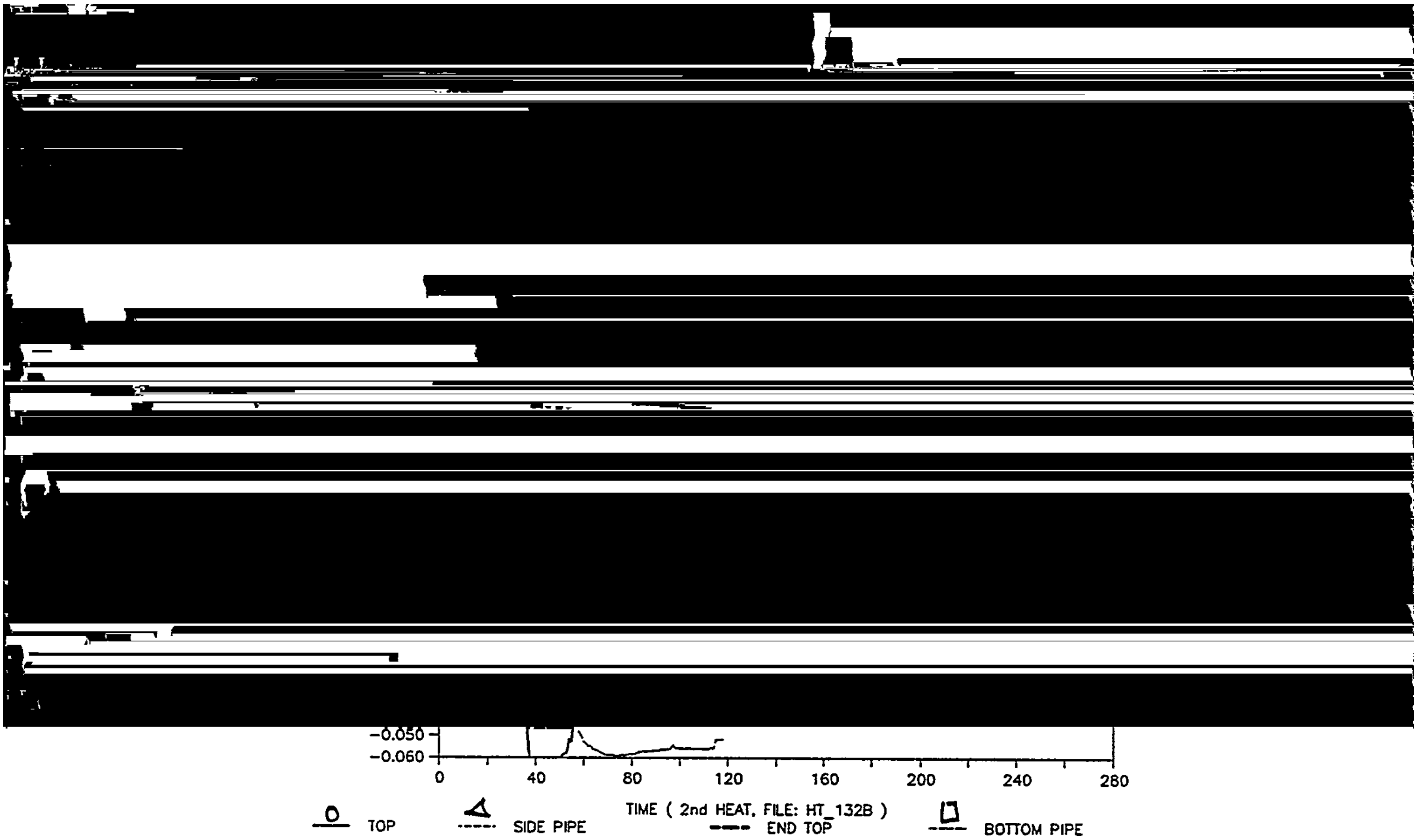

5" PIPE, 1/4" WALL, 70/30 CU-NI
2.5" VEE, 3.75" HINGE, UPHILL
FILE: HT_1263D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: Heat_1263B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

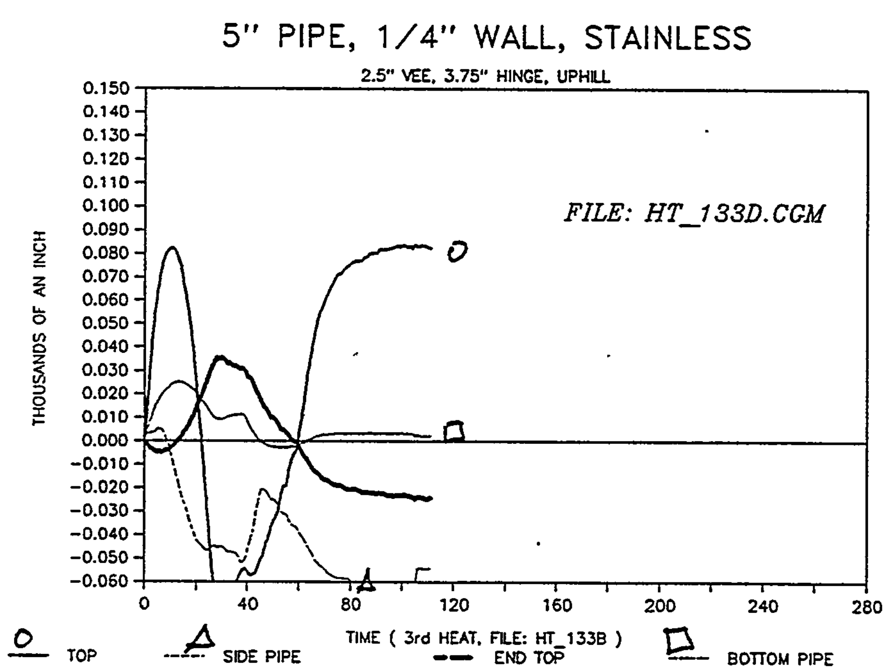

5" PIPE, 1/4" WALL, 70/30 CU-NI
1st LINE HEAT, UPHILL, 3.75" HINGE
FILE: HT_1301D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (1st HEAT, FILE: HT_1301B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

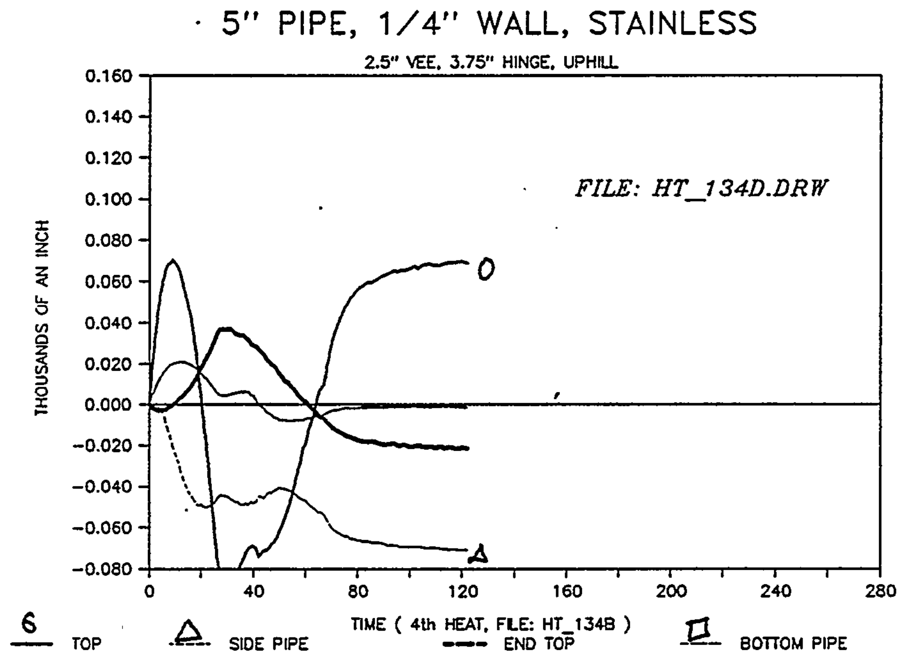

5" PIPE, 1/4" WALL, 70/30 CU-NI
2nd LINE HEAT, UPHILL, 3.75" HINGE
FILE: HT_1302D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: HT_1302B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

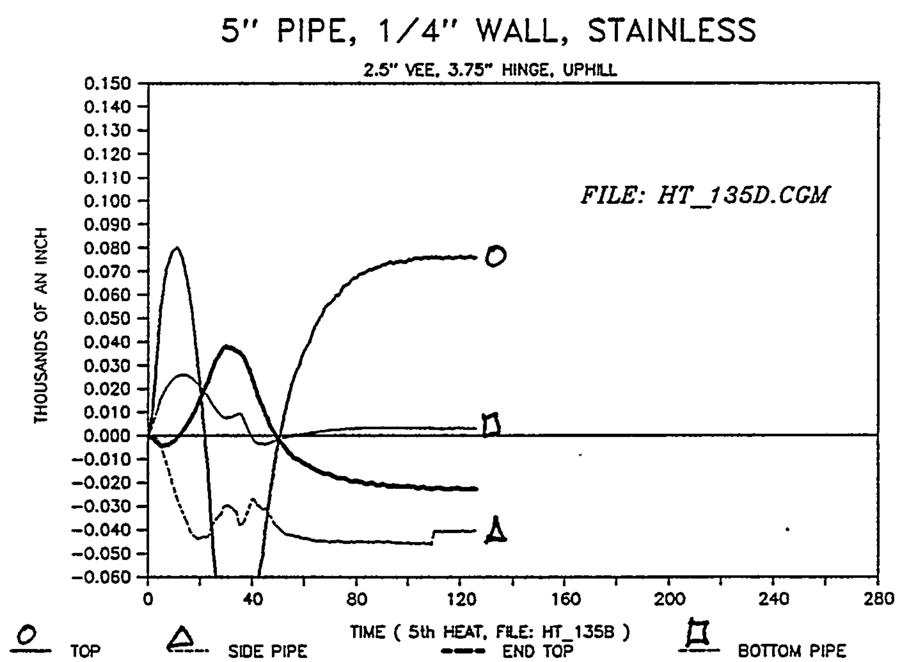

5" PIPE, 1/4" WALL, 70/30 CU-NI
3rd LINE HEAT, UPHILL, 3.75 HINGE
FILE: HT_1303D.CGM
THOUSANDS OF AN INCH
TIME (3rd HEAT, FILE: HT_1303B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


5" PIPE, 1/4" WALL, STAINLESS
2.5" VEE, 3.75" HINGE, UPHILL
FILE: HT_131D.CGM
THOUSANDS OF AN INCH
TIME (1st HEAT, FILE: HT_131B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

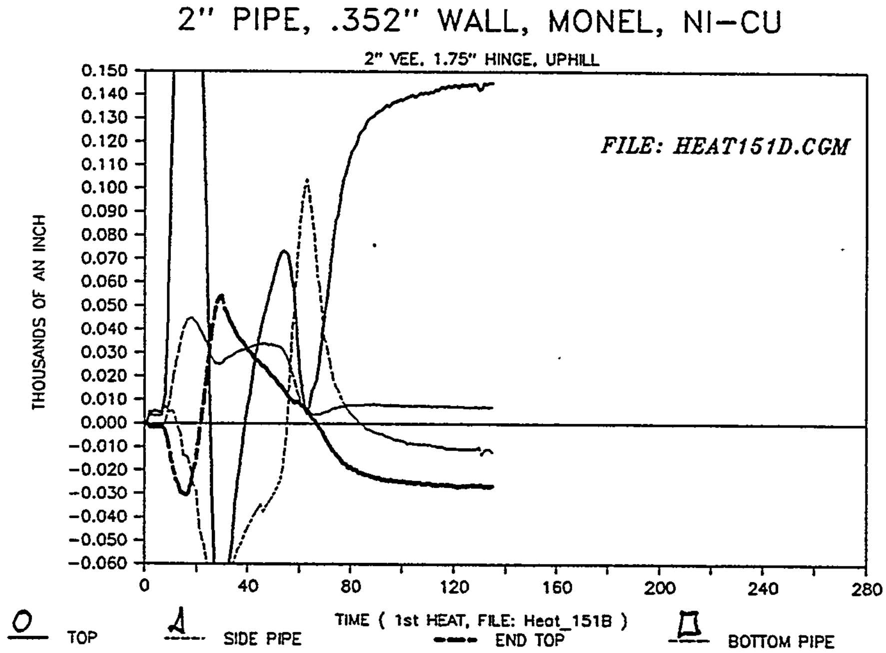

-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (2nd HEAT, FILE: HT_132B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

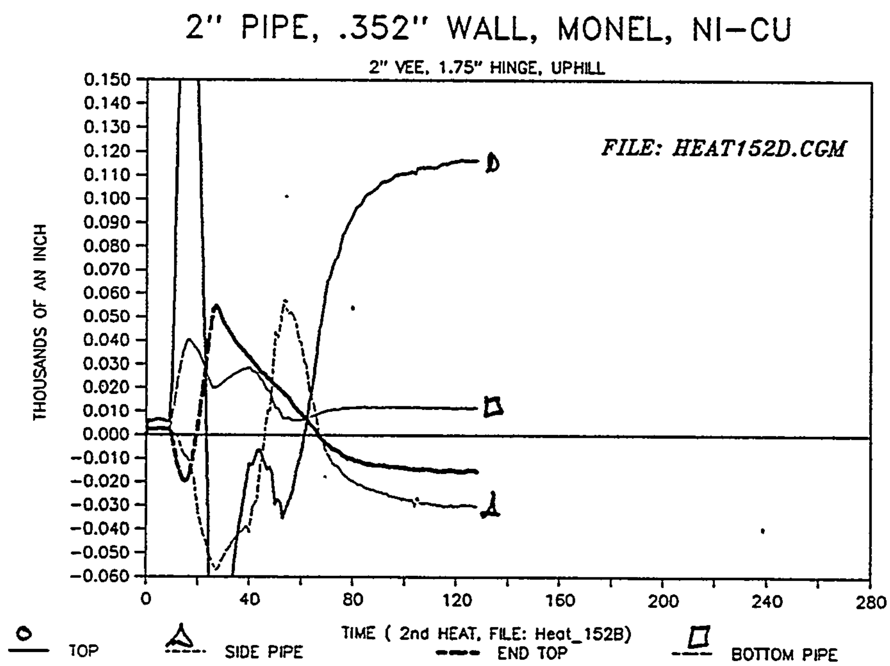

5" PIPE, 1/4" WALL, STAINLESS
2.5" VEE, 3.75" HINGE, UPHILL
FILE: HT_133D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (3rd HEAT, FILE: HT_133B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

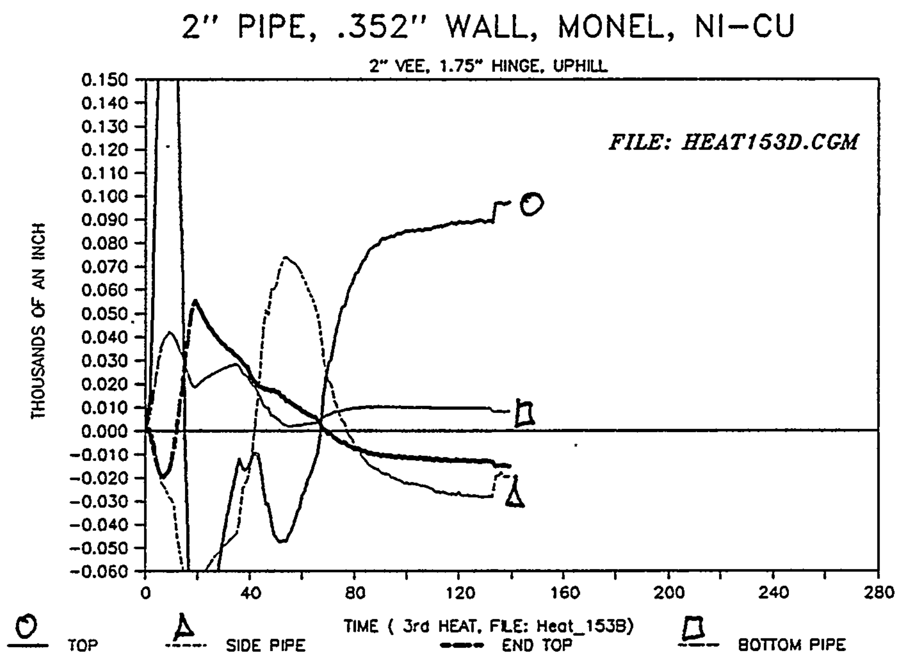

5" PIPE, 1/4" WALL, STAINLESS
2.5" VEE, 3.75" HINGE, UPHILL
FILE: HT_134D.DRW
THOUSANDS OF AN INCH
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
0
40
80
120
160
200
240
280
TIME (4th HEAT, FILE: HT_134B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

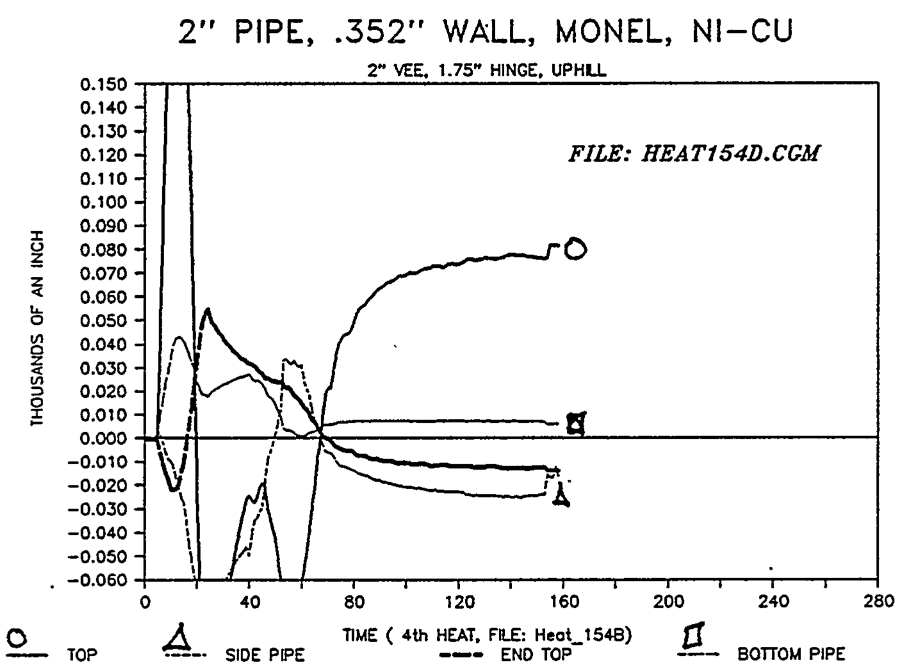

5" PIPE, 1/4" WALL, STAINLESS
2.5" VEE, 3.75" HINGE, UPHILL
FILE: HT_135D.CGM
THOUSANDS OF AN INCH
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
0
40
80
120
160
200
240
280
TIME (5th HEAT, FILE: HT_135B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

APPENDIX C
FLAME BENDING GRAPHS






2" PIPE, .352" WALL, MONEL, NI-CU
2" VEE, 1.75" HINGE, UPHILL
FILE: HEAT153D.CGM
THOUSANDS OF AN INCH
TIME (3rd HEAT, FILE: Heat_153B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE


2" PIPE, .352" WALL, MONEL, NI-CU
2" VEE, 1.75" HINGE, UPHILL
FILE: HEAT154D.CGM
THOUSANDS OF AN INCH
TIME (4th HEAT, FILE: Heat_154B)
TOP
SIDE PIPE
END TOP
BOTTOM PIPE

APPENDIX C
FLAME BENDING GRAPHS