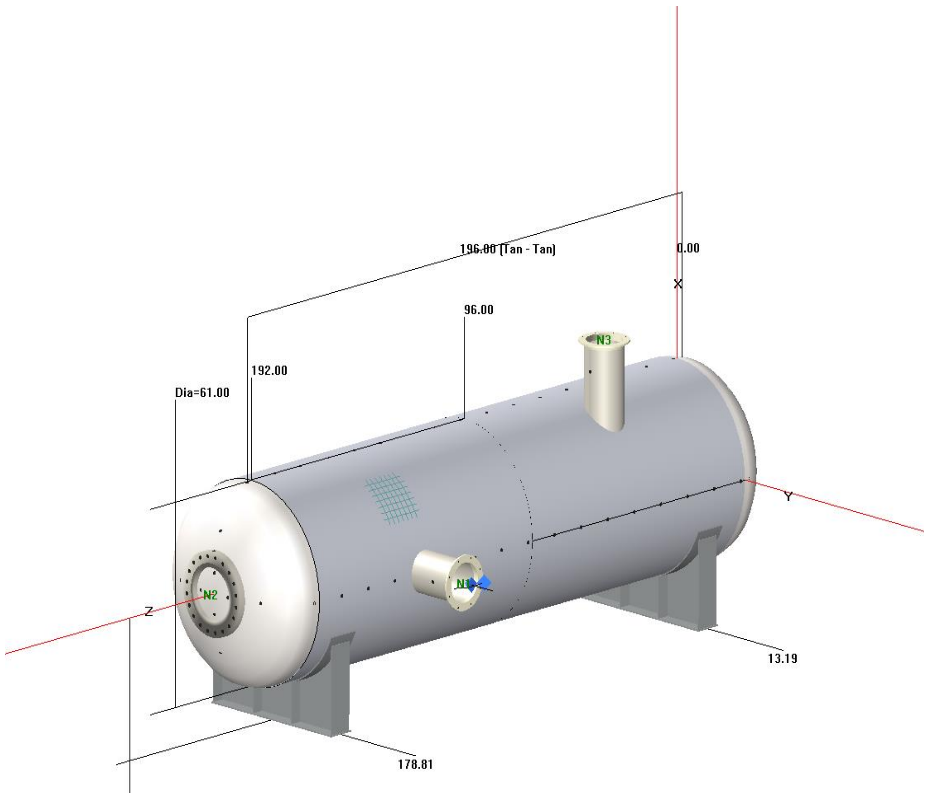
**Codeware, Inc.**

Sarasota, FL, USA

www.codeware.com

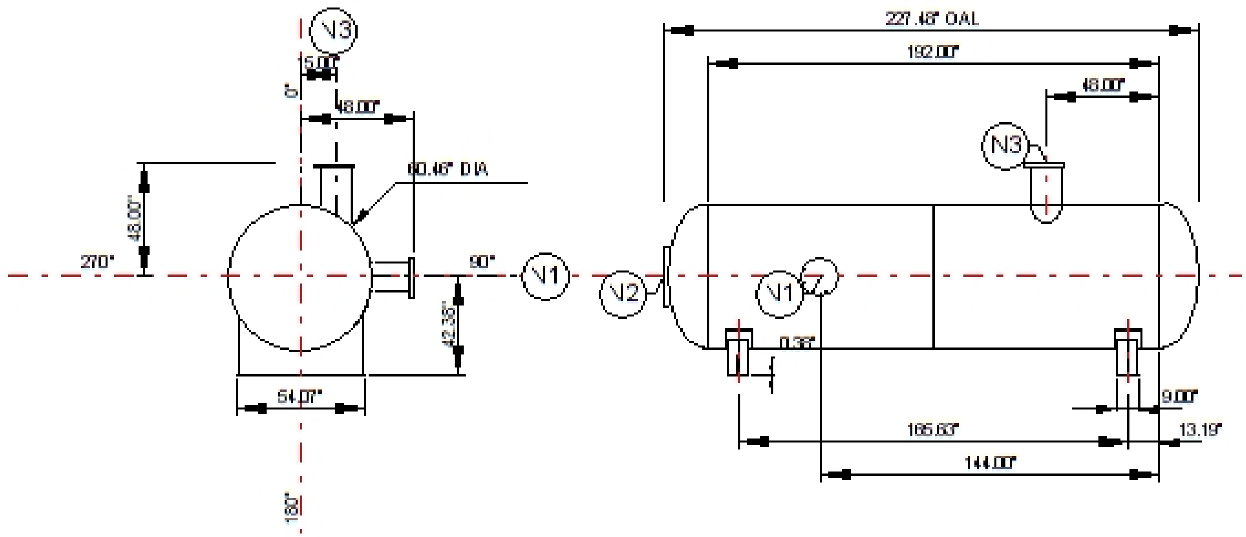



# INSPECT Pressure Vessel Design Calculations

| | |
|---|---|
| **Item:** | Split Stream Dearator |
| **Vessel No:** | V-1234 |
| **Customer:** | Magaladon Oil Venture |
| **Contract:** | C-45490-R56 |
| **Designer:** | John Doe |
| **Date:** | May 14, 2009 |

You can edit this page by selecting ***Cover Page settings...*** in the ***report*** menu.

# Table of Contents




## DESIGN DATA

| | |
|---|---|
| Design Pressure | 100 psi |
| Vacuum Pressure | 0 psi |
| Test Pressure | |
| Design Temperature | 650 °F |
| MDMT | -20 °F |
| Corrosion Allowance | 0" |
| Radiography | RT1 |
| PWHT | None |

## Estimated Weights

Dry: 5,409 lb Wet: 5,409 lb

Weight at left sad 2,810 lb (Oper), 13,969 lb (T

Weight at right s 2,599 lb (Oper), 13,745 lb (T

## Materials

Cylinder(s): SA-516 70
Head(s): SA-516 70
Transition(s):
Support:

## NOZZLE SCHEDULE

| MARK | NOZZLE | SIZE & SCH | FLANGE | MARK | NOZZLE | SIZE & SCH | FLANGE |
|---|---|---|---|---|---|---|---|
| N3 | Nozzle #3 | NPS 12 Std We | Part 4.16 Weld | | | | |
| N1 | Nozzle #1 | NPS 12 Std We | Part 4.16 Weld | | | | |
| N2 | Nozzle #2 | S.O. NPS 16 C | | | | | |

## REVISIONS

| REV | DATE | DESCRIP |
|---|---|---|
| 0 | 08/13/20 | FOR APP |

**ABC Fabricators Inc.**
2600 Washington Blvd.
Dallas, TX, 75204

DWN BY:
CHK BY:
DATE:

General Arran

DWG NO. 145685-1 Rev 0

7400.CW7

## Deficiencies Summary

**Deficiencies for Nozzle #1 (N1)**
$Leg_{41}$ = 0.25 in is less than minimum required leg size of 0.3571 in.
$Leg_{42}$ = 0.1875 in is less than minimum required leg size of 0.2143 in.

**Deficiencies for Nozzle #2 (N2)**
Shell opening diameter (16.3372 in) must be larger than 16.46 in [stud pad inner diameter (16 in) plus 2 times the lower fillet weld leg (0.23 in)].

**Deficiencies for Nozzle #3 (N3)**
$Leg_{41}$ = 0.25 in is less than minimum required leg size of 0.3571 in.
$Leg_{42}$ = 0.1875 in is less than minimum required leg size of 0.2143 in.

## Warnings Summary

**Warnings for Cylinder #1**
INSPECT only supports butt joint construction in shell components. Please check the circumferential joint between Cylinder #1 and Cylinder #2. A common source of this error is specifying one component as an OD design and an adjacent component as an ID design. (warning)

**Warnings for Cylinder #2**
INSPECT only supports butt joint construction in shell components. Please check the circumferential joint between Cylinder #2 and Ellipsoidal Head #2. A common source of this error is specifying one component as an OD design and an adjacent component as an ID design. (warning)

**Warnings for Ellipsoidal Head #1**
INSPECT only supports butt joint construction in shell components. Please check the circumferential joint between Ellipsoidal Head #1 and Cylinder #1. A common source of this error is specifying one component as an OD design and an adjacent component as an ID design. (warning)

**Warnings for Nozzle #1 (N1)**
$Leg_{41}$ = 0.25 in is less than minimum required leg size of 0.3571 in. (new condition) (warning)
$Leg_{42}$ = 0.1875 in is less than minimum required leg size of 0.2143 in. (new condition) (warning)
The design of this nozzle does not include mill undertolerance because a minimum (as built) thickness was entered. (warning)

**Warnings for Nozzle #3 (N3)**
$Leg_{41}$ = 0.25 in is less than minimum required leg size of 0.3571 in. (new condition) (warning)
$Leg_{42}$ = 0.1875 in is less than minimum required leg size of 0.2143 in. (new condition) (warning)
The design of this nozzle does not include mill undertolerance because a minimum (as built) thickness was entered. (warning)

## Nozzle Schedule

| Nozzle mark | Service | Size | Materials | | Impact Tested | Normalized | Fine Grain | Flange | Blind |
|---|---|---|---|---|---|---|---|---|---|
| N1 | Nozzle #1 | NPS 12 Std Weight | Nozzle | SA-106 B Smls pipe | No | No | No | Part 4.16 Weld Neck Integral SA-516 70 | No |
| | | | Pad | SA-516 70 | No | No | No | | |
| N2 | Nozzle #2 | Studding Outlet NPS 16 Class 300 | Nozzle | SA-105 | No | No | No | N/A | No |
| N3 | Nozzle #3 | NPS 12 Std Weight | Nozzle | SA-106 B Smls pipe | No | No | No | Part 4.16 Weld Neck Integral SA-516 70 | No |
| | | | Pad | SA-516 70 | No | No | No | | |

## Nozzle Summary

| Nozzle mark | OD (in) | $t_n$ (in) | Req $t_n$ (in) | Shell | | | Reinforcement Pad | | Corr (in) | Gov. Stress Ratio (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Nom t (in) | Design t (in) | User t (in) | Width (in) | $t_{pad}$ (in) | | |
| N1 | 12.75 | 0.375 | 0.3281 | 0.371 | N/A | 0.371 | 3 | 0.25 | 0 | 100.0 |
| N2 | 25.5 | 4.75 | 0.2556 | 0.23* | 0.207 | 0.23 | N/A | N/A | 0 | 119.6 |
| N3 | 12.75 | 0.375 | 0.3281 | 0.37 | N/A | 0.37 | 3 | 0.25 | 0 | 100.0 |

| | |
|---|---|
| $t_n$: | Nozzle thickness |
| Req $t_n$: | Nozzle thickness required per 4.5.4.1 |
| Nom t: | Vessel wall thickness |
| Design t: | Required vessel wall thickness due to pressure + corrosion allowance per 4.5.17 |
| User t: | Local vessel wall thickness (near opening) |
| Gov. Stress Ratio: | Minimum stress ratio, $S_{allow} / P_L$, $S / \tau$ , $S / \tau_n$ |
| Corr: | Corrosion allowance on nozzle wall |
| * | Head minimum thickness after forming |

## Pressure Summary for Chamber bounded by Ellipsoidal Head #2 and Ellipsoidal Head #1

<table>
<tr><th>Identifier</th><th>P Design ( psi)</th><th>T Design ( °F)</th><th>MAWP ( psi)</th><th>MDMT ( °F)</th><th colspan="2">MDMT Exemption</th><th>Impact Tested</th></tr>
<tr><td>Ellipsoidal Head #1</td><td>100</td><td>650</td><td>144.02</td><td>N/A</td><td colspan="2">N/A</td><td>No</td></tr>
<tr><td>Ellipsoidal Head #1 (Dished Region)</td><td>100</td><td>650</td><td>160.69</td><td>N/A</td><td colspan="2">N/A</td><td>No</td></tr>
<tr><td>Straight Flange on Ellipsoidal Head #1</td><td>100</td><td>650</td><td>233.25</td><td>N/A</td><td colspan="2">N/A</td><td>No</td></tr>
<tr><td>Cylinder #1</td><td>100</td><td>650</td><td>230.08</td><td>N/A</td><td colspan="2">N/A</td><td>No</td></tr>
<tr><td>Cylinder #2</td><td>100</td><td>650</td><td>230.12</td><td>N/A</td><td colspan="2">N/A</td><td>No</td></tr>
<tr><td>Straight Flange on Ellipsoidal Head #2</td><td>100</td><td>650</td><td>233.25</td><td>N/A</td><td colspan="2">N/A</td><td>No</td></tr>
<tr><td>Ellipsoidal Head #2</td><td>100</td><td>650</td><td>144.02</td><td>N/A</td><td colspan="2">N/A</td><td>No</td></tr>
<tr><td>Ellipsoidal Head #2 (Dished Region)</td><td>100</td><td>650</td><td>160.69</td><td>N/A</td><td colspan="2">N/A</td><td>No</td></tr>
<tr><td>Saddle #1</td><td>100</td><td>650</td><td>144.02</td><td>N/A</td><td colspan="2">N/A</td><td>N/A</td></tr>
<tr><td rowspan="2">Nozzle #1 (N1)</td><td rowspan="2">100</td><td rowspan="2">650</td><td rowspan="2">175.89</td><td rowspan="2">N/A</td><td>Nozzle</td><td>N/A</td><td>No</td></tr>
<tr><td>Pad</td><td>N/A</td><td>No</td></tr>
<tr><td>Flange #2</td><td>100</td><td>650</td><td>166.57</td><td>N/A</td><td colspan="2">N/A</td><td>No</td></tr>
<tr><td>Nozzle #2 (N2)</td><td>100</td><td>650</td><td>160.01</td><td>N/A</td><td colspan="2">N/A</td><td>No</td></tr>
<tr><td rowspan="2">Nozzle #3 (N3)</td><td rowspan="2">100</td><td rowspan="2">650</td><td rowspan="2">176.02</td><td rowspan="2">N/A</td><td>Nozzle</td><td>N/A</td><td>No</td></tr>
<tr><td>Pad</td><td>N/A</td><td>No</td></tr>
<tr><td>Flange #3</td><td>100</td><td>650</td><td>166.57</td><td>N/A</td><td colspan="2">N/A</td><td>No</td></tr>
</table>

Chamber MAWP hot & corroded is 144.02 psi @ 650 °F

This pressure chamber is not designed for external pressure.

Design notes are available on the Settings Summary page.

## Revision History

| No. | Date | Operator | Notes |
|---|---|---|---|
| 0 | 8/13/2013 | Matt | New vessel created ASME Section VIII Division 1 [COMPRESS 2013 Build 7330] |
| 1 | 12/13/2013 | Matt | Converted from ASME Section VIII Division 1, 2010 Edition, A11 Addenda to ASME Section VIII Division 1, 2013 Edition. During the conversion, changes may have been made to your vessel (some may be listed above). Please check your vessel carefully. |

## Settings Summary

## INSPECT 2014 Build 7400

**Vessel calculations are based on the projected corroded state of the vessel at the date of the inspection on 12/12/2013**

**Units: U.S. Customary**

**Datum Line Location: 0.00" from right seam**

### Design

ASME Section VIII Division 1, 2013 Edition

| | |
|---|---|
| Design or Rating: | Get Pressure Rating and Calculate Required Thickness |
| Minimum thickness: | 0.0625" per UG-16(b) |
| Design for cold shut down only: | No |
| Design for lethal service (full radiography required): | No |
| Rate nozzles for: | Find nozzle MAWP |
| Corrosion weight loss: | 100% of theoretical loss |
| UG-23 Stress Increase: | 1.20 |
| Skirt/legs stress increase: | 1.0 |
| Minimum nozzle projection: | 0.001" |
| Juncture calculations for $\alpha$ > 30 only: | Yes |
| Preheat P-No 1 Materials > 1.25" and <= 1.50" thick: | No |
| UG-37(a) shell tr calculation considers longitudinal stress: | No |

Pipe under-tolerance is not applied to cylindrical shell thicknesses.
Pipe under-tolerance is not applied to nozzle wall thicknesses.
Pipe under-tolerance is not applied to pipe cap thicknesses.
Butt welds are tapered per Figure UCS-66.3(a).

### Hydro/Pneumatic Test

| | |
|---|---|
| Maximum stress during test: | 90% of yield |

### Required Marking - UG-116

| | |
|---|---|
| UG-116(e) Radiography: | RT1 |
| UG-116(f) Postweld heat treatment: | None |

### Code Cases\Interpretations

| | |
|---|---|
| Use Code Case 2547: | No |
| Use Code Case 2695: | Yes |
| Apply interpretation VIII-1-83-66: | Yes |
| Apply interpretation VIII-1-86-175: | Yes |
| Apply interpretation VIII-1-01-37: | Yes |
| No UCS-66.1 MDMT reduction: | No |
| No UCS-68(c) MDMT reduction: | No |
| Disallow UG-20(f) exemptions: | No |

**UG-22 Loadings**

| | |
|---|---|
| UG-22(a) Internal or External Design Pressure : | Yes |
| UG-22(b) Weight of the vessel and normal contents under operating or test conditions: | Yes |
| UG-22(c) Superimposed static reactions from weight of attached equipment (external loads): | No |
| UG-22(d)(2) Vessel supports such as lugs, rings, skirts, saddles and legs: | Yes |
| UG-22(f) Wind reactions: | No |
| UG-22(f) Seismic reactions: | No |
| UG-22(j) Test pressure and coincident static head acting during the test: | No |

Note: UG-22(b),(c) and (f) loads only considered when supports are present.

## Radiography Summary

### Radiography for Chamber bounded by Ellipsoidal Head #2 and Ellipsoidal Head #1

| Component | Longitudinal Seam | | Left Circumferential Seam | | Right Circumferential Seam | | Mark |
|---|---|---|---|---|---|---|---|
| | Category (Fig UW-3) | Radiography / Joint Type | Category (Fig UW-3) | Radiography / Joint Type | Category (Fig UW-3) | Radiography / Joint Type | |
| Ellipsoidal Head #1 | N/A | Seamless No RT | N/A | N/A | B | Full UW-11(a) / Type 1 | RT1 |
| Cylinder #1 | A | Full UW-11(a) / Type 1 | B | Full UW-11(a) / Type 1 | B | Full UW-11(a) / Type 1 | RT1 |
| Cylinder #2 | A | Full UW-11(a) / Type 1 | B | Full UW-11(a) / Type 1 | B | Full UW-11(a) / Type 1 | RT1 |
| Ellipsoidal Head #2 | N/A | Seamless No RT | B | Full UW-11(a) / Type 1 | N/A | N/A | RT1 |
| **Nozzle** | **Longitudinal Seam** | | **Nozzle to Vessel Circumferential Seam** | | **Nozzle free end Circumferential Seam** | | |
| Nozzle #2 (N2) | N/A | Seamless No RT | D | N/A / Type 7 | N/A | N/A | N/A |
| Nozzle #1 (N1) | N/A | Seamless No RT | D | N/A / Type 7 | C | Full UW-11(a) / Type 1 | RT1 |
| Nozzle #3 (N3) | N/A | Seamless No RT | D | N/A / Type 7 | C | Full UW-11(a) / Type 1 | RT1 |
| **Nozzle Flange** | **Longitudinal Seam** | | **Flange Face** | | **Nozzle to Flange Circumferential Seam** | | |
| Flange #2 | N/A | Seamless No RT | N/A | N/A / Gasketed | C | Full UW-11(a) / Type 1 | RT1 |
| Flange #3 | N/A | Seamless No RT | N/A | N/A / Gasketed | C | Full UW-11(a) / Type 1 | RT1 |
| Chamber bounded by Ellipsoidal Head #2 and Ellipsoidal Head #1 - UG-116(e) Radiography: **RT1** | | | | | | | |

## Thickness Summary

| Component Identifier | Material | Diameter (in) | Length (in) | Nominal t (in) | Design t (in) | Total Corrosion (in) | Joint E | Load |
|---|---|---|---|---|---|---|---|---|
| Ellipsoidal Head #1 | SA-516 70 | 60 ID | 15.23 | 0.23* | 0.1597 | 0 | 1.00 | Internal |
| Straight Flange on Ellipsoidal Head #1 | SA-516 70 | 60 ID | 2 | 0.375 | 0.1601 | 0 | 1.00 | Internal |
| Ellipsoidal Head #1 (Dished Region) | SA-516 70 | 107.5463 ID | 54.0031 | 0.23* | 0.1431 | 0 | 1.00 | Internal |
| Cylinder #1 | SA-516 70 | 60.258 ID | 96 | 0.371 | 0.1607 | 0 | 1.00 | Internal |
| Cylinder #2 | SA-516 70 | 60.085 ID | 96 | 0.37 | 0.1602 | 0 | 1.00 | Internal |
| Straight Flange on Ellipsoidal Head #2 | SA-516 70 | 60 ID | 2 | 0.375 | 0.1601 | 0 | 1.00 | Internal |
| Ellipsoidal Head #2 | SA-516 70 | 60 ID | 15.23 | 0.23* | 0.1597 | 0 | 1.00 | Internal |
| Ellipsoidal Head #2 (Dished Region) | SA-516 70 | 107.5463 ID | 54.0031 | 0.23* | 0.1431 | 0 | 1.00 | Internal |

| | |
|---|---|
| Nominal t: | Vessel wall nominal thickness |
| Design t: | Required vessel thickness due to governing loading + corrosion |
| Joint E: | Longitudinal seam joint efficiency |
| * | Head minimum thickness after forming |

Load

| | |
|---|---|
| internal: | Circumferential stress due to internal pressure governs |
| external: | External pressure governs |
| Wind: | Combined longitudinal stress of pressure + weight + wind governs |
| Seismic: | Combined longitudinal stress of pressure + weight + seismic governs |

## Weight Summary

| Component | Weight ( lb) Contributed by Vessel Elements | | | | | | | | | | Surface Area ft² |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Metal New* | Metal Corroded* | Insulation | Insulation Supports | Lining | Piping + Liquid | Operating Liquid | | Test Liquid | | |
| | | | | | | | New | Corroded | New | Corroded | |
| Ellipsoidal Head #1 | 279.5 | 279.5 | 0 | 0 | 0 | 0 | 0 | 0 | 1,232.1 | 1,232.1 | 30 |
| Cylinder #1 | 1,906.4 | 1,906.4 | 0 | 0 | 0 | 0 | 0 | 0 | 9,953.9 | 9,953.9 | 127 |
| Cylinder #2 | 1,895.8 | 1,895.8 | 0 | 0 | 0 | 0 | 0 | 0 | 9,913.7 | 9,913.7 | 127 |
| Ellipsoidal Head #2 | 312.8 | 312.8 | 0 | 0 | 0 | 0 | 0 | 0 | 1,224.7 | 1,224.7 | 33 |
| Saddle #1 | 578 | 578 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 59 |
| **TOTAL:** | **4,972.5** | **4,972.5** | **0** | **0** | **0** | **0** | **0** | **0** | **22,324.4** | **22,324.4** | **376** |

* Shells with attached nozzles have weight reduced by material cut out for opening.

| Component | Weight ( lb) Contributed by Attachments | | | | | | | | | Surface Area ft² |
|---|---|---|---|---|---|---|---|---|---|---|
| | Body Flanges | | Nozzles & Flanges | | Packed Beds | Trays | Tray Supports | Rings & Clips | Vertical Loads | |
| | New | Corroded | New | Corroded | | | | | | |
| Ellipsoidal Head #1 | 0 | 0 | 198.9 | 198.9 | 0 | 0 | 0 | 0 | 0 | 1 |
| Cylinder #1 | 0 | 0 | 102.1 | 102.1 | 0 | 0 | 0 | 0 | 0 | 6 |
| Cylinder #2 | 0 | 0 | 135.9 | 135.9 | 0 | 0 | 0 | 0 | 0 | 7 |
| Ellipsoidal Head #2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL:** | **0** | **0** | **436.9** | **436.9** | **0** | **0** | **0** | **0** | **0** | **13** |

Vessel operating weight, Corroded: 5,409 lb
Vessel operating weight, New: 5,409 lb
Vessel empty weight, Corroded: 5,409 lb
Vessel empty weight, New: 5,409 lb
Vessel test weight, New: 27,734 lb
Vessel test weight, Corroded: 27,734 lb
Vessel surface area: 388 ft²

### Vessel center of gravity location - from datum - lift condition

Vessel Lift Weight, New: 5,409 lb
Center of Gravity: 99.2098"

### Vessel Capacity

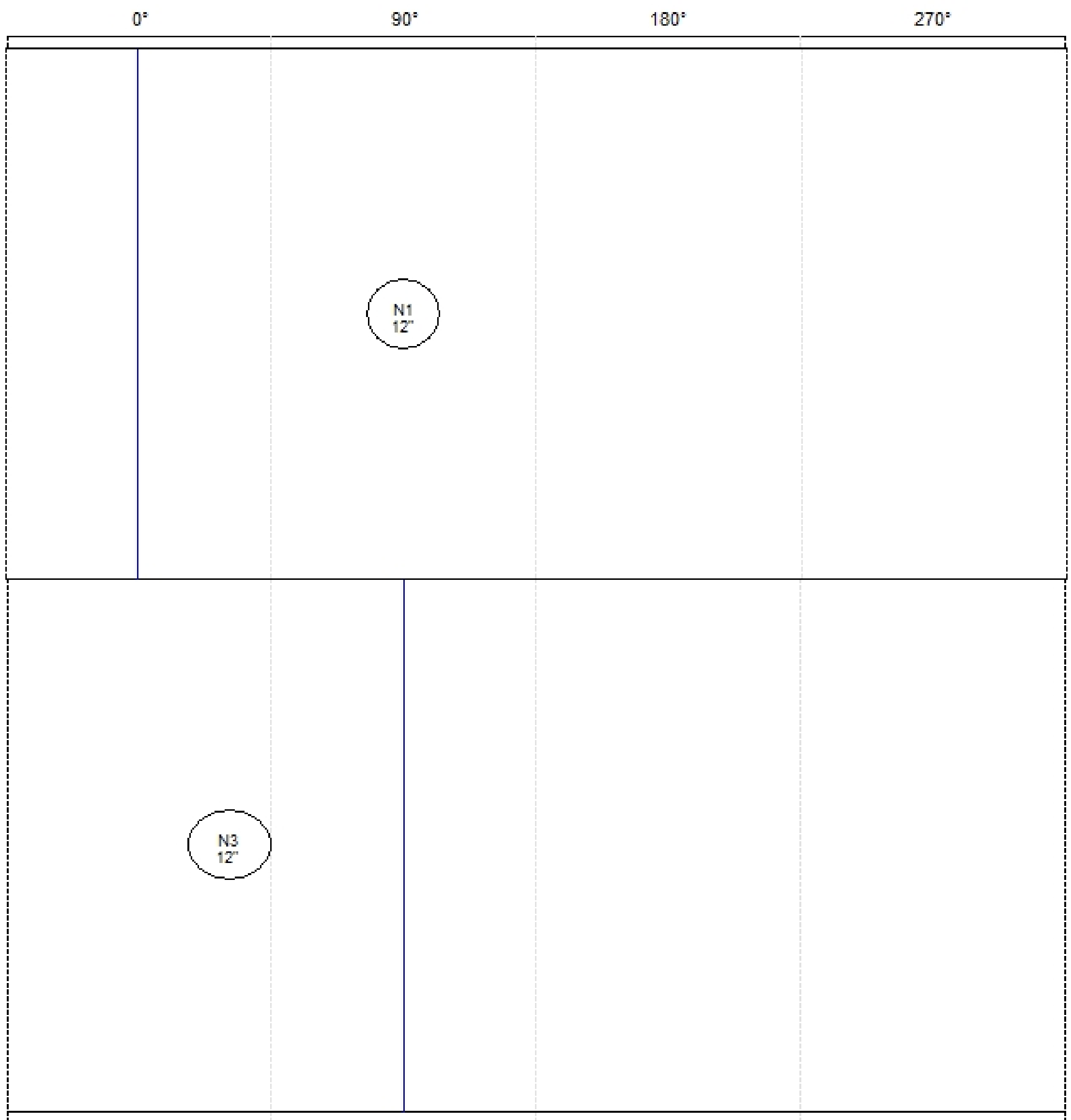
Vessel Capacity** (New): 2,657 US gal
Vessel Capacity** (Corroded): 2,657 US gal
**The vessel capacity does not include volume of nozzle, piping or other attachments.

## Long Seam Summary

| Shell Long Seam Angles | |
|---|---|
| Component | Seam 1 |
| Cylinder #1 | 0° |
| Cylinder #2 | 90° |

| Shell Plate Lengths | | |
|---|---|---|
| Component | Starting Angle | Plate 1 |
| Cylinder #1 | 0° | 190.4716" |
| Cylinder #2 | 90° | 189.925" |

*Plate Lengths use the circumference of the vessel based on the mid diameter of the components




Shell Rollout

## Test Report

The shop test condition has not been investigated for the Chamber bounded by Ellipsoidal Head #2 and Ellipsoidal Head #1.

The field test condition has not been investigated for the Chamber bounded by Ellipsoidal Head #2 and Ellipsoidal Head #1.

**Inspection on 12/12/2013**

| Calculation Results Summary | | | |
|---|---|---|---|
| **Projected Retirement Date:** | 8/10/2845 | **Governing Component:** | Nozzle #3 (N3) |
| **Governing CML:** | CML 28 on Cylinder #2 | **Projected Thickness at Retirement Date:** | 0.1621" |
| **Target MAWP:** | 100 psi @ 650 °F | **Target MAEP:** | N/A |

| Equipment Information | |
|---|---|
| **Vessel Name:** | 7400 |

**Summary of Thickness Measurements**

| Component | Previous Average Thickness | Average Measured Thickness | Governing CML Thickness | Minimum Required Thickness | Short Term Corrosion Rate | Long Term Corrosion Rate | Remaining Life | Governing Component |
|---|---|---|---|---|---|---|---|---|
| Ellipsoidal Head #1 | 0.23" | 0.23" | 0.23" | 0.1597" | 0"/yr | 0"/yr | - | No |
| Cylinder #1 | 0.375" | 0.3748" | 0.371" | 0.1616" | 0.0002"/yr | 0.0002"/yr | 1,047.111 years | No |
| Cylinder #2 | 0.375" | 0.3748" | 0.37" | 0.1621" | 0.00025"/yr | 0.00025"/yr | 831.66 years | No |
| Ellipsoidal Head #2 | 0.23" | 0.23" | 0.23" | 0.1597" | 0"/yr | 0"/yr | - | No |
| Nozzle #3 (N3) | 0.375" | 0.375" | 0.375" | 0.375" | 0"/yr | 0"/yr | 831.66 years | **Yes** |

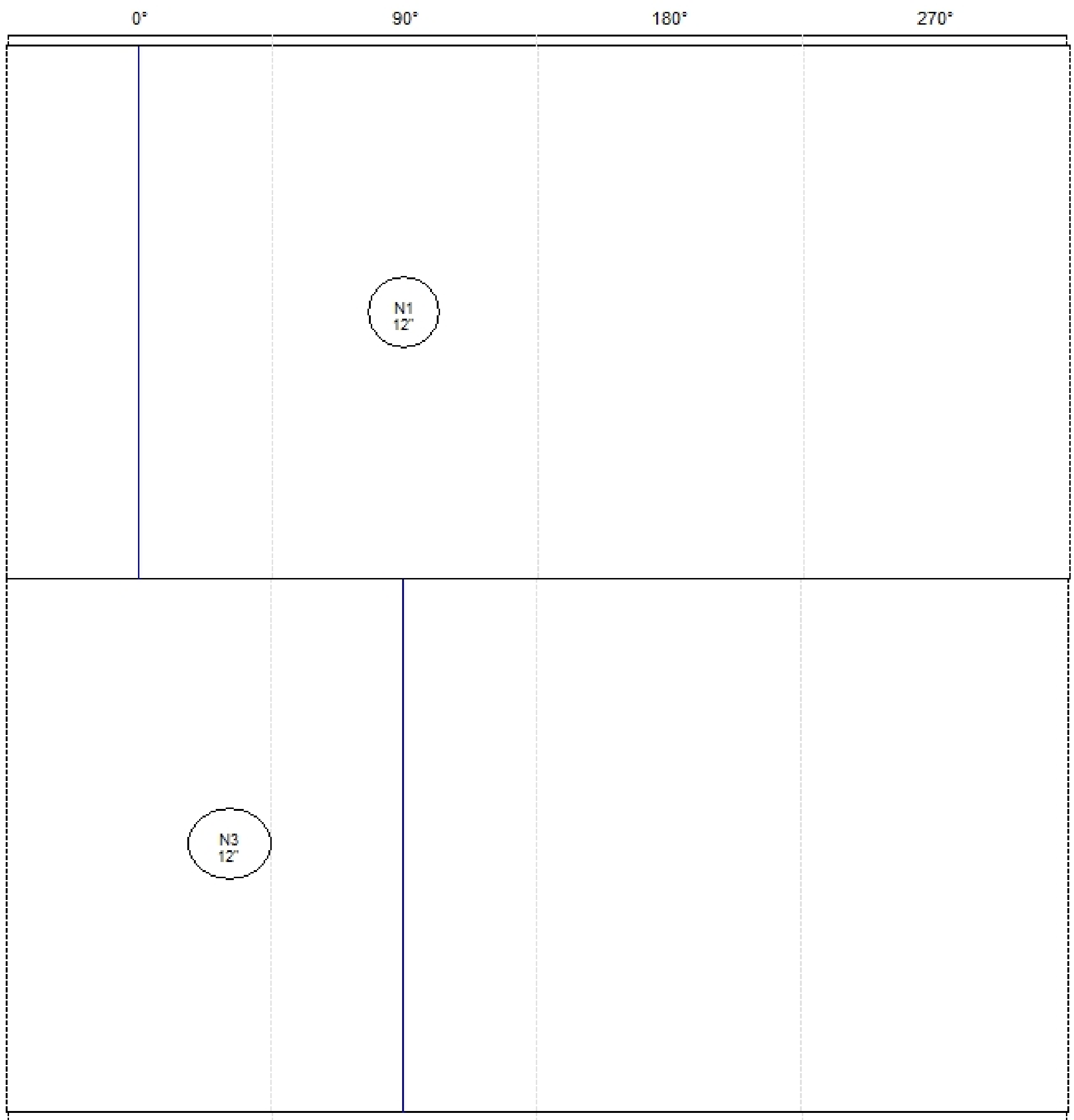
*The Previous Average Thickness is average measured thickness from the previous thickness inspection of each component.

| Inspection on 12/12/2013 | | | |
|---|---|---|---|
| **Inspection Date:** | 12/12/2013 | **Report Date:** | 12/12/2013 |
| **Inspections Performed** | | | |
| **Visual Inspection(VT): External** | YES | **Visual Inspection(VT): Internal** | YES |
| **Thickness Inspection:** | YES | | |

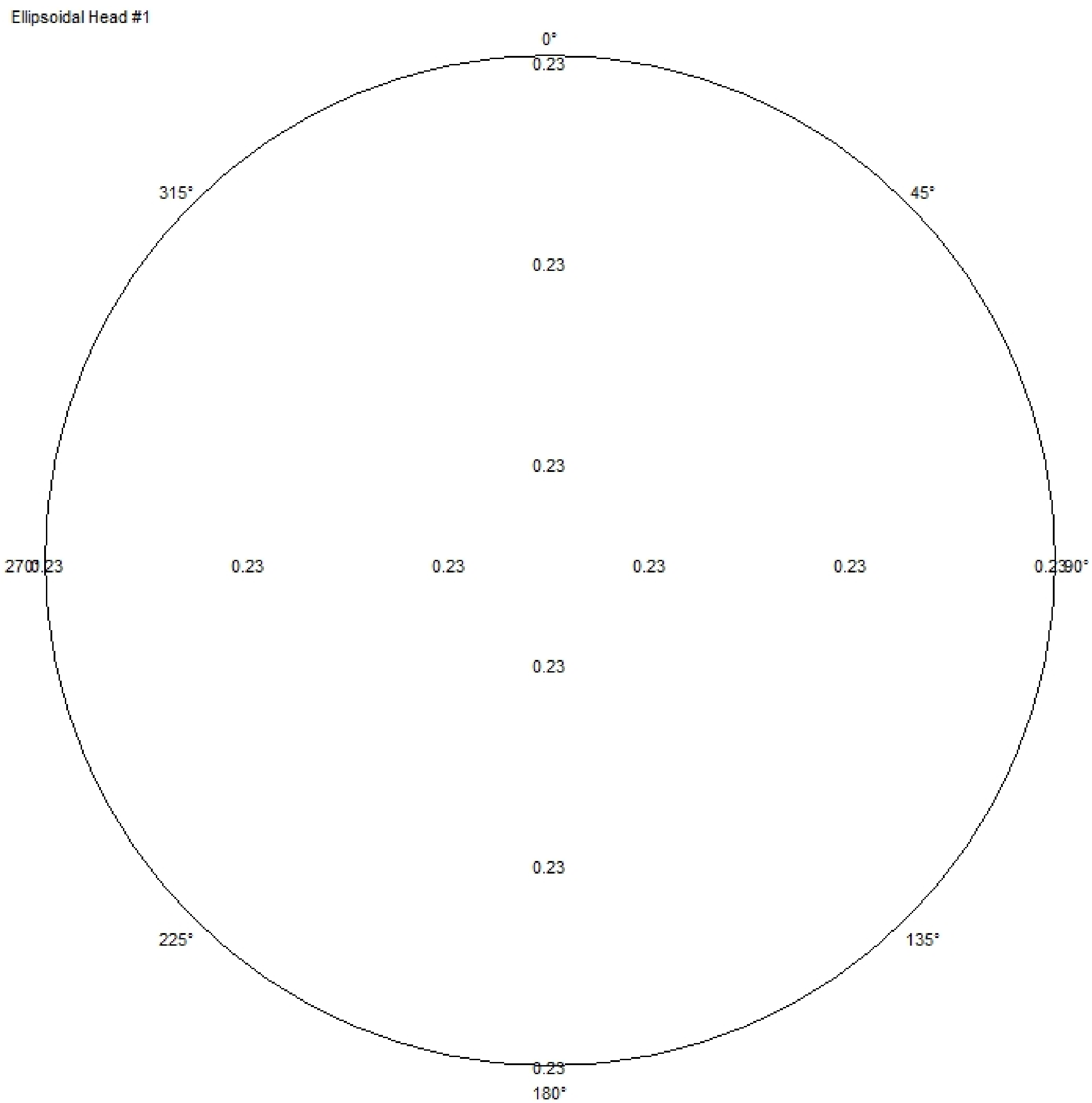
| Shell Courses | | | | | | |
|---|---|---|---|---|---|---|
| Course | ID | Course Length | Allowable Stress | Joint Efficiency (circ, long) | Actual Thickness | Required Thickness |
| 1 | Straight Flange on Ellipsoidal Head #1 | 192" - 194" | 18,800 psi | 1, 1 | N/A | 0.1601" |
| 2 | Cylinder #1 | 96" - 192" | 18,800 psi | 1, 1 | 0.371" | 0.1616" |
| 3 | Cylinder #2 | 0" - 96" | 18,800 psi | 1, 1 | 0.37" | 0.1621" |
| 4 | Straight Flange on Ellipsoidal Head #2 | -2" - 0" | 18,800 psi | 1, 1 | N/A | 0.1601" |

| Shell Measured Thickness | | | | |
|---|---|---|---|---|
| | **0 °** | **90 °** | **180 °** | **270 °** |
| **182"** | 0.375" | 0.375" | 0.375" | 0.375" |
| **170"** | 0.375" | 0.375" | 0.375" | 0.375" |
| **158"** | 0.375" | 0.375" | 0.375" | 0.375" |
| **146"** | 0.374" | 0.375" | 0.371" | 0.375" |
| **134"** | 0.375" | 0.375" | 0.375" | 0.375" |
| **122"** | 0.375" | 0.375" | 0.375" | 0.375" |
| **110"** | 0.375" | 0.373" | 0.375" | 0.375" |
| **98"** | 0.375" | 0.375" | 0.375" | 0.375" |
| **86"** | 0.375" | 0.375" | 0.375" | 0.375" |
| **74"** | 0.375" | 0.375" | **0.37"** | 0.375" |
| **62"** | 0.375" | 0.375" | 0.375" | 0.375" |
| **50"** | 0.375" | 0.375" | 0.375" | 0.375" |
| **38"** | 0.375" | 0.375" | 0.375" | 0.375" |
| **26"** | 0.375" | 0.375" | 0.375" | 0.375" |
| **14"** | 0.375" | 0.375" | 0.375" | 0.375" |
| **2"** | 0.375" | 0.375" | 0.375" | 0.375" |

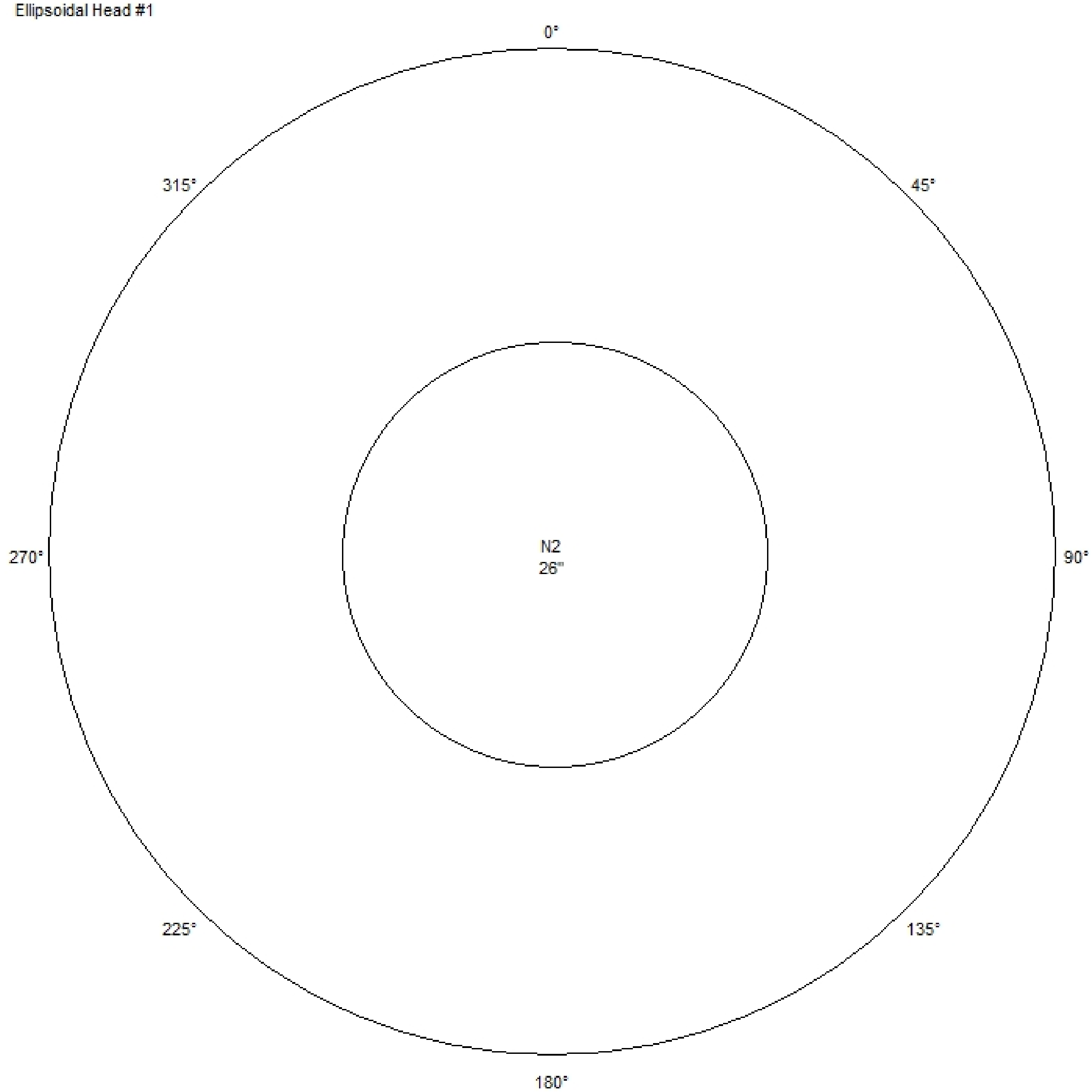
| 0° | 90° | 180° | 270° |
|---|---|---|---|
| 0.375 | 0.375 | 0.375 | 0.375 |
| 0.375 | 0.375 | 0.375 | 0.375 |
| 0.375 | 0.375 | 0.375 | 0.375 |
| 0.374 | 0.375 | 0.371 | 0.375 |
| 0.375 | 0.375 | 0.375 | 0.375 |
| 0.375 | 0.375 | 0.375 | 0.375 |
| 0.375 | 0.373 | 0.375 | 0.375 |
| 0.375 | 0.375 | 0.375 | 0.375 |
| 0.375 | 0.375 | 0.375 | 0.375 |
| 0.375 | 0.375 | 0.37 | 0.375 |
| 0.375 | 0.375 | 0.375 | 0.375 |
| 0.375 | 0.375 | 0.375 | 0.375 |
| 0.375 | 0.375 | 0.375 | 0.375 |
| 0.375 | 0.375 | 0.375 | 0.375 |
| 0.375 | 0.375 | 0.375 | 0.375 |
| 0.375 | 0.375 | 0.375 | 0.375 |


0°
90°
180°
270°
N1
12"
N3
12"

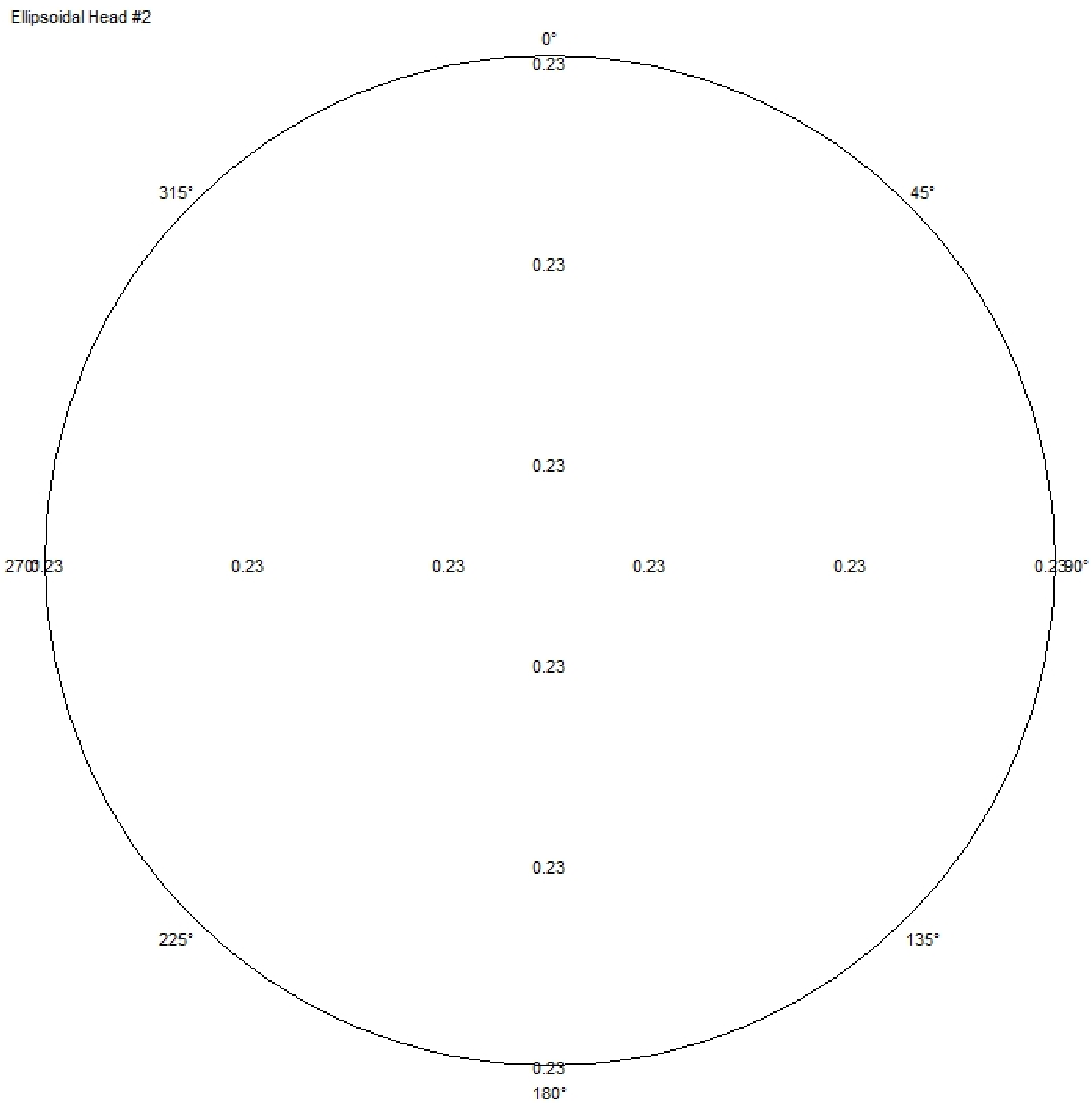
| Ellipsoidal Head #1 Measured Thickness | | | | |
|---|---|---|---|---|
| | **0 °** | **90 °** | **180 °** | **270 °** |
| **30"** | 0.23" | 0.23" | 0.23" | 0.23" |
| **18"** | 0.23" | 0.23" | 0.23" | 0.23" |
| **6"** | 0.23" | 0.23" | 0.23" | 0.23" |



Ellipsoidal Head #1



| Ellipsoidal Head #2 Measured Thickness | | | | |
|---|---|---|---|---|
| | 0 ° | 90 ° | 180 ° | 270 ° |
| **30"** | 0.23" | 0.23" | 0.23" | 0.23" |
| **18"** | 0.23" | 0.23" | 0.23" | 0.23" |
| **6"** | 0.23" | 0.23" | 0.23" | 0.23" |



| Nozzle Readings | | | |
|---|---|---|---|
| | **Dist from Nozzle End** | **0 °** | **180 °** |
| **N2** | **1.2191"** | 4.75" | 4.75" |
| **N1** | **7.9063"** | 0.375" | 0.375" |
| **N3** | **8.5314"** | 0.375" | 0.375" |

| Shell Details | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Component** | **Measured Thickness** | **Min. Reqired Thickness** | **Length** | **Rem Corr.** | **Governs** | **Corr. Allow** | **Material** |
| Cylinder #1 | 0.371" | 0.1616" | 96" | 0.2094" | No | 0" | SA-516 70 |
| Cylinder #2 | 0.37" | 0.1621" | 96" | 0.2079" | No | 0" | SA-516 70 |

| Head Details | | | | | | |
|---|---|---|---|---|---|---|
| **Component** | **Measured Thickness** | **Min. Reqired Thickness** | **Rem Corr.** | **Governs** | **Corr. Allow** | **Material** |
| Ellipsoidal Head #1 | 0.23" | 0.1597" | 0.0703" | No | 0" | SA-516 70 |
| Ellipsoidal Head #2 | 0.23" | 0.1597" | 0.0703" | No | 0" | SA-516 70 |

| Nozzle Details | | | | |
|---|---|---|---|---|
| **Nozzle** | **Minimum Measured Thickness** | **Governs** | **Corr. Allow** | **Material** |
| Nozzle #2 (N2) | 4.75" | No | 0" | SA-105 |
| Nozzle #1 (N1) | 0.375" | No | 0" | SA-106 B |
| Nozzle #3 (N3) | 0.375" | **Yes** | 0" | SA-106 B |

*The minimum required thickness may be calculated for each nozzle by activating the switch on the *Remaining Life Basis* dialog.

## Remaining Life Calculation

| | |
|---|---|
| Governing Component: | Nozzle #3 (N3) due to corrosion on Cylinder #2 |
| Corrosion Basis: | Short Term Corrosion Rate (ST) |
| Target MAWP: | 100 psi @ 650 °F |
| Target MAEP: | N/A |
| Current Inspection Date: | 12/12/2013 |

**Governing CML**

| | |
|---|---|
| CML ID: | CML 28 on Cylinder #2 |
| Minimum Required Thickness, $t_{required}$: | 0.1621" |
| Measured Thickness, $t_{actual}$: | 0.37" |

| | |
|---|---|
| Measured On: | 12/12/2013 |
| Previous Measured Thickness, $t_{previous}$: | 0.375" |
| Previously Measured On: | 12/12/1993 |
| Time Between Measurements: | 20 years |

*Nozzle #3 (N3) governs, yet does not have a valid corrosion rate.

*$t_{required}$ in this case is the thickness of Cylinder #2, at the point where Nozzle #3 (N3) fails.

**Corrosion Rate**

Corrosion Rate = ($t_{previous}$ - $t_{actual}$) / Years Difference
= (0.375 - 0.37) / 20
= 0.00025"/yr

**Remaining Life**

Remaining Life = ($t_{actual}$ - $t_{required}$) / Corrosion Rate
= (0.37 - 0.1621) / 0.00025
= 831.66 years

**Thickness Inspection Interval, API 510 6.5**

415.83 years or 10 years (whichever is less) = 10 years
Next Thickness Inspection required by **12/12/2023**

**Internal Inspection Interval, API 510 6.5**

415.83 years or 10 years (whichever is less) = 10 years
Next Internal Inspection required by **12/12/2023**

**External Inspection Interval, API 510 6.4**

415.83 years or 5 years (whichever is less) = 5 years
Next External Inspection required by **12/12/2018**

**Projected Retirement Date**

12/12/2013 + 831.66 years = **8/10/2845**

## Cylinder #1

| ASME Section VIII Division 1, 2013 Edition (Code Case 2695) | | | | |
|---|---|---|---|---|
| **Component** | | Cylinder | | |
| **Material** | | SA-516 70 (II-D p. 22, ln. 6) | | |
| **Impact Tested** | **Normalized** | **Fine Grain Practice** | **PWHT** | **Optimize MDMT/ Find MAWP** |
| No | No | No | No | No |
| | | **Design Pressure (psi)** | **Design Temperature (°F)** | **Design MDMT (°F)** |
| **Internal** | | 100 | 650 | -20 |
| **Dimensions** | | | | |
| **Inner Diameter** | | 60.258" | | |
| **Length** | | 96" | | |
| **Nominal Thickness** | | 0.371" | | |
| **Corrosion** | **Inner** | 0" | | |
| | **Outer** | 0" | | |
| | | **Weight (lb)** | | **Capacity (US gal)** |
| **New** | | 1,906.42 | | 1,185.16 |
| **Corroded** | | 1,906.42 | | 1,185.16 |
| **Radiography** | | | | |
| **Longitudinal seam** | | Full UW-11(a) Type 1 | | |
| **Left Circumferential seam** | | Full UW-11(a) Type 1 | | |
| **Right Circumferential seam** | | Full UW-11(a) Type 1 | | |

| Results Summary | |
|---|---|
| Governing condition | Operating Hot & Corroded |
| Design thickness due to internal pressure (t) | 0.1607" |
| Minimum thickness per 4.1.2 | 0.0625" |
| Maximum allowable working pressure (MAWP) | 230.08 psi |

| Division 2 4.3.3.1 Design Thickness for Internal Pressure | |
|---|---|
| $t_d$ = D / 2 * (exp[P / (S*E)] - 1) + Corrosion | (4.3.1) |
| **Operating Hot & Corroded** | |
| $t_d$ = 60.258 / 2 * (exp[(100 + 0) / (18,800*1)] - 1) + 0 = | 0.1607" |
| **Operating Cold & Corroded** | |
| $t_r$ = 60.258 / 2 * (exp[(144.02 + 0) / (20,000*1)] - 1) = | 0.2177" |

| Division 2 4.3.3.1 Maximum Pressure Circumferential Stress | |
|---|---|
| $P_{max}$ = S*E*ln[$D_o$ / D] | (4.3.1) |
| **MAWP** | |
| $P_{max}$ = 18,800*1*ln[61 / 60.258] - 0 = | 230.08 psi |

## Cylinder #2

| ASME Section VIII Division 1, 2013 Edition (Code Case 2695) | | | | | |
|---|---|---|---|---|---|
| **Component** | | Cylinder | | | |
| **Material** | | SA-516 70 (II-D p. 22, ln. 6) | | | |
| **Impact Tested** | **Normalized** | **Fine Grain Practice** | **PWHT** | **Optimize MDMT/ Find MAWP** | |
| No | No | No | No | No | |
| | | **Design Pressure (psi)** | **Design Temperature (°F)** | **Design MDMT (°F)** | |
| **Internal** | | 100 | 650 | -20 | |
| **Dimensions** | | | | | |
| **Inner Diameter** | | 60.085" | | | |
| **Length** | | 96" | | | |
| **Nominal Thickness** | | 0.37" | | | |
| **Corrosion** | **Inner** | 0" | | | |
| | **Outer** | 0" | | | |
| | | **Weight (lb)** | | **Capacity (US gal)** | |
| **New** | | 1,895.79 | | 1,178.37 | |
| **Corroded** | | 1,895.79 | | 1,178.37 | |
| **Radiography** | | | | | |
| **Longitudinal seam** | | Full UW-11(a) Type 1 | | | |
| **Left Circumferential seam** | | Full UW-11(a) Type 1 | | | |
| **Right Circumferential seam** | | Full UW-11(a) Type 1 | | | |

| Results Summary | |
|---|---|
| Governing condition | Operating Hot & Corroded |
| Design thickness due to internal pressure (t) | 0.1602" |
| Minimum thickness per 4.1.2 | 0.0625" |
| Maximum allowable working pressure (MAWP) | 230.12 psi |

| Division 2 4.3.3.1 Design Thickness for Internal Pressure | |
|---|---|
| $t_d$ = D / 2 * (exp[P / (S*E)] - 1) + Corrosion | (4.3.1) |
| **Operating Hot & Corroded** | |
| $t_d$ = 60.085 / 2 * (exp[(100 + 0) / (18,800*1)] - 1) + 0 = | 0.1602" |
| **Operating Cold & Corroded** | |
| $t_r$ = 60.085 / 2 * (exp[(144.02 + 0) / (20,000*1)] - 1) = | 0.2171" |

| Division 2 4.3.3.1 Maximum Pressure Circumferential Stress | |
|---|---|
| $P_{max}$ = S*E*ln[$D_o$ / D] | (4.3.1) |
| **MAWP** | |
| $P_{max}$ = 18,800*1*ln[60.825 / 60.085] - 0 = | 230.12 psi |

## Ellipsoidal Head #1

**ASME Section VIII Division 1, 2013 Edition**

Component: Ellipsoidal Head
Material Specification: SA-516 70 (II-D p.22, ln. 6)
Internal design pressure: P = 100 psi @ 650 °F

**Static liquid head:**

$P_s$= 0 psi (SG=1, $H_s$=0" Operating head)

Corrosion allowance: Inner C = 0" Outer C = 0"

Design MDMT = -20°F
Rated MDMT = N/A

No impact test performed
Material is not normalized
Material is not produced to fine grain practice
PWHT is not performed
Do not Optimize MDMT / Find MAWP

| | | |
|---|---|---|
| Radiography: | Category A joints - | Seamless No RT |
| | Head to shell seam - | Full UW-11(a) Type 1 |

| | | |
|---|---|---|
| Estimated weight*: | new = 279.5 lb | corr = 279.5 lb |
| Capacity*: | new = 146.9 US gal | corr = 146.9 US gal |

* includes straight flange

| | | |
|---|---|---|
| Inner diameter | = | 60" |
| Minimum head thickness | = | 0.23" |
| Head ratio D/2h | = | 2 (new) |
| Head ratio D/2h | = | 2 (corroded) |
| Straight flange length $L_{sf}$ | = | 2" |
| Nominal straight flange thickness $t_{sf}$ | = | 0.375" |

**Results Summary**

The governing condition is internal pressure.

| | | |
|---|---|---|
| Minimum thickness per UG-16 | = | 0.0625" + 0" = 0.0625" |
| Design thickness due to internal pressure (t) | = | 0.1597" |
| Maximum allowable working pressure (MAWP) | = | 144.02 psi |
| Maximum allowable external pressure (MAEP) | = | 28.01 psi |

**Design thickness for internal pressure, (Corroded at 650 °F) UG-32(d)(1)**

t = P*D / (2*S*E - 0.2*P) + Corrosion
= 100*60 / (2*18,800*1 - 0.2*100) + 0
= 0.1597"

The head internal pressure design thickness is 0.1597".

**Maximum allowable working pressure, (Corroded at 650 °F) UG-32(d)(1)**

P = 2*S*E*t / (D + 0.2*t) - $P_s$
= 2*18,800*1*0.23 / (60 +0.2*0.23) - 0
= 144.02 psi

The maximum allowable working pressure (MAWP) is 144.02 psi.

**Maximum Allowable External Pressure, (Corroded at 650 °F) UG-33(d)**

Equivalent outside spherical radius ($R_o$)

$R_o$ = $K_o$*$D_o$
= 0.8932*60.46
= 54.0031 in

A = 0.125 / ($R_o$ / t)
= 0.125 / (54.0031 / 0.23)
= 0.000532

From Table CS-2: B = 6,576.1909 psi

$P_a$ = B / ($R_o$ / t)
= 6,576.1909 / (54.0031 / 0.23)
= 28.0081 psi

**Check the Maximum External Pressure, UG-33(a)(1) UG-32(d)(1)**

P = 2*S*E*t / ((D + 0.2*t)*1.67) - $P_{s2}$
= 2*18,800*1*0.23 / ((60 +0.2*0.23)*1.67) - 0
= 86.24 psi

The maximum allowable external pressure (MAEP) is 28.01 psi.

## Straight Flange on Ellipsoidal Head #1

**ASME Section VIII Division 1, 2013 Edition**

| | |
|---|---|
| Component: | Straight Flange |
| Material specification: | SA-516 70 (II-D p. 22, ln. 6) |

Internal design pressure: P = 100 psi @ 650 °F

**Static liquid head:**

Corrosion allowance  Inner C = 0"  Outer C = 0"

PWHT is not performed

| | | |
|---|---|---|
| Radiography: | Longitudinal joint - | Seamless No RT |
| | Circumferential joint - | Full UW-11(a) Type 1 |

| | | |
|---|---|---|
| Estimated weight | New = 40.3 lb | corr = 40.3 lb |
| Capacity | New = 24.48 US gal | corr = 24.48 US gal |

| | | |
|---|---|---|
| ID | = | 60" |
| Length $L_c$ | = | 2" |
| t | = | 0.375" |

**Design thickness, (at 650 °F) UG-27(c)(1)**

t = P*R / (S*E - 0.60*P) + Corrosion
= 100*30 / (18,800*1.00 - 0.60*100) + 0
= 0.1601"

**Maximum allowable working pressure, (at 650 °F) UG-27(c)(1)**

P = S*E*t / (R + 0.60*t) - $P_s$
= 18,800*1.00*0.375 / (30 + 0.60*0.375) - 0
= 233.25 psi

**Maximum Allowable External Pressure, (Corroded & at 650 °F) UG-28(c)**

$L / D_o$ = 206 / 60.75 = 3.3909
$D_o / t$ = 60.75 / 0.375 = 162.0000
From table G: A = 0.000183
From table CS-2: B = 2,244.3648 psi

$P_a$ = 4*B / (3*($D_o$ / t))
= 4*2,244.36 / (3*(60.75 / 0.375))
= 18.47 psi

**% Extreme fiber elongation - UCS-79(d)**

EFE = (50*t / $R_f$)*(1 - $R_f$ / $R_o$)
= (50*0.375 / 30.1875)*(1 - 30.1875 / ∞)
= 0.6211%

The extreme fiber elongation does not exceed 5%.

**Allowable Compressive Stress, Hot and Corroded- $S_{cHC}$, (table CS-2)**

| | | |
|---|---|---|
| A | = | $0.125 / (R_o / t)$ |
| | = | 0.125 / (30.375 / 0.375) |
| | = | 0.001543 |
| B | = | 9,261 psi |
| S | = | 18,800 / 1.00 = 18,800 psi |
| $S_{cHC}$ | = | min(B, S) = 9,261 psi |

**Allowable Compressive Stress, Hot and New- $S_{cHN}$**

| | | |
|---|---|---|
| $S_{cHN}$ | = | $S_{cHC}$ |
| | = | 9,261 psi |

**Allowable Compressive Stress, Cold and New- $S_{cCN}$, (table CS-2)**

| | | |
|---|---|---|
| A | = | $0.125 / (R_o / t)$ |
| | = | 0.125 / (30.375 / 0.375) |
| | = | 0.001543 |
| B | = | 13,927 psi |
| S | = | 20,000 / 1.00 = 20,000 psi |
| $S_{cCN}$ | = | min(B, S) = 13,927 psi |

**Allowable Compressive Stress, Cold and Corroded- $S_{cCC}$**

| | | |
|---|---|---|
| $S_{cCC}$ | = | $S_{cCN}$ |
| | = | 13,927 psi |

**Allowable Compressive Stress, Vacuum and Corroded- $S_{cVC}$, (table CS-2)**

| | | |
|---|---|---|
| A | = | $0.125 / (R_o / t)$ |
| | = | 0.125 / (30.375 / 0.375) |
| | = | 0.001543 |
| B | = | 9,261 psi |
| S | = | 18,800 / 1.00 = 18,800 psi |
| $S_{cVC}$ | = | min(B, S) = 9,261 psi |

## Ellipsoidal Head #1 (Dished Region)

### ASME Section VIII Division 1, 2013 Edition

| | |
|---|---|
| Component: | Hemi Head |
| Material specification: | SA-516 70 (II-D p. 22, ln. 6) |

Internal design pressure: P = 100 psi @ 650 °F

Corrosion allowance    Inner C = 0"    Outer C = 0"

PWHT is not performed

| | | |
|---|---|---|
| Radiography: | RT on Category A Joints - Long. Seam - | Seamless No RT |
| | RT on Category A Joints - Circ. Seam - | User Defined (E = 1.) |

| | | |
|---|---|---|
| Estimated weight | New = 1,187.6 lb | corr = 1,187.6 lb |
| Capacity | New = 1,409.8 US gal | corr = 1,409.8 US gal |

| | | |
|---|---|---|
| Inner diameter | = | 107.5463" |
| Minimum head thickness | = | 0.23" |

### Design thickness, (at 650 °F) UG-32(f)

t = P*R / (2*S*E - 0.20*P) + Corrosion
= 100*53.7731 / (2*18,800*1.00 - 0.20*100) + 0
= 0.1431"

### Maximum allowable working pressure, (at 650 °F) UG-32(f)

P = 2*S*E*t / (R + 0.20*t) - $P_s$
= 2*18,800*1.00*0.23 / (53.7731 + 0.20*0.23) - 0
= 160.69 psi

### Maximum Allowable External Pressure, (Corroded @ 650 °F)

A = 0.125 / ($R_o$ / t)
= 0.125 / (54.0031 / 0.23)
= 0.000532
From table CS-2: B = 6,576.1909 psi

$P_a$ = B / ($R_o$ / t)
= 6,576.19 / (54.0031 / 0.23)
= 28.01 psi
The maximum allowable external pressure is 28.01 psi

### % Extreme fiber elongation - UCS-79(d)

EFE = (75*t / $R_f$)*(1 - $R_f$ / $R_o$)
= (75*0.23 / 53.8881)*(1 - 53.8881 / ∞)
= 0.3201%

The extreme fiber elongation does not exceed 5%.

**Head design thickness = 0.1431"**

The governing condition is due to internal pressure.

The head thickness of 0.23" is adequate.

## Straight Flange on Ellipsoidal Head #2

**ASME Section VIII Division 1, 2013 Edition**

Component: Straight Flange
Material specification: SA-516 70 (II-D p. 22, ln. 6)

Internal design pressure: P = 100 psi @ 650 °F

**Static liquid head:**

Corrosion allowance Inner C = 0" Outer C = 0"

PWHT is not performed

| | | |
|---|---|---|
| Radiography: | Longitudinal joint - | Seamless No RT |
| | Circumferential joint - | Full UW-11(a) Type 1 |

| | | |
|---|---|---|
| Estimated weight | New = 40.3 lb | corr = 40.3 lb |
| Capacity | New = 24.48 US gal | corr = 24.48 US gal |

| | | |
|---|---|---|
| ID | = | 60" |
| Length $L_c$ | = | 2" |
| t | = | 0.375" |

**Design thickness, (at 650 °F) UG-27(c)(1)**

t = P*R / (S*E - 0.60*P) + Corrosion
= 100*30 / (18,800*1.00 - 0.60*100) + 0
= 0.1601"

**Maximum allowable working pressure, (at 650 °F) UG-27(c)(1)**

P = S*E*t / (R + 0.60*t) - $P_s$
= 18,800*1.00*0.375 / (30 + 0.60*0.375) - 0
= 233.25 psi

**Maximum Allowable External Pressure, (Corroded & at 650 °F) UG-28(c)**

$L / D_o$ = 206 / 60.75 = 3.3909
$D_o / t$ = 60.75 / 0.375 = 162.0000
From table G: A = 0.000183
From table CS-2: B = 2,244.3648 psi

$P_a$ = 4*B / (3*($D_o$ / t))
= 4*2,244.36 / (3*(60.75 / 0.375))
= 18.47 psi

**% Extreme fiber elongation - UCS-79(d)**

EFE = (50*t / $R_f$)*(1 - $R_f$ / $R_o$)
= (50*0.375 / 30.1875)*(1 - 30.1875 / ∞)
= 0.6211%

The extreme fiber elongation does not exceed 5%.

**Allowable Compressive Stress, Hot and Corroded- $S_{cHC}$, (table CS-2)**

| | | |
|---|---|---|
| A | = | 0.125 / ($R_o$ / t) |
| | = | 0.125 / (30.375 / 0.375) |
| | = | 0.001543 |
| B | = | 9,261 psi |
| S | = | 18,800 / 1.00 = 18,800 psi |
| $S_{cHC}$ | = | min(B, S) = 9,261 psi |

**Allowable Compressive Stress, Hot and New- $S_{cHN}$**

| | | |
|---|---|---|
| $S_{cHN}$ | = | $S_{cHC}$ |
| | = | 9,261 psi |

**Allowable Compressive Stress, Cold and New- $S_{cCN}$, (table CS-2)**

| | | |
|---|---|---|
| A | = | 0.125 / ($R_o$ / t) |
| | = | 0.125 / (30.375 / 0.375) |
| | = | 0.001543 |
| B | = | 13,927 psi |
| S | = | 20,000 / 1.00 = 20,000 psi |
| $S_{cCN}$ | = | min(B, S) = 13,927 psi |

**Allowable Compressive Stress, Cold and Corroded- $S_{cCC}$**

| | | |
|---|---|---|
| $S_{cCC}$ | = | $S_{cCN}$ |
| | = | 13,927 psi |

**Allowable Compressive Stress, Vacuum and Corroded- $S_{cVC}$, (table CS-2)**

| | | |
|---|---|---|
| A | = | 0.125 / ($R_o$ / t) |
| | = | 0.125 / (30.375 / 0.375) |
| | = | 0.001543 |
| B | = | 9,261 psi |
| S | = | 18,800 / 1.00 = 18,800 psi |
| $S_{cVC}$ | = | min(B, S) = 9,261 psi |

## Ellipsoidal Head #2

**ASME Section VIII Division 1, 2013 Edition**

Component: Ellipsoidal Head
Material Specification: SA-516 70 (II-D p.22, ln. 6)
Internal design pressure: P = 100 psi @ 650 °F

**Static liquid head:**

$P_s$= 0 psi (SG=1, $H_s$=0" Operating head)

Corrosion allowance: Inner C = 0" Outer C = 0"

Design MDMT = -20°F
Rated MDMT = N/A

No impact test performed
Material is not normalized
Material is not produced to fine grain practice
PWHT is not performed
Do not Optimize MDMT / Find MAWP

| | | |
|---|---|---|
| Radiography: | Category A joints - | Seamless No RT |
| | Head to shell seam - | Full UW-11(a) Type 1 |

| | | |
|---|---|---|
| Estimated weight*: | new = 312.8 lb | corr = 312.8 lb |
| Capacity*: | new = 146.9 US gal | corr = 146.9 US gal |

* includes straight flange

| | | |
|---|---|---|
| Inner diameter | = | 60" |
| Minimum head thickness | = | 0.23" |
| Head ratio D/2h | = | 2 (new) |
| Head ratio D/2h | = | 2 (corroded) |
| Straight flange length $L_{sf}$ | = | 2" |
| Nominal straight flange thickness $t_{sf}$ | = | 0.375" |

**Results Summary**

The governing condition is internal pressure.

| | | |
|---|---|---|
| Minimum thickness per UG-16 | = | 0.0625" + 0" = 0.0625" |
| Design thickness due to internal pressure (t) | = | 0.1597" |
| Maximum allowable working pressure (MAWP) | = | 144.02 psi |
| Maximum allowable external pressure (MAEP) | = | 28.01 psi |

**Design thickness for internal pressure, (Corroded at 650 °F) UG-32(d)(1)**

t = P*D / (2*S*E - 0.2*P) + Corrosion
= 100*60 / (2*18,800*1 - 0.2*100) + 0
= 0.1597"

The head internal pressure design thickness is 0.1597".

**Maximum allowable working pressure, (Corroded at 650 °F) UG-32(d)(1)**

P = 2*S*E*t / (D + 0.2*t) - $P_s$
= 2*18,800*1*0.23 / (60 +0.2*0.23) - 0
= 144.02 psi

The maximum allowable working pressure (MAWP) is 144.02 psi.

**Maximum Allowable External Pressure, (Corroded at 650 °F) UG-33(d)**

Equivalent outside spherical radius ($R_o$)

$R_o$ = $K_o$*$D_o$
= 0.8932*60.46
= 54.0031 in

A = 0.125 / ($R_o$ / t)
= 0.125 / (54.0031 / 0.23)
= 0.000532

| | | | |
|---|---|---|---|
| From Table CS-2: | B | = | 6,576.1909 psi |

$P_a$ = B / ($R_o$ / t)
= 6,576.1909 / (54.0031 / 0.23)
= 28.0081 psi

**Check the Maximum External Pressure, UG-33(a)(1) UG-32(d)(1)**

P = 2*S*E*t / ((D + 0.2*t)*1.67) - $P_{s2}$
= 2*18,800*1*0.23 / ((60 +0.2*0.23)*1.67) - 0
= 86.24 psi

The maximum allowable external pressure (MAEP) is 28.01 psi.

## Ellipsoidal Head #2 (Dished Region)

**ASME Section VIII Division 1, 2013 Edition**

| | |
|---|---|
| Component: | Hemi Head |
| Material specification: | SA-516 70 (II-D p. 22, ln. 6) |

Internal design pressure: P = 100 psi @ 650 °F

Corrosion allowance    Inner C = 0"    Outer C = 0"

PWHT is not performed

| | | |
|---|---|---|
| Radiography: | RT on Category A Joints - Long. Seam - | Seamless No RT |
| | RT on Category A Joints - Circ. Seam - | User Defined (E = 1.) |

| | | |
|---|---|---|
| Estimated weight | New = 1,187.6 lb | corr = 1,187.6 lb |
| Capacity | New = 1,409.8 US gal | corr = 1,409.8 US gal |

| | | |
|---|---|---|
| Inner diameter | = | 107.5463" |
| Minimum head thickness | = | 0.23" |

**Design thickness, (at 650 °F) UG-32(f)**

t = P*R / (2*S*E - 0.20*P) + Corrosion
= 100*53.7731 / (2*18,800*1.00 - 0.20*100) + 0
= 0.1431"

**Maximum allowable working pressure, (at 650 °F) UG-32(f)**

P = 2*S*E*t / (R + 0.20*t) - $P_s$
= 2*18,800*1.00*0.23 / (53.7731 + 0.20*0.23) - 0
= 160.69 psi

**Maximum Allowable External Pressure, (Corroded @ 650 °F)**

A = 0.125 / ($R_o$ / t)
= 0.125 / (54.0031 / 0.23)
= 0.000532
From table CS-2: B = 6,576.1909 psi

$P_a$ = B / ($R_o$ / t)
= 6,576.19 / (54.0031 / 0.23)
= 28.01 psi
The maximum allowable external pressure is 28.01 psi

**% Extreme fiber elongation - UCS-79(d)**

EFE = (75*t / $R_f$)*(1 - $R_f$ / $R_o$)
= (75*0.23 / 53.8881)*(1 - 53.8881 / ∞)
= 0.3201%

The extreme fiber elongation does not exceed 5%.

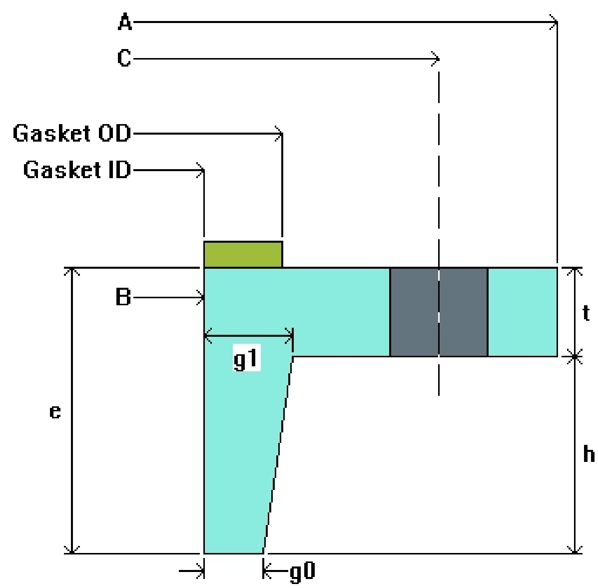
**Head design thickness = 0.1431"**

The governing condition is due to internal pressure.

The head thickness of 0.23" is adequate.

## Flange #2

| ASME Section VIII Division 1, 2013 Edition (Code Case 2695) | | | | |
|---|---|---|---|---|
| **Flange Type** | Weld neck integral | | | |
| **Flange Material** | SA-516 70 (II-D p. 22, ln. 6) | | | |
| **Attached To** | Nozzle #1 (N1) | | | |
| **Impact Tested** | **Normalized** | **Fine Grain Practice** | **PWHT** | **Optimize MDMT/ Find MAWP** |
| No | No | No | No | No |
| | | **Design Pressure (psi)** | **Design Temperature (°F)** | **Design MDMT (°F)** |
| **Internal** | | 100 | 650 | -20 |
| **Static Liquid Head** | | | | |
| **Condition** | | **$P_s$ (psi)** | | |
| **Operating** | | 0 | | |
| **Dimensions** | | | | |
| **Flange OD, A** | | 16.5" | | |
| **Flange ID, B** | | 12" | | |
| **Bolt Circle, C** | | 15" | | |
| **Gasket OD** | | 13" | | |
| **Gasket ID** | | 12" | | |
| **Flange Thickness, t** | | 0.5625" | | |
| **Hub Thickness, $g_1$** | | 0.5625" | | |
| **Hub Thickness, $g_0$** | | 0.375" | | |
| **Hub Length, h** | | 1.25" | | |
| **Length, e** | | 1.8125" | | |
| **Corrosion** | **Bore** | 0" | | |
| | **Flange** | 0" | | |
| **Bolting** | | | | |
| **Material** | SA-193 B7 Bolt <= 2 1/2 (II-D p. 352, ln. 31) | | | |
| **Description** | 8- 0.625 in dia series 8 threaded | | | |
| **Corrosion on root** | 0" | | | |
| **Gasket** | | | | |
| **Factor, m** | 2 | | | |
| **Seating Stress, y** | 2,500 psi | | | |



| | |
|---|---|
| **Gasket Thickness** | 0.175" |
| **Weight (lb)** | |
| **New** | 22.5 lb |
| **Corroded** | 22.5 lb |

| **Results Summary** | |
|---|---|
| Flange design thickness: | 0.5525" |
| Maximum allowable working pressure, MAWP: | 166.57 psi @ 650 °F |
| Rated MDMT | N/A °F |

Note: this flange is calculated as an integral type.

## Flange calculations for MAWP + Weight Only

| **Division 2 4.16.6.1 Step 3 - Gasket Factors** | |
|---|---|
| $b_0$ = N / 2 | (Table 4.16.3) |
| b = $b_0$ for $b_0 \leq$ 0.25 in | (4.16.1) |
| G = ($G_c$ + Gasket ID) / 2 | (4.16.3) |
| **Results** | |
| Table 4.16.3 Facing Sketch Detail | 1(a) or (b), Column II |
| Gasket width, N | 0.5" |
| $b_0$ = 0.5 / 2 | 0.25" |
| b = 0.25 | 0.25" |
| G = (13 + 12) / 2 | 12.5" |

| **Division 2 4.16.6.1 Step 4 - Design Bolt Load for Operating** | |
|---|---|
| $W_o = 0.785 \cdot G^2 \cdot P + 2 \cdot b \cdot \pi \cdot G \cdot m \cdot P$ | (4.16.4) |
| **Results** | |
| $W_o = 0.785 \cdot 12.5^2 \cdot 166.57 + 2 \cdot 0.25 \cdot \pi \cdot 12.5 \cdot 2 \cdot 166.57$ | 26,972.17 $lb_f$ |

| Division 2 4.16.6.1 Step 5 - Design Bolt Load for Gasket Seating and Required Bolt Area | |
|---|---|
| $W_{gs} = \pi*b*G*(C_{us}*y)$ | (4.16.8) |
| $A_m = \max [ (W_o + F_A + 4*M_E / G) / S_{bo} , W_{gs} / S_{bg} ]$ | (4.16.7) |
| $W_g = \{(A_m + A_b) / 2\}*S_{bg}$ | (4.16.6) |
| **Results** | |
| $W_{gs} = \pi*0.25*12.5*(1*2,500)$ | 24,543.69 $lb_f$ |
| $A_m = \max [ (26,972.17 + 0 + 4*0 / 12.5) / 25,000 , 24,543.69 / 25,000 ]$ | 1.0789 $in^2$ |
| Total corroded bolt area for 8- 0.625 in dia bolts, $A_b$ | 1.616 $in^2$ |
| $W_g = \{(1.0789 + 1.616) / 2\}*25,000$ | 33,686.09 $lb_f$ |

| Division 2 4.16.7.2 Step 4 - Flange Stress Factors |
| --- |
| $K = A / B$ |
| $Y = 1 / (K - 1)*[\ 0.66845 + 5.7169*K^2*\log_{10}[K] / (K^2 - 1)]$ |
| $T = \{K^2*(1 + 8.55246*\log_{10}[K]) - 1\} / \{(1.0472 + 1.9448*K^2)*(K - 1)\}$ |
| $U = \{K^2*(1 + 8.55246*\log_{10}[K]) - 1\} / \{1.36136*(K^2 - 1)*(K - 1)\}$ |
| $Z = (K^2 + 1) / (K^2 - 1)$ |
| $h_o = (B*g_0)^{0.5}$ |
| $X_g = g_1 / g_0$ |
| $X_h = h / h_o$ |
| $F = 0.897697 - 0.297012*\ln[X_g] + 0.0095257*\ln[X_h] + 0.123586*(\ln[X_g])^2 + 0.035858*(\ln[X_h])^2 - 0.194422*\ln[X_g]*\ln[X_h] - 0.0181259*(\ln[X_g])^3 + 0.012936*(\ln[X_h])^3 - 0.0377693*\ln[X_g]*(\ln[X_h])^2 + 0.0273791*(\ln[X_g])^2*\ln[X_h]$ |
| $V = 0.0144868 - 0.135977 / X_g - 0.0461919 / X_h + 0.560718 / X_g^2 + 0.0529829 / X_h^2 + 0.244313 / (X_g*X_h) + 0.113929 / X_g^3 - 0.00928265 / X_h^3 - 0.0266293 / (X_g*X_h^2) - 0.217008 / (X_g^2*X_h)$ |
| $f = \max [\ 1\ , (0.0927779 - 0.0336633*X_g + 0.964176*X_g^2 + 0.0566286*X_h + 0.347074*X_h^2 - 4.18699*X_h^3) / (1 - 0.00596093*X_g + 1.62904*X_h + 3.49329*X_h^2 + 1.39052*X_h^3)\ ]$ |
| $e = F / h_o$ |
| $d = U*g_0^2*h_o / V$ |
| $L = (t*e + 1) / T + t^3 / d$ |

| Results | |
| --- | --- |
| $K = 16.5 / 12$ | 1.375 |
| $Y = 1 / (1.375 - 1)*[\ 0.66845 + 5.7169*1.375^2*\log_{10}[1.375] / (1.375^2 - 1)]$ | 6.2583 |
| $T = \{1.375^2*(1 + 8.55246*\log_{10}[1.375]) - 1\} / \{(1.0472 + 1.9448*1.375^2)*(1.375 - 1)\}$ | 1.7651 |
| $U = \{1.375^2*(1 + 8.55246*\log_{10}[1.375]) - 1\} / \{1.36136*(1.375^2 - 1)*(1.375 - 1)\}$ | 6.8773 |
| $Z = (1.375^2 + 1) / (1.375^2 - 1)$ | 3.2456 |
| $h_o = (12*0.375)^{0.5}$ | 2.1213" |
| $X_g = 0.5625 / 0.375$ | 1.5 |
| $X_h = 1.25 / 2.1213$ | 0.5893 |
| $F = 0.897697 - 0.297012*\ln[1.5] + 0.0095257*\ln[0.5893] + 0.123586*(\ln[1.5])^2 + 0.035858*(\ln[0.5893])^2 - 0.194422*\ln[1.5]*\ln[0.5893] - 0.0181259*(\ln[1.5])^3 + 0.012936*(\ln[0.5893])^3 - 0.0377693*\ln[1.5]*(\ln[0.5893])^2 + 0.0273791*(\ln[1.5])^2*\ln[0.5893]$ | 0.8345 |
| $V = 0.0144868 - 0.135977 / 1.5 - 0.0461919 / 0.5893 + 0.560718 / 1.5^2 + 0.0529829 / 0.5893^2 + 0.244313 / (1.5*0.5893) + 0.113929 / 1.5^3 - 0.00928265 / 0.5893^3 - 0.0266293 / (1.5*0.5893^2) - 0.217008 / (1.5^2*0.5893)$ | 0.2972 |
| $f = \max [\ 1\ , (0.0927779 - 0.0336633*1.5 + 0.964176*1.5^2 + 0.0566286*0.5893 + 0.347074*0.5893^2 - 4.18699*0.5893^3) / (1 - 0.00596093*1.5 + 1.62904*0.5893 + 3.49329*0.5893^2 + 1.39052*0.5893^3)\ ]$ | 1 |
| $e = 0.8345 / 2.1213$ | 0.3934 1/in |
| $d = 6.8773*0.375^2*2.1213 / 0.2972$ | 6.9022 $in^3$ |
| $L = (0.5625*0.3934 + 1) / 1.7651 + 0.5625^3 / 6.9022$ | 0.7177 |

| Division 2 4.16.7.2 Step 5 - Flange Forces | |
|---|---|
| $H_D = 0.785*B^2*P$ | |
| $H = 0.785*G^2*P$ | |
| $H_T = H - H_D$ | |
| $H_G = W_o - H$ | |
| **Results** | |
| $H_D = 0.785*12^2*166.57$ | 18,829.16 $lb_f$ |
| $H = 0.785*12.5^2*166.57$ | 20,430.95 $lb_f$ |
| $H_T = 20,430.95 - 18,829.16$ | 1,601.79 $lb_f$ |
| $H_G = 26,972.17 - 20,430.95$ | 6,541.22 $lb_f$ |

| Division 2 4.16.7.2 Step 6 - Flange Moments of Inertia | |
|---|---|
| $I = 0.0874*L*g_0^2*h_o*B / V$ | |
| $A_R = 0.5*(A - B)$ | |
| $G_{avg} = 0.5*(g_0 + g_1)$ | |
| $t \geq G_{avg}$ | |
| $A_A = A_R$, $B_B = t$, $C_C = h$, $D_{DG} = G_{avg}$ | |
| $K_{AB} = (A_A*B_B^3)*[1 / 3 - 0.21*(B_B / A_A)*(1 - 1 / 12*\{B_B / A_A\}^4)]$ | |
| $K_{CD} = (C_C*D_{DG}^3)*[1 / 3 - 0.105*(D_{DG} / C_C)*(1 - 1 / 192*\{D_{DG} / C_C\}^4)]$ | |
| $I_p = K_{AB} + K_{CD}$ | |
| **Results** | |
| $I = 0.0874*0.7177*0.375^2*2.1213*12 / 0.2972$ | 0.7554 $in^4$ |
| $A_R = 0.5*(16.5 - 12)$ | 2.25" |
| $G_{avg} = 0.5*(0.375 + 0.5625)$ | 0.4688" |
| $t = 0.5625$ in $\geq G_{avg} = 0.4688$ in | |
| $A_A = 2.25$ in, $B_B = 0.5625$ in, $C_C = 1.25$ in, $D_{DG} = 0.4688$ in | |
| $K_{AB} = (2.25*0.5625^3)*[1 / 3 - 0.21*(0.5625 / 2.25)*(1 - 1 / 12*\{0.5625 / 2.25\}^4)]$ | 0.1125 $in^4$ |
| $K_{CD} = (1.25*0.4688^3)*[1 / 3 - 0.105*(0.4688 / 1.25)*(1 - 1 / 192*\{0.4688 / 1.25\}^4)]$ | 0.0378 $in^4$ |
| $I_p = 0.1125 + 0.0378$ | 0.1503 $in^4$ |

| Division 2 4.16.7.2 Step 6 - Flange Moment Arms | |
|---|---|
| $h_D = (C - B - g_1) / 2$ | |
| $h_T = 1 / 2*[(C - B) / 2 + h_G]$ | |
| $h_G = (C - G) / 2$ | |
| **Results** | |
| $h_D = (15 - 12 - 0.5625) / 2$ | 1.2188" |
| $h_T = 1 / 2*[(15 - 12) / 2 + 1.25]$ | 1.375" |
| $h_G = (15 - 12.5) / 2$ | 1.25" |

| Division 2 4.16.7.2 Step 6 - Flange Moment for Operating | |
|---|---|
| $M_{oe} = 4*M_E*[I / (0.3846*I_p + I)]*[h_D / (C - 2*h_D)] + F_A*h_D$ | (4.16.16) |
| $M_o = abs [ (H_D*h_D + H_T*h_T + H_G*h_G + M_{oe})*F_S ]$ | (4.16.14) |
| **Results** | |
| $M_{oe} = 4*0*[0.7554 / (0.3846*0.1503 + 0.7554)]*[1.2188 / (15 - 2*1.2188)] + 0*1.2188$ | 0 $lb_f$-in |
| $M_o = abs [ (18,829.16*1.2188 + 1,601.79*1.375 + 6,541.22*1.25 + 0)*1 ]$ | 33,327 $lb_f$-in |

| Division 2 4.16.7.2 Step 7 - Flange Moment for Gasket Seating | |
|---|---|
| $M_g = W_g*(C - G)*F_S / 2$ | (4.16.17) |
| **Results** | |
| $M_g = 33,686.09*(15 - 12.5)*1 / 2$ | 42,107.6 $lb_f$-in |

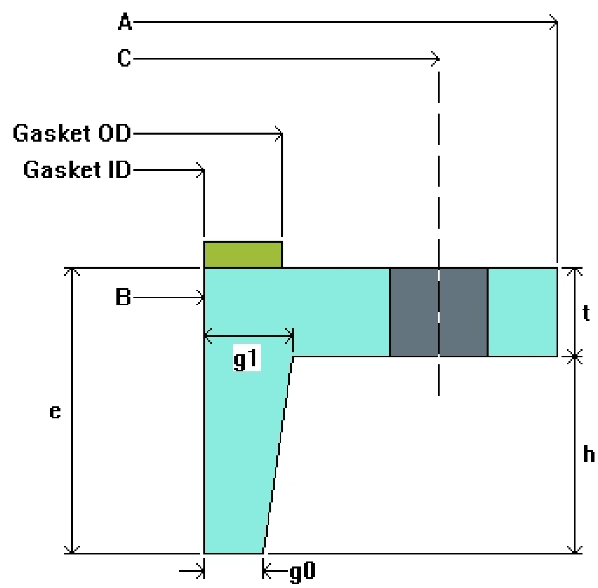
| Division 2 4.16.7.2 Step 8 - Flange Stresses | |
|---|---|
| **Operating** | **Gasket Seating** |
| $S_H = f*M_o / (L*g_1^2*B)$ | $S_H = f*M_g / (L*g_1^2*B)$ |
| $S_R = (1.33*t*e + 1)*M_o / (L*t^2*B)$ | $S_R = (1.33*t*e + 1)*M_g / (L*t^2*B)$ |
| $S_T = Y*M_o / (t^2*B) - Z*S_R$ | $S_T = Y*M_g / (t^2*B) - Z*S_R$ |
| $S_H \le \min[\ 1.5*S_{fo}\ ,\ 2.5*S_{no}]$ | $S_H \le \min[\ 1.5*S_{fg}\ ,\ 2.5*S_{ng}]$ |
| $S_H \le 1.5*S_{fo}$ | $S_H \le 1.5*S_{fg}$ |
| $S_R \le S_{fo}$ | $S_R \le S_{fg}$ |
| $S_T \le S_{fo}$ | $S_T \le S_{fg}$ |
| $(S_H + S_R) / 2 \le S_{fo}$ | $(S_H + S_R) / 2 \le S_{fg}$ |
| $(S_H + S_T) / 2 \le S_{fo}$ | $(S_H + S_T) / 2 \le S_{fg}$ |
| $S_{fo}$ = 18,800 psi | $S_{fg}$ = 20,000 psi |
| $S_{no}$ = 17,100 psi | $S_{ng}$ = 17,100 psi |

| Operating | | | |
|---|---|---|---|
| | **Stress (psi)** | **Allowable (psi)** | **Overstressed** |
| $S_H = 1*33{,}327 / (0.7177*0.5625^2*12)$ | 12,230 | 28,200 | OK |
| $S_R = (1.33*0.5625*0.3934 + 1)*33{,}327 / (0.7177*0.5625^2*12)$ | 15,829 | 18,800 | OK |
| $S_T = 6.2583*33{,}327 / (0.5625^2*12) - 3.2456*15{,}829$ | 3,556 | 18,800 | OK |
| $(S_H + S_R) / 2 = (12{,}230 + 15{,}829) / 2$ | 14,030 | 18,800 | OK |
| $(S_H + S_T) / 2 = (12{,}230 + 3{,}556) / 2$ | 7,893 | 18,800 | OK |

| Gasket Seating | | | |
|---|---|---|---|
| | **Stress (psi)** | **Allowable (psi)** | **Overstressed** |
| $S_H = 1*42{,}107.6 / (0.7177*0.5625^2*12)$ | 15,452 | 30,000 | OK |
| $S_R = (1.33*0.5625*0.3934 + 1)*42{,}107.6 / (0.7177*0.5625^2*12)$ | 20,000 | 20,000 | OK |
| $S_T = 6.2583*42{,}107.6 / (0.5625^2*12) - 3.2456*20{,}000$ | 4,493 | 20,000 | OK |
| $(S_H + S_R) / 2 = (15{,}452 + 20{,}000) / 2$ | 17,726 | 20,000 | OK |
| $(S_H + S_T) / 2 = (15{,}452 + 4{,}493) / 2$ | 9,973 | 20,000 | OK |

| Division 2 4.16.7.2 Step 10 - Flange Rigidity | | | |
|---|---|---|---|
| **Operating** | **Gasket Seating** | | |
| J = 52.14*V*$M_o$ / (L*$E_{yo}$*$g_0^2$*$K_R$*$h_o$) ≤ 1 | J = 52.14*V*$M_g$ / (L*$E_{yg}$*$g_0^2$*$K_R$*$h_o$) ≤ 1 | | |
| $K_R$ = 0.3 | | | |
| **Operating** | | | |
| J = 52.14*0.2972*33,327 / (0.7177*26.0E+06*$0.375^2$*0.3*2.1213) | 0.3093 | ≤ 1 | OK |
| **Gasket Seating** | | | |
| J = 52.14*0.2972*42,107.6 / (0.7177*29.4E+06*$0.375^2$*0.3*2.1213) | 0.3456 | ≤ 1 | OK |

**Flange #3**

| | | | | |
|---|---|---|---|---|
| **ASME Section VIII Division 1, 2013 Edition (Code Case 2695)** | | | | |
| **Flange Type** | | Weld neck integral | | |
| **Flange Material** | | SA-516 70 (II-D p. 22, ln. 6) | | |
| **Attached To** | | Nozzle #3 (N3) | | |
| **Impact Tested** | **Normalized** | **Fine Grain Practice** | **PWHT** | **Optimize MDMT/ Find MAWP** |
| No | No | No | No | No |
| | | **Design Pressure (psi)** | **Design Temperature (°F)** | **Design MDMT (°F)** |
| **Internal** | | 100 | 650 | -20 |
| **Static Liquid Head** | | | | |
| **Condition** | | **$P_s$ (psi)** | | |
| **Operating** | | 0 | | |
| **Dimensions** | | | | |
| **Flange OD, A** | | 16.5" |  | |
| **Flange ID, B** | | 12" | | |
| **Bolt Circle, C** | | 15" | | |
| **Gasket OD** | | 13" | | |
| **Gasket ID** | | 12" | | |
| **Flange Thickness, t** | | 0.5625" | | |
| **Hub Thickness, $g_1$** | | 0.5625" | | |
| **Hub Thickness, $g_0$** | | 0.375" | | |
| **Hub Length, h** | | 1.25" | | |
| **Length, e** | | 1.8125" | | |
| **Corrosion** | **Bore** | 0" | | |
| | **Flange** | 0" | | |
| **Bolting** | | | | |
| **Material** | | SA-193 B7 Bolt <= 2 1/2 (II-D p. 352, ln. 31) | | |
| **Description** | | 8- 0.625 in dia series 8 threaded | | |
| **Corrosion on root** | | 0" | | |
| **Gasket** | | | | |
| **Factor, m** | | 2 | | |
| **Seating Stress, y** | | 2,500 psi | | |

| | |
|---|---|
| **Gasket Thickness** | 0.175" |
| **Weight (lb)** | |
| **New** | 22.5 lb |
| **Corroded** | 22.5 lb |

| **Results Summary** | |
|---|---|
| Flange design thickness: | 0.5525" |
| Maximum allowable working pressure, MAWP: | 166.57 psi @ 650 °F |
| Rated MDMT | N/A °F |

Note: this flange is calculated as an integral type.

## Flange calculations for MAWP + Weight Only

| **Division 2 4.16.6.1 Step 3 - Gasket Factors** | |
|---|---|
| $b_0 = N / 2$ | (Table 4.16.3) |
| $b = b_0$ for $b_0 \leq 0.25$ in | (4.16.1) |
| $G = (G_c$ + Gasket ID$) / 2$ | (4.16.3) |
| **Results** | |
| Table 4.16.3 Facing Sketch Detail | 1(a) or (b), Column II |
| Gasket width, N | 0.5" |
| $b_0 = 0.5 / 2$ | 0.25" |
| $b = 0.25$ | 0.25" |
| $G = (13 + 12) / 2$ | 12.5" |

| **Division 2 4.16.6.1 Step 4 - Design Bolt Load for Operating** | |
|---|---|
| $W_o = 0.785 \cdot G^2 \cdot P + 2 \cdot b \cdot \pi \cdot G \cdot m \cdot P$ | (4.16.4) |
| **Results** | |
| $W_o = 0.785 \cdot 12.5^2 \cdot 166.57 + 2 \cdot 0.25 \cdot \pi \cdot 12.5 \cdot 2 \cdot 166.57$ | 26,972.17 $lb_f$ |

| Division 2 4.16.6.1 Step 5 - Design Bolt Load for Gasket Seating and Required Bolt Area | |
|---|---|
| $W_{gs} = \pi*b*G*(C_{us}*y)$ | (4.16.8) |
| $A_m = \max [ (W_o + F_A + 4*M_E / G) / S_{bo} , W_{gs} / S_{bg} ]$ | (4.16.7) |
| $W_g = \{(A_m + A_b) / 2\}*S_{bg}$ | (4.16.6) |
| **Results** | |
| $W_{gs} = \pi*0.25*12.5*(1*2,500)$ | 24,543.69 $lb_f$ |
| $A_m = \max [ (26,972.17 + 0 + 4*0 / 12.5) / 25,000 , 24,543.69 / 25,000 ]$ | 1.0789 $in^2$ |
| Total corroded bolt area for 8- 0.625 in dia bolts, $A_b$ | 1.616 $in^2$ |
| $W_g = \{(1.0789 + 1.616) / 2\}*25,000$ | 33,686.09 $lb_f$ |

| Division 2 4.16.7.2 Step 4 - Flange Stress Factors | |
|---|---|
| $K = A / B$ | |
| $Y = 1 / (K - 1)*[ 0.66845 + 5.7169*K^2*\log_{10}[K] / (K^2 - 1)]$ | |
| $T = \{K^2*(1 + 8.55246*\log_{10}[K]) - 1\} / \{(1.0472 + 1.9448*K^2)*(K - 1)\}$ | |
| $U = \{K^2*(1 + 8.55246*\log_{10}[K]) - 1\} / \{1.36136*(K^2 - 1)*(K - 1)\}$ | |
| $Z = (K^2 + 1) / (K^2 - 1)$ | |
| $h_o = (B*g_0)^{0.5}$ | |
| $X_g = g_1 / g_0$ | |
| $X_h = h / h_o$ | |
| $F = 0.897697 - 0.297012*\ln[X_g] + 0.0095257*\ln[X_h] + 0.123586*(\ln[X_g])^2 + 0.035858*(\ln[X_h])^2 - 0.194422*\ln[X_g]*\ln[X_h] - 0.0181259*(\ln[X_g])^3 + 0.012936*(\ln[X_h])^3 - 0.0377693*\ln[X_g]*(\ln[X_h])^2 + 0.0273791*(\ln[X_g])^2*\ln[X_h]$ | |
| $V = 0.0144868 - 0.135977 / X_g - 0.0461919 / X_h + 0.560718 / X_g^2 + 0.0529829 / X_h^2 + 0.244313 / (X_g*X_h) + 0.113929 / X_g^3 - 0.00928265 / X_h^3 - 0.0266293 / (X_g*X_h^2) - 0.217008 / (X_g^2*X_h)$ | |
| $f = \max [ 1 , (0.0927779 - 0.0336633*X_g + 0.964176*X_g^2 + 0.0566286*X_h + 0.347074*X_h^2 - 4.18699*X_h^3) / (1 - 0.00596093*X_g + 1.62904*X_h + 3.49329*X_h^2 + 1.39052*X_h^3) ]$ | |
| $e = F / h_o$ | |
| $d = U*g_0^2*h_o / V$ | |
| $L = (t*e + 1) / T + t^3 / d$ | |
| **Results** | |
| $K = 16.5 / 12$ | 1.375 |
| $Y = 1 / (1.375 - 1)*[ 0.66845 + 5.7169*1.375^2*\log_{10}[1.375] / (1.375^2 - 1)]$ | 6.2583 |
| $T = \{1.375^2*(1 + 8.55246*\log_{10}[1.375]) - 1\} / \{(1.0472 + 1.9448*1.375^2)*(1.375 - 1)\}$ | 1.7651 |
| $U = \{1.375^2*(1 + 8.55246*\log_{10}[1.375]) - 1\} / \{1.36136*(1.375^2 - 1)*(1.375 - 1)\}$ | 6.8773 |
| $Z = (1.375^2 + 1) / (1.375^2 - 1)$ | 3.2456 |
| $h_o = (12*0.375)^{0.5}$ | 2.1213" |
| $X_g = 0.5625 / 0.375$ | 1.5 |
| $X_h = 1.25 / 2.1213$ | 0.5893 |
| $F = 0.897697 - 0.297012*\ln[1.5] + 0.0095257*\ln[0.5893] + 0.123586*(\ln[1.5])^2 + 0.035858*(\ln[0.5893])^2 - 0.194422*\ln[1.5]*\ln[0.5893] - 0.0181259*(\ln[1.5])^3 + 0.012936*(\ln[0.5893])^3 - 0.0377693*\ln[1.5]*(\ln[0.5893])^2 + 0.0273791*(\ln[1.5])^2*\ln[0.5893]$ | 0.8345 |
| $V = 0.0144868 - 0.135977 / 1.5 - 0.0461919 / 0.5893 + 0.560718 / 1.5^2 + 0.0529829 / 0.5893^2 + 0.244313 / (1.5*0.5893) + 0.113929 / 1.5^3 - 0.00928265 / 0.5893^3 - 0.0266293 / (1.5*0.5893^2) - 0.217008 / (1.5^2*0.5893)$ | 0.2972 |
| $f = \max [ 1 , (0.0927779 - 0.0336633*1.5 + 0.964176*1.5^2 + 0.0566286*0.5893 + 0.347074*0.5893^2 - 4.18699*0.5893^3) / (1 - 0.00596093*1.5 + 1.62904*0.5893 + 3.49329*0.5893^2 + 1.39052*0.5893^3) ]$ | 1 |
| $e = 0.8345 / 2.1213$ | 0.3934 1/in |
| $d = 6.8773*0.375^2*2.1213 / 0.2972$ | 6.9022 $in^3$ |
| $L = (0.5625*0.3934 + 1) / 1.7651 + 0.5625^3 / 6.9022$ | 0.7177 |

| Division 2 4.16.7.2 Step 5 - Flange Forces | |
|---|---|
| $H_D = 0.785*B^2*P$ | |
| $H = 0.785*G^2*P$ | |
| $H_T = H - H_D$ | |
| $H_G = W_o - H$ | |
| **Results** | |
| $H_D = 0.785*12^2*166.57$ | 18,829.16 $lb_f$ |
| $H = 0.785*12.5^2*166.57$ | 20,430.95 $lb_f$ |
| $H_T = 20{,}430.95 - 18{,}829.16$ | 1,601.79 $lb_f$ |
| $H_G = 26{,}972.17 - 20{,}430.95$ | 6,541.22 $lb_f$ |

| Division 2 4.16.7.2 Step 6 - Flange Moments of Inertia | |
|---|---|
| $I = 0.0874*L*g_0{}^2*h_o*B / V$ | |
| $A_R = 0.5*(A - B)$ | |
| $G_{avg} = 0.5*(g_0 + g_1)$ | |
| $t \geq G_{avg}$ | |
| $A_A = A_R, \quad B_B = t, \quad C_C = h, \quad D_{DG} = G_{avg}$ | |
| $K_{AB} = (A_A*B_B{}^3)*[1 / 3 - 0.21*(B_B / A_A)*(1 - 1 / 12*\{B_B / A_A\}^4)]$ | |
| $K_{CD} = (C_C*D_{DG}{}^3)*[1 / 3 - 0.105*(D_{DG} / C_C)*(1 - 1 / 192*\{D_{DG} / C_C\}^4)]$ | |
| $I_p = K_{AB} + K_{CD}$ | |
| **Results** | |
| $I = 0.0874*0.7177*0.375^2*2.1213*12 / 0.2972$ | 0.7554 $in^4$ |
| $A_R = 0.5*(16.5 - 12)$ | 2.25" |
| $G_{avg} = 0.5*(0.375 + 0.5625)$ | 0.4688" |
| $t = 0.5625$ in $\geq G_{avg} = 0.4688$ in | |
| $A_A = 2.25$ in, $B_B = 0.5625$ in, $C_C = 1.25$ in, $D_{DG} = 0.4688$ in | |
| $K_{AB} = (2.25*0.5625^3)*[1 / 3 - 0.21*(0.5625 / 2.25)*(1 - 1 / 12*\{0.5625 / 2.25\}^4)]$ | 0.1125 $in^4$ |
| $K_{CD} = (1.25*0.4688^3)*[1 / 3 - 0.105*(0.4688 / 1.25)*(1 - 1 / 192*\{0.4688 / 1.25\}^4)]$ | 0.0378 $in^4$ |
| $I_p = 0.1125 + 0.0378$ | 0.1503 $in^4$ |

| Division 2 4.16.7.2 Step 6 - Flange Moment Arms | |
|---|---|
| $h_D = (C - B - g_1) / 2$ | |
| $h_T = 1 / 2*[(C - B) / 2 + h_G]$ | |
| $h_G = (C - G) / 2$ | |
| **Results** | |
| $h_D = (15 - 12 - 0.5625) / 2$ | 1.2188" |
| $h_T = 1 / 2*[(15 - 12) / 2 + 1.25]$ | 1.375" |
| $h_G = (15 - 12.5) / 2$ | 1.25" |

| Division 2 4.16.7.2 Step 6 - Flange Moment for Operating | |
|---|---|
| $M_{oe} = 4*M_E*[I / (0.3846*I_p + I)]*[h_D / (C - 2*h_D)] + F_A*h_D$ | (4.16.16) |
| $M_o = abs [ (H_D*h_D + H_T*h_T + H_G*h_G + M_{oe})*F_S ]$ | (4.16.14) |
| **Results** | |
| $M_{oe} = 4*0*[0.7554 / (0.3846*0.1503 + 0.7554)]*[1.2188 / (15 - 2*1.2188)] + 0*1.2188$ | 0 $lb_f$-in |
| $M_o = abs [ (18,829.16*1.2188 + 1,601.79*1.375 + 6,541.22*1.25 + 0)*1 ]$ | 33,327 $lb_f$-in |

| Division 2 4.16.7.2 Step 7 - Flange Moment for Gasket Seating | |
|---|---|
| $M_g = W_g*(C - G)*F_S / 2$ | (4.16.17) |
| **Results** | |
| $M_g = 33,686.09*(15 - 12.5)*1 / 2$ | 42,107.6 $lb_f$-in |

| Division 2 4.16.7.2 Step 8 - Flange Stresses | |
|---|---|
| **Operating** | **Gasket Seating** |
| $S_H = f*M_o / (L*{g_1}^2*B)$ | $S_H = f*M_g / (L*{g_1}^2*B)$ |
| $S_R = (1.33*t*e + 1)*M_o / (L*t^2*B)$ | $S_R = (1.33*t*e + 1)*M_g / (L*t^2*B)$ |
| $S_T = Y*M_o / (t^2*B) - Z*S_R$ | $S_T = Y*M_g / (t^2*B) - Z*S_R$ |
| $S_H \leq \min[\ 1.5*S_{fo}\ ,\ 2.5*S_{no}]$ | $S_H \leq \min[\ 1.5*S_{fg}\ ,\ 2.5*S_{ng}]$ |
| $S_H \leq 1.5*S_{fo}$ | $S_H \leq 1.5*S_{fg}$ |
| $S_R \leq S_{fo}$ | $S_R \leq S_{fg}$ |
| $S_T \leq S_{fo}$ | $S_T \leq S_{fg}$ |
| $(S_H + S_R) / 2 \leq S_{fo}$ | $(S_H + S_R) / 2 \leq S_{fg}$ |
| $(S_H + S_T) / 2 \leq S_{fo}$ | $(S_H + S_T) / 2 \leq S_{fg}$ |
| $S_{fo}$ = 18,800 psi | $S_{fg}$ = 20,000 psi |
| $S_{no}$ = 17,100 psi | $S_{ng}$ = 17,100 psi |

**Operating**

| | Stress (psi) | Allowable (psi) | Overstressed |
|---|---|---|---|
| $S_H = 1*33{,}327 / (0.7177*0.5625^2*12)$ | 12,230 | 28,200 | OK |
| $S_R = (1.33*0.5625*0.3934 + 1)*33{,}327 / (0.7177*0.5625^2*12)$ | 15,829 | 18,800 | OK |
| $S_T = 6.2583*33{,}327 / (0.5625^2*12) - 3.2456*15{,}829$ | 3,556 | 18,800 | OK |
| $(S_H + S_R) / 2 = (12{,}230 + 15{,}829) / 2$ | 14,030 | 18,800 | OK |
| $(S_H + S_T) / 2 = (12{,}230 + 3{,}556) / 2$ | 7,893 | 18,800 | OK |

**Gasket Seating**

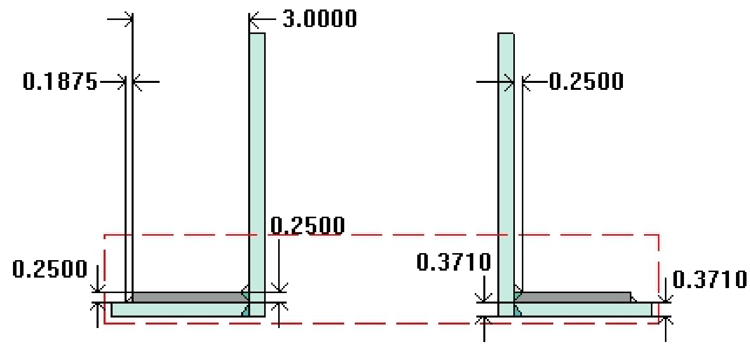
| | Stress (psi) | Allowable (psi) | Overstressed |
|---|---|---|---|
| $S_H = 1*42{,}107.6 / (0.7177*0.5625^2*12)$ | 15,452 | 30,000 | OK |
| $S_R = (1.33*0.5625*0.3934 + 1)*42{,}107.6 / (0.7177*0.5625^2*12)$ | 20,000 | 20,000 | OK |
| $S_T = 6.2583*42{,}107.6 / (0.5625^2*12) - 3.2456*20{,}000$ | 4,493 | 20,000 | OK |
| $(S_H + S_R) / 2 = (15{,}452 + 20{,}000) / 2$ | 17,726 | 20,000 | OK |
| $(S_H + S_T) / 2 = (15{,}452 + 4{,}493) / 2$ | 9,973 | 20,000 | OK |

| Division 2 4.16.7.2 Step 10 - Flange Rigidity | | | |
|---|---|---|---|
| **Operating** | **Gasket Seating** | | |
| $J = 52.14*V*M_o / (L*E_{yo}*g_0{}^2*K_R*h_o) \le 1$ | $J = 52.14*V*M_g / (L*E_{yg}*g_0{}^2*K_R*h_o) \le 1$ | | |
| $K_R = 0.3$ | | | |
| **Operating** | | | |
| $J = 52.14*0.2972*33{,}327 / (0.7177*26.0E{+}06*0.375^2*0.3*2.1213)$ | 0.3093 | ≤ 1 | OK |
| **Gasket Seating** | | | |
| $J = 52.14*0.2972*42{,}107.6 / (0.7177*29.4E{+}06*0.375^2*0.3*2.1213)$ | 0.3456 | ≤ 1 | OK |

## Nozzle #1 (N1)

| ASME Section VIII Division 1, 2013 Edition (Code Case 2695) | | | | | |
|---|---|---|---|---|---|
| **Component** | Nozzle | | | | |
| **Nozzle Material** | SA-106 B Smls pipe (II-D p. 14, ln. 19) | | | | |
| **Pad Material** | SA-516 70 (II-D p. 22, ln. 6) | | | | |
| | **Impact Tested** | **Normalized** | **Fine Grain Practice** | **PWHT** | **Optimize MDMT/ Find MAWP** |
| **Nozzle** | No | No | No | No | No |
| **Pad** | No | No | No | No | No |
| | **Design Pressure (psi)** | | **Design Temperature (°F)** | | **Design MDMT (°F)** |
| **Internal** | 100 | | 650 | | -20 |
| **Location and Orientation** | | | | | |
| **Attached to** | Cylinder #1 | | | | |
| **Orientation** | radial | | | | |
| **Offset, L** | 48" | | | | |
| **Angle, θ** | 90° | | | | |
| **Distance, r** | 48" | | | | |
| **Through a Category A Joint** | No | | | | |

| Dimensions | | |
|---|---|---|
| Description | | NPS 12 Std Weight |
| Inside Diameter | | 12" |
| Nominal Wall Thickness | | 0.375" |
| Local Vessel Minimum Thickness | | 0.371" |
| Nozzle to Pad Groove Weld, $t_{w2}$ | | 0.25" |
| $Leg_{41}$ | | 0.25" |
| $Leg_{42}$ | | 0.1875" |
| Pad Width, W | | 3" |
| Pad Thickness, $t_e$ | | 0.25" |
| External Projection Available, $L_{pr1}$ | | 15.6875" |
| Projection outside vessel to flange face, $L_f$ | | 17.5" |
| Corrosion | Inner | 0" |
| | Outer | 0" |



## Summary Tables

| Division 2 4.5.5 Maximum local primary membrane stress | | | | | |
|---|---|---|---|---|---|
| **Condition** | **P (psi)** | **$P_L$ (psi)** | **$S_{allow}$ (psi)** | **Over stressed** | **$P_{max}$ (psi)** |
| Design P | 100 | 16,033 | 28,200 | No | 175.89 |

| Division 2 4.5.4.1 Nozzle Neck Minimum Thickness | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Condition** | **P (psi)** | **$t_{d1}$ (in)** | **$t_{d,STD}$ (in)** | **t (in)** | **$t_d$ (in)** | **$t_n$ (in)** | **Status** | **$P_{max}$ (psi)** |
| Design P | 100 | 0.0352 | 0.3281 | 0.371 | 0.3281 | 0.375 | OK | 1,036.68 |

| Division 2 4.5.14 Strength of Nozzle Attachment Welds Summary | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Condition** | **P (psi)** | **$k_y$** | **$L_\tau$ (in)** | **$L_{\tau p}$ (in)** | **$f_{welds}$ ($lb_f$)** | **$\tau_1$ (psi)** | **$\tau_2$ (psi)** | **$\tau_3$ (psi)** | **$\tau$ (psi)** | **S (psi)** | **Over stressed** |
| Design P | 100 | 1.0625 | 10.0138 | 14.7262 | 3,191.91 | 855 | 542 | 1,343 | 1,343 | 18,800 | No |
| MAWP | 175.89 | 1.0625 | 10.0138 | 14.7262 | 5,614.26 | 1,505 | 954 | 2,363 | 2,363 | 18,800 | No |

| Division 2 Table 4.2.11 Minimum Fillet Weld Sizes | | | |
|---|---|---|---|
| **Fillet Leg** | **Required Leg Size (in)** | **Actual Leg Size (in)** | **Status** |
| $Leg_{41}$ | 0.3571 | 0.25 | **weld size is NOT adequate** |
| $Leg_{42}$ | 0.2143 | 0.1875 | **weld size is NOT adequate** |

| WRC 107 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Load Case** | **P (psi)** | **$P_r$ ($lb_f$)** | **$M_c$ ($lb_f$-in)** | **$V_c$ ($lb_f$)** | **$M_L$ ($lb_f$-in)** | **$V_L$ ($lb_f$)** | **$M_t$ ($lb_f$-in)** | **Max Comb Stress (psi)** | **Allow Comb Stress (psi)** | **Max Local Primary Stress (psi)** | **Allow Local Primary Stress (psi)** | **Over stressed** |
| Operating | 100 | 600 | 500 | 400 | 300 | 200 | 100 | **16,148** | **56,400** | 15,827 | 28,200 | No |
| Operating (Hot Shut Down) | 0 | 600 | 500 | 400 | 300 | 200 | 100 | -2,050 | 56,400 | -452 | 28,200 | No |
| Start up | 100 | 100 | 200 | 300 | 400 | 500 | 600 | 16,060 | 56,400 | **16,015** | **28,200** | No |
| Start up (Hot Shut Down) | 0 | 100 | 200 | 300 | 400 | 500 | 600 | -392 | 56,400 | -90 | 28,200 | No |

| WRC 107 MAWP | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Load Case** | **P (psi)** | **$P_r$ ($lb_f$)** | **$M_c$ ($lb_f$-in)** | **$V_c$ ($lb_f$)** | **$M_L$ ($lb_f$-in)** | **$V_L$ ($lb_f$)** | **$M_t$ ($lb_f$-in)** | **Max Comb Stress (psi)** | **Allow Comb Stress (psi)** | **Max Local Primary Stress (psi)** | **Allow Local Primary Stress (psi)** | **Over stressed** |
| Operating | 176.01 | 600 | 500 | 400 | 300 | 200 | 100 | **28,333** | **56,400** | 28,012 | 28,200 | No |
| Operating (Hot Shut Down) | 0 | 600 | 500 | 400 | 300 | 200 | 100 | -2,050 | 56,400 | -452 | 28,200 | No |
| Start up | 176.01 | 100 | 200 | 300 | 400 | 500 | 600 | 28,245 | 56,400 | **28,200** | **28,200** | No |
| Start up (Hot Shut Down) | 0 | 100 | 200 | 300 | 400 | 500 | 600 | -392 | 56,400 | -90 | 28,200 | No |

## Detailed Calculations

| Division 2 4.5.5 Vessel effective radius | |
|---|---|
| $R_{eff} = 0.5*D_i$ | (4.5.3) |
| $R_{xn} = t_n / \ln[1 + t_n / R_n]$ | (4.5.51) |
| **Corroded\New** | |
| $R_{eff} = 0.5*60.258 =$ | 30.129" |
| $R_{xn} = 0.375 / \ln[1 + 0.375 / 6] =$ | 6.1856" |

| Division 2 4.5.5 Limit of reinforcement along the vessel wall | |
|---|---|
| $L_{R1} = (R_{eff}*t)^{0.5} + W$ | (4.5.6) |
| $L_{R2} = ((R_{eff} + t)*(t + t_e))^{0.5}$ | (4.5.7) |
| $L_{R3} = 2*R_n$ | (4.5.8) |
| $L_R = \min[ L_{R1}, L_{R2}, L_{R3}]$ | (4.5.9) |
| **Corroded\New** | |
| $L_{R1} = (30.129*0.371)^{0.5} + 3 =$ | 6.3433" |
| $L_{R2} = ((30.129 + 0.371)*(0.371 + 0.25))^{0.5} =$ | 4.3521" |
| $L_{R3} = 2*6 =$ | 12" |
| $L_R = \min[ 6.3433, 4.3521, 12] =$ | 4.3521" |

| Division 2 4.5.5 Limit of reinforcement along the nozzle wall projecting outside the vessel surface | |
|---|---|
| $L_{H1} = \min[ 1.5*t , t_e] + (R_n*t_n)^{0.5}$ | (4.5.11) |
| $L_{H2} = L_{pr1}$ | (4.5.12) |
| $L_{H3} = 8*(t + t_e)$ | (4.5.13) |
| $L_H = \min[ L_{H1}, L_{H2}, L_{H3}] + t$ | (4.5.14) |
| **Corroded\New** | |
| $L_{H1} = \min[ 1.5*0.371 , 0.25] + (6*0.375)^{0.5} =$ | 1.75" |
| $L_{H2} = 15.6875 =$ | 15.6875" |
| $L_{H3} = 8*(0.371 + 0.25) =$ | 4.968" |
| $L_H = \min[ 1.75, 15.6875, 4.968] + 0.371 =$ | 2.121" |

| Division 2 4.5.5 Available area near the nozzle opening | |
|---|---|
| $\lambda = \min[ (2*R_n + t_n) / ((D_i + t_{eff})*t_{eff})^{0.5}, 12]$ | (4.5.24) |
| $A_1 = t*L_R*\max[ (\lambda / 5)^{0.85} , 1]$ | (4.5.23) |
| $A_2 = t_n*L_H$ | (4.5.27) |
| $A_{41} = 0.5*L_{41}^2$ | (4.5.39) |
| $A_{42} = 0.5*L_{42}^2$ | (4.5.40) |
| $A_{5a} = W*t_e$ | (4.5.42) |
| $A_{5b} = L_R*t_e$ | (4.5.43) |
| $A_5 = \min[ A_{5a}, A_{5b}]$ | (4.5.45) |
| **Corroded\New** | |
| $\lambda = \min[ (2*6 + 0.375) / ((60.258 + 0.5433)*0.5433)^{0.5}, 12] =$ | 2.1531 |
| $A_1 = 0.371*4.3521*\max[ (2.1531 / 5)^{0.85} , 1] =$ | 1.6146 $in^2$ |
| $A_2 = 0.375*2.121 =$ | 0.7954 $in^2$ |
| $A_{41} = 0.5*0.25^2 =$ | 0.0313 $in^2$ |
| $A_{42} = 0.5*0.1875^2 =$ | 0.0176 $in^2$ |
| $A_{5a} = 3*0.25 =$ | 0.75 $in^2$ |
| $A_{5b} = 4.3521*0.25 =$ | 1.088 $in^2$ |
| $A_5 = \min[ 0.75, 1.088] =$ | 0.75 $in^2$ |

| Division 2 4.5.5 Equations | |
|---|---|
| $f_{rn}$ = min[ $S_n$ / S , 1 ] | (4.5.21) |
| $f_{rp}$ = min[ $S_p$ / S , 1 ] | (4.5.22) |
| $t_{eff}$ = t + ($A_5$*$f_{rp}$ / $L_R$) | (4.5.25) |
| $R_{xs}$ = $t_{eff}$ / ln[1 + $t_{eff}$ / $R_{eff}$] | (4.5.52) |
| $A_T$ = $A_1$ + $f_{rn}$*$A_2$ + $A_{41}$ + $A_{42}$ + $f_{rp}$*$A_5$ | (4.5.20) |
| $f_N$ = P*$R_{xn}$*$L_H$ | (4.5.46) |
| $f_S$ = P*$R_{xs}$*($L_R$ + $t_n$) | (4.5.48) |
| $f_Y$ = P*$R_{xs}$*$R_{nc}$ | (4.5.50) |
| $\sigma_{avg}$ = ($f_N$ + $f_S$ + $f_Y$) / $A_T$ | (4.5.53) |
| $\sigma_{circ}$ = P*$R_{xs}$ / $t_{eff}$ | (4.5.54) |
| $P_L$ = max[ {2*$\sigma_{avg}$ - $\sigma_{circ}$} , $\sigma_{circ}$] | (4.5.55) |
| $S_{allow}$ = 1.5*S*E | (4.5.57) |
| $P_L \le S_{allow}$ | (4.5.56) |
| $A_p$ = ($f_N$ + $f_S$ + $f_Y$) / P | (4.5.62) |
| $P_{max1}$ = $S_{allow}$ / (2*$A_p$ / $A_T$ - $R_{xs}$ / $t_{eff}$) | (4.5.59) |
| $P_{max2}$ = S*(t / $R_{xs}$) | (4.5.60) |
| $P_{max}$ = min[ $P_{max1}$, $P_{max2}$] | (4.5.61) |

| Division 2 4.5.5 Design Rules for Openings in Shells and Heads | |
|---|---|
| **Design P** | |
| **Total available area near the nozzle opening** | |
| $f_{rn}$ = min[ 17,100 / 18,800 , 1 ] = | 0.9096 |
| $f_{rp}$ = min[ 18,800 / 18,800 , 1 ] = | 1 |
| $t_{eff}$ = 0.371 + (0.75*1 / 4.3521) = | 0.5433" |
| $R_{xs}$ = 0.5433 / ln[1 + 0.5433 / 30.129] = | 30.3999" |
| $A_T$ = 1.6146 + 0.9096*0.7954 + 0.0313 + 0.0176 + 1*0.75 = | 3.1369 $in^2$ |
| **Forces at nozzle to vessel intersection** | |
| $f_N$ = 100*6.1856*2.121 = | 1,311.97 $lb_f$ |
| $f_S$ = 100*30.3999*(4.3521 + 0.375) = | 14,370.22 $lb_f$ |
| $f_Y$ = 100*30.3999*6 = | 18,239.91 $lb_f$ |
| **Average local primary membrane stress** | |
| $\sigma_{avg}$ = (1,311.97 + 14,370.22 + 18,239.91) / 3.1369 = | 10,814 psi |
| **General primary membrane stress** | |
| $\sigma_{circ}$ = 100*30.3999 / 0.5433 = | 5,595 psi |
| **Maximum local primary membrane stress at the nozzle intersection** | |
| $P_L$ = max[ {2*10,814 - 5,595} , 5,595] = | 16,033 psi |
| **Allowable stress** | |
| $S_{allow}$ = 1.5*18,800*1 = | 28,200 psi |
| $P_L$ = 16,033 psi ≤ $S_{allow}$ = 28,200 psi | |
| **Maximum allowable working pressure** | |
| $A_p$ = (1,311.97 + 14,370.22 + 18,239.91) / 100 = | 339.221 $in^2$ |
| $P_{max1}$ = 28,200 / (2*339.221 / 3.1369 - 30.3999 / 0.5433) = | 175.89 psi |
| $P_{max2}$ = 18,800*(0.371 / 30.3999) = | 229.44 psi |
| $P_{max}$ = min[ 175.89, 229.44] = | 175.89 psi |

| Division 2 4.5.14 Equations | |
|---|---|
| $k_y = (R_{nc} + t_n) / R_{nc}$ | (4.5.174) |
| $L_\tau = \pi / 2*(R_n + t_n)$ | (4.5.175) |
| $L_{\tau p} = \pi / 2*(R_n + t_n + W)$ | (4.5.177) |
| $L_{41T} = 0.7071*L_{41}$ | (4.5.179) |
| $L_{42T} = 0.7071*L_{42}$ | (4.5.180) |
| $f_{welds} = \min[ f_Y*k_y, 1.5*S_n*(A_2 + A_3) , \pi / 4*P*R_n^2*k_y^2 ]$ | (4.5.184) |
| $f_{ws} = f_{welds}*t*S / (t*S + t_e*S_p)$ | (4.5.189) |
| $f_{wp} = f_{welds}*t_e*S_p / (t*S + t_e*S_p)$ | (4.5.190) |
| $\tau_1 = f_{ws} / [L_\tau*(0.6*t_{w1} + 0.49*L_{43T})]$ | (4.5.185) |
| $\tau_2 = f_{wp} / [L_\tau*(0.6*t_{w2} + 0.49*L_{41T})]$ | (4.5.186) |
| $\tau_3 = f_{wp} / [L_{\tau p}*0.49*L_{42T}]$ | (4.5.187) |
| $\tau = \max[ \tau_1, \tau_2, \tau_3]$ | |
| $\max[ \tau_1, \tau_2, \tau_3] \le S$ | (4.5.188) |

| Division 2 4.5.14 Strength of Nozzle Attachment Welds | |
|---|---|
| **Corroded\New** | |
| **Discontinuity force factor** | |
| $k_y$ = (6 + 0.375) / 6 = | 1.0625 |
| **Weld length resisting discontinuity force** | |
| $L_\tau = \pi / 2*(6 + 0.375)$ = | 10.0138" |
| $L_{\tau p} = \pi / 2*(6 + 0.375 + 3)$ = | 14.7262" |
| **Weld throat dimensions** | |
| $L_{41T}$ = 0.7071*0.25 = | 0.1768" |
| $L_{42T}$ = 0.7071*0.1875 = | 0.1326" |
| **Design P** | |
| **Average shear stress in weld** | |
| $f_{welds}$ = min[ 18,239.91*1.0625, 1.5*17,100*(0.7954 + 0) , $\pi$ / 4*100*6$^2$*1.0625$^2$ ] = | 3,191.91 $lb_f$ |
| $f_{ws}$ = 3,191.91*0.371*18,800 / (0.371*18,800 + 0.25*18,800) = | 1,906.92 $lb_f$ |
| $f_{wp}$ = 3,191.91*0.25*18,800 / (0.371*18,800 + 0.25*18,800) = | 1,284.99 $lb_f$ |
| $\tau_1$ = 1,906.92 / [10.0138*(0.6*0.371 + 0.49*0)] = | 855 psi |
| $\tau_2$ = 1,284.99 / [10.0138*(0.6*0.25 + 0.49*0.1768)] = | 542 psi |
| $\tau_3$ = 1,284.99 / [14.7262*0.49*0.1326] = | 1,343 psi |
| $\tau$ = max[ 855, 542, 1,343] = | 1,343 psi |
| $\tau$ = 1,343 psi $\le$ S = 18,800 psi | |
| **MAWP** | |
| **Average shear stress in weld** | |
| $f_{welds}$ = min[ 32,082.25*1.0625, 1.5*17,100*(0.7954 + 0) , $\pi$ / 4*175.89*6$^2$*1.0625$^2$ ] = | 5,614.26 $lb_f$ |
| $f_{ws}$ = 5,614.26*0.371*18,800 / (0.371*18,800 + 0.25*18,800) = | 3,354.09 $lb_f$ |
| $f_{wp}$ = 5,614.26*0.25*18,800 / (0.371*18,800 + 0.25*18,800) = | 2,260.17 $lb_f$ |
| $\tau_1$ = 3,354.09 / [10.0138*(0.6*0.371 + 0.49*0)] = | 1,505 psi |
| $\tau_2$ = 2,260.17 / [10.0138*(0.6*0.25 + 0.49*0.1768)] = | 954 psi |
| $\tau_3$ = 2,260.17 / [14.7262*0.49*0.1326] = | 2,363 psi |
| $\tau$ = max[ 1,505, 954, 2,363] = | 2,363 psi |
| $\tau$ = 2,363 psi $\le$ S = 18,800 psi | |

| Division 2 4.3.3.1 Design Thickness for Internal Pressure | |
|---|---|
| $t_d$ = D / 2 * (exp[P / (S*E)] - 1) + Corrosion | (4.3.1) |
| **Operating Hot & Corroded** | |
| $t_d$ = 12 / 2 * (exp[(100 + 0) / (17,100*1)] - 1) + 0 = | 0.0352" |
| **Operating Cold & Corroded** | |
| $t_r$ = 12 / 2 * (exp[(144.02 + 0) / (17,100*1)] - 1) = | 0.0507" |

| Division 2 4.3.3.1 Maximum Pressure Circumferential Stress | |
|---|---|
| $P_{max}$ = S*E*ln[$D_o$ / D] | (4.3.1) |
| **MAWP** | |
| $P_{max}$ = 17,100*1*ln[12.75 / 12] - 0 = | 1,036.68 psi |

| Division 2 4.3.10.2 Combined Loads Summary (Operating governs) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **$\sigma_{\theta m}$ (psi)** | **$\sigma_{sm}$ (psi)** | **$\sigma_T$ (psi)** | **$S_{allow}$ (psi)** | **$t_d$ (in)** | **$P_{max}$ (psi)** |
| **Operating Hot & Corroded** | Weight Only | Left | Windward | 1,600 | 748 | 1,429 | 17,100 | 0.0322 | 1,196.69 |
| | | | Leeward | 1,600 | 721 | 1,430 | 17,100 | 0.0322 | 1,196.69 |

## WRC 107 Operating

**Applied Loads**

| | | | |
|---|---|---|---|
| Radial load: | $P_r$ = | 600 | $lb_f$ |
| Circumferential moment: | $M_c$ = | 500 | $lb_f$-in |
| Circumferential shear: | $V_c$ = | 400 | $lb_f$ |
| Longitudinal moment: | $M_L$ = | 300 | $lb_f$-in |
| Longitudinal shear: | $V_L$ = | 200 | $lb_f$ |
| Torsion moment: | $M_t$ = | 100 | $lb_f$-in |
| Internal pressure: | P = | 176.006 | psi |
| Mean shell radius: | $R_m$ = | 30.3145 | in |
| Local shell thickness: | T = | 0.371 | in |
| Shell yield stress: | $S_y$ = | 28,200 | psi |
| Design factor: | | 3 | |

**Maximum stresses due to the applied loads at the pad edge (includes pressure)**

$\gamma = R_m / T = 30.3145 / 0.371 = 81.7102$

$\beta = 0.875 \cdot r_o / R_m = 0.875 \cdot 9.375 / 30.3145 = 0.2706$

Pressure stress intensity factor, I = 1.0883 (derived from PVP-Vol. 399, pages 77-82)

Local circumferential pressure stress = $I \cdot P \cdot R_i / T$ =15,555 psi

Local longitudinal pressure stress = $I \cdot P \cdot R_i / (2 \cdot T)$ =7,777 psi

Maximum combined stress ($P_L+P_b+Q$) = 15,989 psi
Allowable combined stress ($P_L+P_b+Q$) = +-3*S = +-56,400 psi

The maximum combined stress ($P_L+P_b+Q$) is within allowable limits.

Maximum local primary membrane stress ($P_L$) = 15,160 psi
Allowable local primary membrane stress ($P_L$) = +-1.5*S = +-28,200 psi

The maximum local primary membrane stress ($P_L$) is within allowable limits.

| Stresses at the pad edge per WRC Bulletin 107 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Figure** | **value** | | $A_u$ | $A_l$ | $B_u$ | $B_l$ | $C_u$ | $C_l$ | $D_u$ | $D_l$ |
| 3C* | $N_\phi / (P / R_m)$ | 3.0951 | 0 | 0 | 0 | 0 | -165 | -165 | -165 | -165 |
| 4C* | $N_\phi / (P / R_m)$ | 7.7129 | -411 | -411 | -411 | -411 | 0 | 0 | 0 | 0 |
| 1C | $M_\phi / P$ | 0.0659 | 0 | 0 | 0 | 0 | -1,724 | 1,724 | -1,724 | 1,724 |
| 2C-1 | $M_\phi / P$ | 0.012 | -314 | 314 | -314 | 314 | 0 | 0 | 0 | 0 |
| 3A* | $N_\phi / [M_c / (R_m^2 * \beta)]$ | 2.3025 | 0 | 0 | 0 | 0 | -12 | -12 | 12 | 12 |
| 1A | $M_\phi / [M_c / (R_m * \beta)]$ | 0.0559 | 0 | 0 | 0 | 0 | -149 | 149 | 149 | -149 |
| 3B* | $N_\phi / [M_L / (R_m^2 * \beta)]$ | 4.8813 | -16 | -16 | 16 | 16 | 0 | 0 | 0 | 0 |
| 1B-1 | $M_\phi / [M_L / (R_m * \beta)]$ | 0.0109 | -17 | 17 | 17 | -17 | 0 | 0 | 0 | 0 |
| **Pressure stress*** | | | 15,555 | 15,555 | 15,555 | 15,555 | 14,293 | 14,293 | 14,293 | 14,293 |
| **Total circumferential stress** | | | 14,797 | 15,459 | 14,863 | 15,457 | 12,243 | 15,989 | 12,565 | 15,715 |
| **Primary membrane circumferential stress*** | | | 15,128 | 15,128 | 15,160 | 15,160 | 14,116 | 14,116 | 14,140 | 14,140 |
| 3C* | $N_x / (P / R_m)$ | 3.0951 | -165 | -165 | -165 | -165 | 0 | 0 | 0 | 0 |
| 4C* | $N_x / (P / R_m)$ | 7.7129 | 0 | 0 | 0 | 0 | -411 | -411 | -411 | -411 |
| 1C-1 | $M_x / P$ | 0.0294 | -769 | 769 | -769 | 769 | 0 | 0 | 0 | 0 |
| 2C | $M_x / P$ | 0.0312 | 0 | 0 | 0 | 0 | -816 | 816 | -816 | 816 |
| 4A* | $N_x / [M_c / (R_m^2 * \beta)]$ | 7.5318 | 0 | 0 | 0 | 0 | -41 | -41 | 41 | 41 |
| 2A | $M_x / [M_c / (R_m * \beta)]$ | 0.0232 | 0 | 0 | 0 | 0 | -62 | 62 | 62 | -62 |
| 4B* | $N_x / [M_L / (R_m^2 * \beta)]$ | 2.5238 | -8 | -8 | 8 | 8 | 0 | 0 | 0 | 0 |
| 2B-1 | $M_x / [M_L / (R_m * \beta)]$ | 0.0182 | -29 | 29 | 29 | -29 | 0 | 0 | 0 | 0 |
| **Pressure stress*** | | | 7,146 | 7,146 | 7,146 | 7,146 | 7,777 | 7,777 | 7,777 | 7,777 |
| **Total longitudinal stress** | | | 6,175 | 7,771 | 6,249 | 7,729 | 6,447 | 8,203 | 6,653 | 8,161 |
| **Primary membrane longitudinal stress*** | | | 6,973 | 6,973 | 6,989 | 6,989 | 7,325 | 7,325 | 7,407 | 7,407 |
| **Shear from $M_t$** | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Circ shear from $V_c$** | | | 37 | 37 | -37 | -37 | 0 | 0 | 0 | 0 |
| **Long shear from $V_L$** | | | 0 | 0 | 0 | 0 | -18 | -18 | 18 | 18 |
| **Total Shear stress** | | | 37 | 37 | -37 | -37 | -18 | -18 | 18 | 18 |
| **Combined stress ($P_L+P_b+Q$)** | | | 14,797 | 15,459 | 14,863 | 15,457 | 12,243 | 15,989 | 12,565 | 15,715 |

Note: * denotes primary stress.

**Maximum stresses due to the applied loads at the nozzle OD (includes pressure)**

$\gamma = R_m / T = 30.3145 / 0.621 = 48.8156$

$\beta = 0.875 * r_o / R_m = 0.875 * 6.375 / 30.3145 = 0.184$

Pressure stress intensity factor, I = 1.9742 (derived from PVP-Vol. 399, pages 77-82)

Local circumferential pressure stress = $I*P*R_i / T$ =28,218 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =14,108 psi

Maximum combined stress ($P_L+P_b+Q$) = 28,333 psi
Allowable combined stress ($P_L+P_b+Q$) = +-3*S = +-56,400 psi

The maximum combined stress ($P_L+P_b+Q$) is within allowable limits.

Maximum local primary membrane stress ($P_L$) = 28,012 psi
Allowable local primary membrane stress ($P_L$) = +-1.5*S = +-28,200 psi

The maximum local primary membrane stress ($P_L$) is within allowable limits.

| Stresses at the nozzle OD per WRC Bulletin 107 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Figure** | **value** | | **$A_u$** | **$A_l$** | **$B_u$** | **$B_l$** | **$C_u$** | **$C_l$** | **$D_u$** | **$D_l$** |
| 3C* | $N_\phi / (P / R_m)$ | 4.6113 | 0 | 0 | 0 | 0 | -147 | -147 | -147 | -147 |
| 4C* | $N_\phi / (P / R_m)$ | 6.935 | -221 | -221 | -221 | -221 | 0 | 0 | 0 | 0 |
| 1C | $M_\phi / P$ | 0.0688 | 0 | 0 | 0 | 0 | -642 | 642 | -642 | 642 |
| 2C-1 | $M_\phi / P$ | 0.0354 | -330 | 330 | -330 | 330 | 0 | 0 | 0 | 0 |
| 3A* | $N_\phi / [M_c / (R_m^2*\beta)]$ | 2.0159 | 0 | 0 | 0 | 0 | -10 | -10 | 10 | 10 |
| 1A | $M_\phi / [M_c / (R_m*\beta)]$ | 0.0749 | 0 | 0 | 0 | 0 | -104 | 104 | 104 | -104 |
| 3B* | $N_\phi / [M_L / (R_m^2*\beta)]$ | 5.0821 | -15 | -15 | 15 | 15 | 0 | 0 | 0 | 0 |
| 1B-1 | $M_\phi / [M_L / (R_m*\beta)]$ | 0.0254 | -21 | 21 | 21 | -21 | 0 | 0 | 0 | 0 |
| **Pressure stress*** | | | 28,218 | 28,218 | 28,218 | 28,218 | 14,293 | 14,293 | 14,293 | 14,293 |
| **Total circumferential stress** | | | 27,631 | 28,333 | 27,703 | 28,321 | 13,390 | 14,882 | 13,618 | 14,694 |
| **Primary membrane circumferential stress*** | | | 27,982 | 27,982 | 28,012 | 28,012 | 14,136 | 14,136 | 14,156 | 14,156 |
| 3C* | $N_x / (P / R_m)$ | 4.6113 | -147 | -147 | -147 | -147 | 0 | 0 | 0 | 0 |
| 4C* | $N_x / (P / R_m)$ | 6.935 | 0 | 0 | 0 | 0 | -221 | -221 | -221 | -221 |
| 1C-1 | $M_x / P$ | 0.0681 | -636 | 636 | -636 | 636 | 0 | 0 | 0 | 0 |
| 2C | $M_x / P$ | 0.039 | 0 | 0 | 0 | 0 | -364 | 364 | -364 | 364 |
| 4A* | $N_x / [M_c / (R_m^2*\beta)]$ | 3.8603 | 0 | 0 | 0 | 0 | -18 | -18 | 18 | 18 |
| 2A | $M_x / [M_c / (R_m*\beta)]$ | 0.0371 | 0 | 0 | 0 | 0 | -52 | 52 | 52 | -52 |
| 4B* | $N_x / [M_L / (R_m^2*\beta)]$ | 2.0143 | -6 | -6 | 6 | 6 | 0 | 0 | 0 | 0 |
| 2B-1 | $M_x / [M_L / (R_m*\beta)]$ | 0.0378 | -32 | 32 | 32 | -32 | 0 | 0 | 0 | 0 |
| **Pressure stress*** | | | 7,146 | 7,146 | 7,146 | 7,146 | 14,108 | 14,108 | 14,108 | 14,108 |
| **Total longitudinal stress** | | | 6,325 | 7,661 | 6,401 | 7,609 | 13,453 | 14,285 | 13,593 | 14,217 |
| **Primary membrane longitudinal stress*** | | | 6,993 | 6,993 | 7,005 | 7,005 | 13,869 | 13,869 | 13,905 | 13,905 |
| **Shear from $M_t$** | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Circ shear from $V_c$** | | | 32 | 32 | -32 | -32 | 0 | 0 | 0 | 0 |
| **Long shear from $V_L$** | | | 0 | 0 | 0 | 0 | -16 | -16 | 16 | 16 |
| **Total Shear stress** | | | 33 | 33 | -31 | -31 | -15 | -15 | 17 | 17 |
| **Combined stress ($P_L$+$P_b$+Q)** | | | 27,631 | 28,333 | 27,703 | 28,321 | 13,456 | 14,882 | 13,627 | 14,695 |

Note: * denotes primary stress.

**Shear stress in the nozzle wall due to external loads**

$\sigma_{shear} = (V_L^2 + V_c^2)^{0.5} / (\pi*R_i*t_n)$
$= (200^2 + 400^2)^{0.5} / (\pi*6*0.375)$
= 63 psi

$\sigma_{torsion} = M_t / (2*\pi*R_i^2*t_n)$
$= 100 / (2*\pi*6^2*0.375)$
= 1 psi

$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$
= 63 + 1
= 64 psi

UG-45: The total combined shear stress (64 psi) ≤ allowable ($0.7*S_n = 0.7*17{,}100 = 11{,}970$ psi)

## WRC 107 Start up

### Applied Loads

| | | | |
|---|---|---|---|
| Radial load: | $P_r$ = | 100 | $lb_f$ |
| Circumferential moment: | $M_c$ = | 200 | $lb_f$-in |
| Circumferential shear: | $V_c$ = | 300 | $lb_f$ |
| Longitudinal moment: | $M_L$ = | 400 | $lb_f$-in |
| Longitudinal shear: | $V_L$ = | 500 | $lb_f$ |
| Torsion moment: | $M_t$ = | 600 | $lb_f$-in |
| Internal pressure: | P = | 176.006 | psi |
| Mean shell radius: | $R_m$ = | 30.3145 | in |
| Local shell thickness: | T = | 0.371 | in |
| Shell yield stress: | $S_y$ = | 28,200 | psi |
| Design factor: | | 3 | |

**Maximum stresses due to the applied loads at the pad edge (includes pressure)**

$\gamma = R_m / T = 30.3145 / 0.371 = 81.7102$

$\beta = 0.875*r_o / R_m = 0.875*9.375 / 30.3145 = 0.2706$

Pressure stress intensity factor, I = 1.0883 (derived from PVP-Vol. 399, pages 77-82)

Local circumferential pressure stress = $I*P*R_i$ / T =15,555 psi

Local longitudinal pressure stress = $I*P*R_i$ / (2*T) =7,777 psi

Maximum combined stress ($P_L+P_b$+Q) = 15,540 psi
Allowable combined stress ($P_L+P_b$+Q) = +-3*S = +-56,400 psi

The maximum combined stress ($P_L+P_b$+Q) is within allowable limits.

Maximum local primary membrane stress ($P_L$) = 15,507 psi
Allowable local primary membrane stress ($P_L$) = +-1.5*S = +-28,200 psi

The maximum local primary membrane stress ($P_L$) is within allowable limits.

| Stresses at the pad edge per WRC Bulletin 107 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Figure** | **value** | | **$A_u$** | **$A_l$** | **$B_u$** | **$B_l$** | **$C_u$** | **$C_l$** | **$D_u$** | **$D_l$** |
| 3C* | $N_\phi$ / (P / $R_m$) | 3.0951 | 0 | 0 | 0 | 0 | -28 | -28 | -28 | -28 |
| 4C* | $N_\phi$ / (P / $R_m$) | 7.7129 | -69 | -69 | -69 | -69 | 0 | 0 | 0 | 0 |
| 1C | $M_\phi$ / P | 0.0659 | 0 | 0 | 0 | 0 | -287 | 287 | -287 | 287 |
| 2C-1 | $M_\phi$ / P | 0.012 | -52 | 52 | -52 | 52 | 0 | 0 | 0 | 0 |
| 3A* | $N_\phi$ / [$M_c$ / ($R_m^2$*β)] | 2.3025 | 0 | 0 | 0 | 0 | -5 | -5 | 5 | 5 |
| 1A | $M_\phi$ / [$M_c$ / ($R_m$*β)] | 0.0559 | 0 | 0 | 0 | 0 | -59 | 59 | 59 | -59 |
| 3B* | $N_\phi$ / [$M_L$ / ($R_m^2$*β)] | 4.8813 | -21 | -21 | 21 | 21 | 0 | 0 | 0 | 0 |
| 1B-1 | $M_\phi$ / [$M_L$ / ($R_m$*β)] | 0.0109 | -23 | 23 | 23 | -23 | 0 | 0 | 0 | 0 |
| **Pressure stress*** | | | 15,555 | 15,555 | 15,555 | 15,555 | 14,293 | 14,293 | 14,293 | 14,293 |
| **Total circumferential stress** | | | 15,390 | 15,540 | 15,478 | 15,536 | 13,914 | 14,606 | 14,042 | 14,498 |
| **Primary membrane circumferential stress*** | | | 15,465 | 15,465 | 15,507 | 15,507 | 14,260 | 14,260 | 14,270 | 14,270 |
| 3C* | $N_x$ / (P / $R_m$) | 3.0951 | -28 | -28 | -28 | -28 | 0 | 0 | 0 | 0 |
| 4C* | $N_x$ / (P / $R_m$) | 7.7129 | 0 | 0 | 0 | 0 | -69 | -69 | -69 | -69 |
| 1C-1 | $M_x$ / P | 0.0294 | -128 | 128 | -128 | 128 | 0 | 0 | 0 | 0 |
| 2C | $M_x$ / P | 0.0312 | 0 | 0 | 0 | 0 | -136 | 136 | -136 | 136 |
| 4A* | $N_x$ / [$M_c$ / ($R_m^2$*β)] | 7.5318 | 0 | 0 | 0 | 0 | -16 | -16 | 16 | 16 |
| 2A | $M_x$ / [$M_c$ / ($R_m$*β)] | 0.0232 | 0 | 0 | 0 | 0 | -25 | 25 | 25 | -25 |
| 4B* | $N_x$ / [$M_L$ / ($R_m^2$*β)] | 2.5238 | -11 | -11 | 11 | 11 | 0 | 0 | 0 | 0 |
| 2B-1 | $M_x$ / [$M_L$ / ($R_m$*β)] | 0.0182 | -39 | 39 | 39 | -39 | 0 | 0 | 0 | 0 |
| **Pressure stress*** | | | 7,146 | 7,146 | 7,146 | 7,146 | 7,777 | 7,777 | 7,777 | 7,777 |
| **Total longitudinal stress** | | | 6,940 | 7,274 | 7,040 | 7,218 | 7,531 | 7,853 | 7,613 | 7,835 |
| **Primary membrane longitudinal stress*** | | | 7,107 | 7,107 | 7,129 | 7,129 | 7,692 | 7,692 | 7,724 | 7,724 |
| **Shear from $M_t$** | | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Circ shear from $V_c$** | | | 27 | 27 | -27 | -27 | 0 | 0 | 0 | 0 |
| **Long shear from $V_L$** | | | 0 | 0 | 0 | 0 | -46 | -46 | 46 | 46 |
| **Total Shear stress** | | | 30 | 30 | -24 | -24 | -43 | -43 | 49 | 49 |
| **Combined stress ($P_L$+$P_b$+Q)** | | | 15,390 | 15,540 | 15,478 | 15,536 | 13,914 | 14,606 | 14,042 | 14,498 |

Note: * denotes primary stress.

**Maximum stresses due to the applied loads at the nozzle OD (includes pressure)**

$\gamma = R_m / T = 30.3145 / 0.621 = 48.8156$

$\beta = 0.875 r_o / R_m = 0.875 \cdot 6.375 / 30.3145 = 0.184$

Pressure stress intensity factor, I = 1.9742 (derived from PVP-Vol. 399, pages 77-82)

Local circumferential pressure stress = I*P*$R_i$ / T =28,218 psi

Local longitudinal pressure stress = I*P*$R_i$ / (2*T) =14,108 psi

Maximum combined stress ($P_L$+$P_b$+Q) = 28,245 psi
Allowable combined stress ($P_L$+$P_b$+Q) = +-3*S = +-56,400 psi

The maximum combined stress ($P_L$+$P_b$+Q) is within allowable limits.

Maximum local primary membrane stress ($P_L$) = 28,200 psi
Allowable local primary membrane stress ($P_L$) = +-1.5*S = +-28,200 psi

The maximum local primary membrane stress ($P_L$) is within allowable limits.

| Stresses at the nozzle OD per WRC Bulletin 107 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Figure** | **value** | | **$A_u$** | **$A_l$** | **$B_u$** | **$B_l$** | **$C_u$** | **$C_l$** | **$D_u$** | **$D_l$** |
| 3C* | $N_\phi$ / (P / $R_m$) | 4.6113 | 0 | 0 | 0 | 0 | -24 | -24 | -24 | -24 |
| 4C* | $N_\phi$ / (P / $R_m$) | 6.935 | -37 | -37 | -37 | -37 | 0 | 0 | 0 | 0 |
| 1C | $M_\phi$ / P | 0.0688 | 0 | 0 | 0 | 0 | -107 | 107 | -107 | 107 |
| 2C-1 | $M_\phi$ / P | 0.0354 | -55 | 55 | -55 | 55 | 0 | 0 | 0 | 0 |
| 3A* | $N_\phi$ / [$M_c$ / ($R_m^2$*β)] | 2.0159 | 0 | 0 | 0 | 0 | -4 | -4 | 4 | 4 |
| 1A | $M_\phi$ / [$M_c$ / ($R_m$*β)] | 0.0749 | 0 | 0 | 0 | 0 | -42 | 42 | 42 | -42 |
| 3B* | $N_\phi$ / [$M_L$ / ($R_m^2$*β)] | 5.0821 | -19 | -19 | 19 | 19 | 0 | 0 | 0 | 0 |
| 1B-1 | $M_\phi$ / [$M_L$ / ($R_m$*β)] | 0.0254 | -28 | 28 | 28 | -28 | 0 | 0 | 0 | 0 |
| **Pressure stress*** | | | 28,218 | 28,218 | 28,218 | 28,218 | 14,293 | 14,293 | 14,293 | 14,293 |
| **Total circumferential stress** | | | 28,079 | 28,245 | 28,173 | 28,227 | 14,116 | 14,414 | 14,208 | 14,338 |
| **Primary membrane circumferential stress*** | | | 28,162 | 28,162 | 28,200 | 28,200 | 14,265 | 14,265 | 14,273 | 14,273 |
| 3C* | $N_x$ / (P / $R_m$) | 4.6113 | -24 | -24 | -24 | -24 | 0 | 0 | 0 | 0 |
| 4C* | $N_x$ / (P / $R_m$) | 6.935 | 0 | 0 | 0 | 0 | -37 | -37 | -37 | -37 |
| 1C-1 | $M_x$ / P | 0.0681 | -106 | 106 | -106 | 106 | 0 | 0 | 0 | 0 |
| 2C | $M_x$ / P | 0.039 | 0 | 0 | 0 | 0 | -61 | 61 | -61 | 61 |
| 4A* | $N_x$ / [$M_c$ / ($R_m^2$*β)] | 3.8603 | 0 | 0 | 0 | 0 | -7 | -7 | 7 | 7 |
| 2A | $M_x$ / [$M_c$ / ($R_m$*β)] | 0.0371 | 0 | 0 | 0 | 0 | -21 | 21 | 21 | -21 |
| 4B* | $N_x$ / [$M_L$ / ($R_m^2$*β)] | 2.0143 | -8 | -8 | 8 | 8 | 0 | 0 | 0 | 0 |
| 2B-1 | $M_x$ / [$M_L$ / ($R_m$*β)] | 0.0378 | -42 | 42 | 42 | -42 | 0 | 0 | 0 | 0 |
| **Pressure stress*** | | | 7,146 | 7,146 | 7,146 | 7,146 | 14,108 | 14,108 | 14,108 | 14,108 |
| **Total longitudinal stress** | | | 6,966 | 7,262 | 7,066 | 7,194 | 13,982 | 14,146 | 14,038 | 14,118 |
| **Primary membrane longitudinal stress*** | | | 7,114 | 7,114 | 7,130 | 7,130 | 14,064 | 14,064 | 14,078 | 14,078 |
| **Shear from $M_t$** | | | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Circ shear from $V_c$** | | | 24 | 24 | -24 | -24 | 0 | 0 | 0 | 0 |
| **Long shear from $V_L$** | | | 0 | 0 | 0 | 0 | -40 | -40 | 40 | 40 |
| **Total Shear stress** | | | 28 | 28 | -20 | -20 | -36 | -36 | 44 | 44 |
| **Combined stress ($P_L$+$P_b$+Q)** | | | 28,079 | 28,245 | 28,173 | 28,227 | 14,125 | 14,419 | 14,219 | 14,346 |

Note: * denotes primary stress.

**Shear stress in the nozzle wall due to external loads**

$\sigma_{shear} = (V_L^2 + V_c^2)^{0.5} / (\pi * R_i * t_n)$
$= (500^2 + 300^2)^{0.5} / (\pi*6*0.375)$
= 82 psi

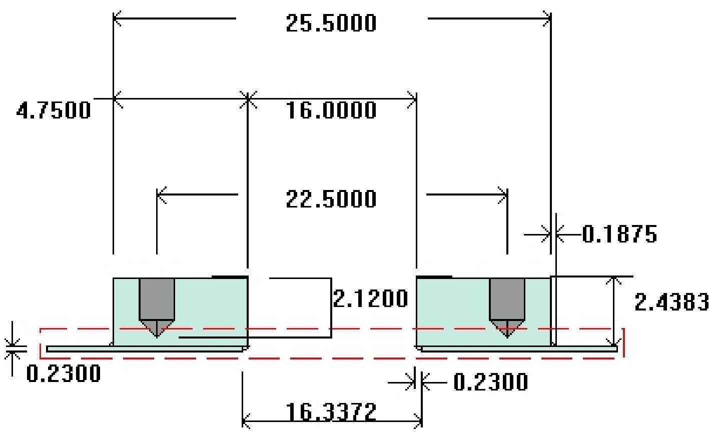
$\sigma_{torsion} = M_t / (2*\pi*R_i^2*t_n)$
$= 600 / (2*\pi*6^2*0.375)$
= 7 psi

$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$
= 82 + 7
= 90 psi

UG-45: The total combined shear stress (90 psi) ≤ allowable (0.7*$S_n$ = 0.7*17,100 = 11,970 psi)

## Nozzle #2 (N2)

### ASME Section VIII Division 1, 2013 Edition




| | |
|---|---|
| Pad inner diameter = | 16 in |
| Shell opening diameter = | 16.3372 in |
| Pad thickness = | 2.5 in |
| Tapped hole diameter = | 1.25 in |
| Tapped hole depth = | 2.12 in |
| Tapped hole bolt circle = | 22.5 in |
| Raised face height = | 0.06 in |
| Raised face outer diameter = | 18.5 in |
| Inner fillet = | 0.1875 in |
| Lower fillet = | 0.23 in |
| $D_p$ = | 25.5 in |
| $t_e$ = | 2.44 in |

Note: round inside edges per UG-76(c)

Note: Thread engagement shall comply with the requirements of UG-43(g).

### Location and Orientation

| | |
|---|---|
| Located on: | Ellipsoidal Head #1 |
| Orientation: | 0° |
| End of nozzle to datum line: | 210.2474 in |
| Calculated as hillside: | No |
| Distance to head center, R: | 0 in |
| Passes through a Category A joint: | No |

### Nozzle

| | |
|---|---|
| Access opening: | No |
| Material specification: | SA-105 (II-D p. 18, ln. 32) |
| Bolt material specification: | SA-193 B7 Bolt <= 2 1/2 (II-D p. 352, ln. 31) |
| Description: | Studding Outlet NPS 16 Class 300 |
| Corrosion allowance: | 0 in |
| Projection available outside vessel, Lpr: | 2.3783 in |
| User input vessel thickness: | 0.23 in |
| Liquid static head included: | 0 psi |
| Longitudinal joint efficiency: | 1 |

### Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

| UG-37 Area Calculation Summary ($in^2$)<br>For P = 160.01 psi @ 650 °F<br>The opening is adequately reinforced | | | | | | | UG-45 Nozzle Wall Thickness Summary (in)<br>The nozzle passes UG-45 | |
|---|---|---|---|---|---|---|---|---|
| A required | A available | $A_1$ | $A_2$ | $A_3$ | $A_5$ | A welds | $t_{req}$ | $t_{min}$ |
| 4.3951 | 5.2553 | -- | -- | -- | 5.1719 | 0.0834 | 0.2556 | 4.75 |

| UG-41 Weld Failure Path Analysis Summary ($lb_f$)<br>All failure paths are stronger than the applicable weld loads | | | | |
|---|---|---|---|---|
| Weld load W | Weld load $W_{1-1}$ | Path 1-1 strength | Weld load $W_{2-2}$ | Path 2-2 strength |
| 82,627.05 | 98,799.55 | 116,985.79 | -- | -- |

| UW-16 Weld Sizing Summary | | | |
|---|---|---|---|
| Weld description | Required weld throat size (in) | Actual weld throat size (in) | Status |
| Pad to shell fillet ($Leg_{42}$) | 0.115 | 0.1312 | weld size is adequate |
| Nozzle to inside shell fillet ($Leg_{43}$) | 0.161 | 0.161 (corroded) | weld size is adequate |

### Calculations for internal pressure 160.01 psi @ 650 °F

### Parallel Limit of reinforcement per UG-40

$L_R$ = MAX(d, $R_n$ + ($t_n$ - $C_n$) + (t - C))
= MAX(16.3372, 8.1686 + (0) + (0.23 - 0))
= 16.3372 in

### Outer Normal Limit of reinforcement per UG-40

$L_H$ = MIN(2.5*(t - C), 2.5*($t_n$ - $C_n$) + $t_e$)
= MIN(2.5*(0.23 - 0), 2.5*(0) + 2.44)
= 0.575 in

### Required thickness $t_r$ from UG-37(a)(c)

$t_r$ = P*$K_1$*D / (2*S*E - 0.2*P)
= 160.0094*0.9*60 / (2*18,800*1 - 0.2*160.0094)
= 0.23 in

**Area required per UG-37(c)**

Allowable stresses: $S_n$ = 17,800, $S_v$ = 18,800, $S_p$ = 17,800 psi

$f_{r1} = 1$

$f_{r2}$ = lesser of 1 or $S_n / S_v$ = 0.9468

$f_{r4}$ = lesser of 1 or $S_p / S_v$ = 0.9468

| | | |
|---|---|---|
| A | = | $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$ + Tapped hole area loss |
| | = | 16.3372*0.23*1 + 2*0*0.23*1*(1 - 1) + 0.6375 |
| | = | 4.3951 $in^2$ |

**Area available from FIG. UG-37.1**

$A_1$ = larger of the following= 0 $in^2$

| | | |
|---|---|---|
| | = | $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$ |
| | = | 16.3372*(1*0.23 - 1*0.23) - 2*0*(1*0.23 - 1*0.23)*(1 - 1) |
| | = | 0 $in^2$ |
| | = | $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$ |
| | = | 2*(0.23 + 0)*(1*0.23 - 1*0.23) - 2*0*(1*0.23 - 1*0.23)*(1 - 1) |
| | = | 0 $in^2$ |

Area $A_2$ is not included in these calculations.

| | | |
|---|---|---|
| $A_{42}$ | = | $Leg^2*f_{r4}$ |
| | = | $0.1875^2*0.9468$ |
| | = | 0.0333 $in^2$ |
| $A_{43}$ | = | $Leg^2*f_{r2}$ |
| | = | $0.23^2*0.9468$ |
| | = | 0.0501 $in^2$ |
| $A_5$ | = | $(D_p$ - Pad ID$)*t_e*f_{r4}$ |
| | = | (25.5 - 16)*0.575*0.9468 |
| | = | 5.1719 $in^2$ |
| Area | = | $A_1 + A_{42} + A_{43} + A_5$ |
| | = | 0 + 0.0333 + 0.0501 + 5.1719 |
| | = | 5.2553 $in^2$ |

As Area >= A the reinforcement is adequate.

**UW-16(d)(2) Weld Check**

Inner fillet: $t_{min}$ = lesser of 0.75 or $t_e$ or t = 0.23 in
$t_{w(min)}$ = 0.5*$t_{min}$ = 0.115 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

The fillet weld size is satisfactory.

Lower fillet: $t_{w(min)}$ = 0.7*$t_{min}$ = 0.161 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.23 = 0.161 in

The fillet weld size is satisfactory.

**UG-45 Nozzle Neck Thickness Check**

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 160.0094*8.1686 / (17,800*1 - 0.6*160.0094) + 0
= 0.0738 in

$t_a$ = max[ $t_{a\ UG\text{-}27}$ , $t_{a\ UG\text{-}22}$ ]
= max[ 0.0738 , 0 ]
= 0.0738 in

$t_{b1}$ = 0.2556 in

$t_{b1}$ = max[ $t_{b1}$ , $t_{b\ UG16}$ ]
= max[ 0.2556 , 0.0625 ]
= 0.2556 in

$t_b$ = min[ $t_{b3}$ , $t_{b1}$ ]
= min[ 0.3281 , 0.2556 ]
= 0.2556 in

$t_{UG\text{-}45}$ = max[ $t_a$ , $t_b$ ]
= max[ 0.0738 , 0.2556 ]
= 0.2556 in

Available nozzle wall thickness new, $t_n$ = 4.75 in

The nozzle neck thickness is adequate.

**Allowable stresses in joints UG-45 and UW-15(c)**

Outer fillet weld in shear: 0.49*17,800 = 8,722 psi
Lower fillet weld in shear: 0.49*17,800 = 8,722 psi

(1) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*$S_o$ = $(\pi / 2)$*25.5*0.1875*8,722 = 65,505.45 $lb_f$

(2) Lower fillet weld in shear
$(\pi / 2)$*16.3372*Leg*$S_l$ = $(\pi / 2)$*16.3372*0.23*8,722 = 51,480.34 $lb_f$

**Loading on welds per UG-41(b)(1)**

| | | |
|---|---|---|
| W | = | $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$ |
| | = | (4.3951 - 0 + 2*0*1*(1*0.23 - 1*0.23))*18,800 |
| | = | 82,627.05 $lb_f$ |

| | | |
|---|---|---|
| $W_{1-1}$ | = | $(A_5 + A_{42} + A_{43})*S_v$ |
| | = | (5.1719 + 0.0333 + 0.0501)*18,800 |
| | = | 98,799.55 $lb_f$ |

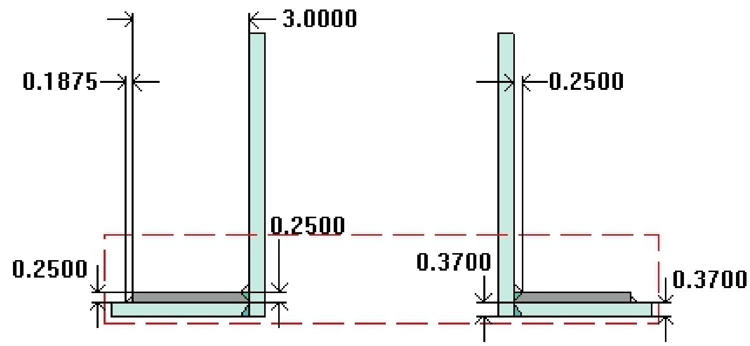
Load for path 1-1 lesser of W or $W_{1-1}$ = 82,627.05 $lb_f$
Path 1-1 through (1) & (2) = 65,505.45 + 51,480.34 = 116,985.79 $lb_f$
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

## Nozzle #3 (N3)

| ASME Section VIII Division 1, 2013 Edition (Code Case 2695) | | | | | |
|---|---|---|---|---|---|
| **Component** | Nozzle | | | | |
| **Nozzle Material** | SA-106 B Smls pipe (II-D p. 14, ln. 19) | | | | |
| **Pad Material** | SA-516 70 (II-D p. 22, ln. 6) | | | | |
| | **Impact Tested** | **Normalized** | **Fine Grain Practice** | **PWHT** | **Optimize MDMT/ Find MAWP** |
| **Nozzle** | No | No | No | No | No |
| **Pad** | No | No | No | No | No |
| | **Design Pressure (psi)** | | **Design Temperature (°F)** | | **Design MDMT (°F)** |
| **Internal** | 100 | | 650 | | -20 |
| **Location and Orientation** | | | | | |
| **Attached to** | Cylinder #2 | | | | |
| **Orientation** | hillside | | | | |
| **Offset, L** | 48" | | | | |
| **Angle, θ** | 0° | | | | |
| **Distance, r** | 48" | | | | |
| **Offset CL to CL, $L_o$** | 15" | | | | |
| **Through a Category A Joint** | No | | | | |

## Dimensions

| | | |
|---|---|---|
| **Description** | | NPS 12 Std Weight |
| **Inside Diameter** | | 12" |
| **Nominal Wall Thickness** | | 0.375" |
| **Local Vessel Minimum Thickness** | | 0.37" |
| **Nozzle to Pad Groove Weld, $t_{w2}$** | | 0.25" |
| **$Leg_{41}$** | | 0.25" |
| **$Leg_{42}$** | | 0.1875" |
| **Pad Width, W** | | 3" |
| **Pad Thickness, $t_e$** | | 0.25" |
| **External Projection Available, $L_{pr1}$** | | 17.0237" |
| **Projection outside vessel to flange face, $L_f$** | | 18.8362" |
| **Corrosion** | **Inner** | 0" |
| | **Outer** | 0" |



### Summary Tables

| Division 2 4.5.6 Maximum local primary membrane stress | | | | | |
|---|---|---|---|---|---|
| Condition | P (psi) | $P_L$ (psi) | $S_{allow}$ (psi) | Over stressed | $P_{max}$ (psi) |
| Design P | 100 | 16,021 | 28,200 | No | 176.02 |

| Division 2 4.5.4.1 Nozzle Neck Minimum Thickness | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Condition | P (psi) | $t_{d1}$ (in) | $t_{d,STD}$ (in) | t (in) | $t_d$ (in) | $t_n$ (in) | Status | $P_{max}$ (psi) |
| Design P | 100 | 0.0352 | 0.3281 | 0.37 | 0.3281 | 0.375 | OK | 1,036.68 |

| Division 2 4.5.14 Strength of Nozzle Attachment Welds Summary | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Condition | P (psi) | $k_y$ | $L_\tau$ (in) | $L_{\tau p}$ (in) | $f_{welds}$ ($lb_f$) | $\tau_1$ (psi) | $\tau_2$ (psi) | $\tau_3$ (psi) | $\tau$ (psi) | S (psi) | Over stressed |
| Design P | 100 | 1.0625 | 10.0138 | 14.7262 | 3,191.91 | 857 | 543 | 1,345 | 1,345 | 18,800 | No |
| MAWP | 176.02 | 1.0625 | 10.0138 | 14.7262 | 5,618.38 | 1,508 | 956 | 2,368 | 2,368 | 18,800 | No |

| Division 2 Table 4.2.11 Minimum Fillet Weld Sizes | | | |
|---|---|---|---|
| Fillet Leg | Required Leg Size (in) | Actual Leg Size (in) | Status |
| $Leg_{41}$ | 0.3571 | 0.25 | weld size is NOT adequate |
| $Leg_{42}$ | 0.2143 | 0.1875 | weld size is NOT adequate |

## Detailed Calculations

| Division 2 4.5.6 Vessel effective radius | |
|---|---|
| $R_{eff} = 0.5*D_i$ | (4.5.3) |
| $R_{xn} = t_n / \ln[1 + t_n / R_n]$ | (4.5.51) |
| **Corroded\New** | |
| $R_{eff} = 0.5*60.085 =$ | 30.0425" |
| $R_{xn} = 0.375 / \ln[1 + 0.375 / 6] =$ | 6.1856" |

| Division 2 4.5.6 Radius of nozzle opening along the long chord | |
|---|---|
| $D_x = Abs(Lo)$ | |
| $\theta_1 = \arccos[D_x / R_{eff}]$ | (4.5.65) |
| $\theta_2 = \arccos[(D_x + R_n) / R_{eff}]$ | (4.5.66) |
| $R_{ncl} = R_{eff}*(\theta_1 - \theta_2)*\pi / 180$ | (4.5.64) |
| $R_{nc} = \max[ (R_{ncl} / 2) , R_n]$ | (4.5.63) |
| **Corroded\New** | |
| $D_x = Abs(Lo) =$ | 15" |
| $\theta_1 = \arccos[15 / 30.0425] =$ | 60.0468° |
| $\theta_2 = \arccos[(15 + 6) / 30.0425] =$ | 45.6524° |
| $R_{ncl} = 30.0425*(60.0468 - 45.6524)*\pi / 180 =$ | 7.5476" |
| $R_{nc} = \max[ (7.5476 / 2) , 6] =$ | 6" |

| Division 2 4.5.6 Limit of reinforcement along the vessel wall | |
|---|---|
| $L_{R1} = (R_{eff}*t)^{0.5} + W$ | (4.5.6) |
| $L_{R2} = ((R_{eff} + t)*(t + t_e))^{0.5}$ | (4.5.7) |
| $L_{R3} = 2*R_n$ | (4.5.8) |
| $L_R = \min[ L_{R1}, L_{R2}, L_{R3}]$ | (4.5.9) |
| **Corroded\New** | |
| $L_{R1} = (30.0425*0.37)^{0.5} + 3 =$ | 6.334" |
| $L_{R2} = ((30.0425 + 0.37)*(0.37 + 0.25))^{0.5} =$ | 4.3423" |
| $L_{R3} = 2*6 =$ | 12" |
| $L_R = \min[ 6.334, 4.3423, 12] =$ | 4.3423" |

| Division 2 4.5.6 Limit of reinforcement along the nozzle wall projecting outside the vessel surface | |
|---|---|
| $L_{H1}$ = min[ 1.5*t , $t_e$] + $(R_n*t_n)^{0.5}$ | (4.5.11) |
| $L_{H2}$ = $L_{pr1}$ | (4.5.12) |
| $L_{H3}$ = 8*(t + $t_e$) | (4.5.13) |
| $L_H$ = min[ $L_{H1}$, $L_{H2}$, $L_{H3}$] + t | (4.5.14) |
| **Corroded\New** | |
| $L_{H1}$ = min[ 1.5*0.37 , 0.25] + $(6*0.375)^{0.5}$ = | 1.75" |
| $L_{H2}$ = 17.0237 = | 17.0237" |
| $L_{H3}$ = 8*(0.37 + 0.25) = | 4.96" |
| $L_H$ = min[ 1.75, 17.0237, 4.96] + 0.37 = | 2.12" |

| Division 2 4.5.6 Available area near the nozzle opening | |
|---|---|
| λ = min[ $(2*R_n + t_n) / ((D_i + t_{eff})*t_{eff})^{0.5}$, 12] | (4.5.24) |
| $A_1$ = t*$L_R$*max[ $(\lambda / 5)^{0.85}$ , 1] | (4.5.23) |
| $A_2$ = $t_n$*$L_H$ | (4.5.27) |
| $A_{41}$ = 0.5*$L_{41}^2$ | (4.5.39) |
| $A_{42}$ = 0.5*$L_{42}^2$ | (4.5.40) |
| $A_{5a}$ = W*$t_e$ | (4.5.42) |
| $A_{5b}$ = $L_R$*$t_e$ | (4.5.43) |
| $A_5$ = min[ $A_{5a}$, $A_{5b}$] | (4.5.45) |
| **Corroded\New** | |
| λ = min[ $(2*6 + 0.375) / ((60.085 + 0.5427)*0.5427)^{0.5}$, 12] = | 2.1574 |
| $A_1$ = 0.37*4.3423*max[ $(2.1574 / 5)^{0.85}$ , 1] = | 1.6067 $in^2$ |
| $A_2$ = 0.375*2.12 = | 0.795 $in^2$ |
| $A_{41}$ = 0.5*$0.25^2$ = | 0.0313 $in^2$ |
| $A_{42}$ = 0.5*$0.1875^2$ = | 0.0176 $in^2$ |
| $A_{5a}$ = 3*0.25 = | 0.75 $in^2$ |
| $A_{5b}$ = 4.3423*0.25 = | 1.0856 $in^2$ |
| $A_5$ = min[ 0.75, 1.0856] = | 0.75 $in^2$ |

| Division 2 4.5.6 Equations | |
|---|---|
| $f_{rn} = \min[ S_n / S , 1 ]$ | (4.5.21) |
| $f_{rp} = \min[ S_p / S , 1 ]$ | (4.5.22) |
| $t_{eff} = t + (A_5 * f_{rp} / L_R)$ | (4.5.25) |
| $R_{xs} = t_{eff} / \ln[1 + t_{eff} / R_{eff}]$ | (4.5.52) |
| $A_T = A_1 + f_{rn} * A_2 + A_{41} + A_{42} + f_{rp} * A_5$ | (4.5.20) |
| $f_N = P * R_{xn} * L_H$ | (4.5.46) |
| $f_S = P * R_{xs} * (L_R + t_n)$ | (4.5.48) |
| $f_Y = P * R_{xs} * R_{nc}$ | (4.5.50) |
| $\sigma_{avg} = (f_N + f_S + f_Y) / A_T$ | (4.5.53) |
| $\sigma_{circ} = P * R_{xs} / t_{eff}$ | (4.5.54) |
| $P_L = \max[ \{2 * \sigma_{avg} - \sigma_{circ}\} , \sigma_{circ}]$ | (4.5.55) |
| $S_{allow} = 1.5 * S * E$ | (4.5.57) |
| $P_L \le S_{allow}$ | (4.5.56) |
| $A_p = (f_N + f_S + f_Y) / P$ | (4.5.62) |
| $P_{max1} = S_{allow} / (2 * A_p / A_T - R_{xs} / t_{eff})$ | (4.5.59) |
| $P_{max2} = S * (t / R_{xs})$ | (4.5.60) |
| $P_{max} = \min[ P_{max1}, P_{max2}]$ | (4.5.61) |

| Division 2 4.5.6 Design Rules for Openings in Shells and Heads | |
|---|---|
| **Design P** | |
| **Total available area near the nozzle opening** | |
| $f_{rn}$ = min[ 17,100 / 18,800 , 1 ] = | 0.9096 |
| $f_{rp}$ = min[ 18,800 / 18,800 , 1 ] = | 1 |
| $t_{eff}$ = 0.37 + (0.75*1 / 4.3423) = | 0.5427" |
| $R_{xs}$ = 0.5427 / ln[1 + 0.5427 / 30.0425] = | 30.3131" |
| $A_T$ = 1.6067 + 0.9096*0.795 + 0.0313 + 0.0176 + 1*0.75 = | 3.1286 $in^2$ |
| **Forces at nozzle to vessel intersection** | |
| $f_N$ = 100*6.1856*2.12 = | 1,311.35 $lb_f$ |
| $f_S$ = 100*30.3131*(4.3423 + 0.375) = | 14,299.64 $lb_f$ |
| $f_Y$ = 100*30.3131*6 = | 18,187.83 $lb_f$ |
| **Average local primary membrane stress** | |
| $\sigma_{avg}$ = (1,311.35 + 14,299.64 + 18,187.83) / 3.1286 = | 10,803 psi |
| **General primary membrane stress** | |
| $\sigma_{circ}$ = 100*30.3131 / 0.5427 = | 5,585 psi |
| **Maximum local primary membrane stress at the nozzle intersection** | |
| $P_L$ = max[ {2*10,803 - 5,585} , 5,585] = | 16,021 psi |
| **Allowable stress** | |
| $S_{allow}$ = 1.5*18,800*1 = | 28,200 psi |
| $P_L$ = 16,021 psi ≤ $S_{allow}$ = 28,200 psi | |
| **Maximum allowable working pressure** | |
| $A_p$ = (1,311.35 + 14,299.64 + 18,187.83) / 100 = | 337.9882 $in^2$ |
| $P_{max1}$ = 28,200 / (2*337.9882 / 3.1286 - 30.3131 / 0.5427) = | 176.02 psi |
| $P_{max2}$ = 18,800*(0.37 / 30.3131) = | 229.47 psi |
| $P_{max}$ = min[ 176.02, 229.47] = | 176.02 psi |

| Division 2 4.5.14 Equations | |
|---|---|
| $k_y = (R_{nc} + t_n) / R_{nc}$ | (4.5.174) |
| $L_\tau = \pi / 2*[((R_{nc} + t_n)^2 + (R_n + t_n)^2) / 2]^{0.5}$ | (4.5.176) |
| $L_{\tau p} = \pi / 2*[((R_{nc} + t_n + W)^2 + (R_n + t_n + W)^2) / 2]^{0.5}$ | (4.5.178) |
| $L_{41T} = 0.7071*L_{41}$ | (4.5.179) |
| $L_{42T} = 0.7071*L_{42}$ | (4.5.180) |
| $f_{welds} = \min[\ f_Y*k_y, 1.5*S_n*(A_2 + A_3)\ , \pi / 4*P*R_n^2*k_y^2\ ]$ | (4.5.184) |
| $f_{ws} = f_{welds}*t*S / (t*S + t_e*S_p)$ | (4.5.189) |
| $f_{wp} = f_{welds}*t_e*S_p / (t*S + t_e*S_p)$ | (4.5.190) |
| $\tau_1 = f_{ws} / [L_\tau*(0.6*t_{w1} + 0.49*L_{43T})]$ | (4.5.185) |
| $\tau_2 = f_{wp} / [L_\tau*(0.6*t_{w2} + 0.49*L_{41T})]$ | (4.5.186) |
| $\tau_3 = f_{wp} / [L_{\tau p}*0.49*L_{42T}]$ | (4.5.187) |
| $\tau = \max[\ \tau_1, \tau_2, \tau_3]$ | |
| $\max[\ \tau_1, \tau_2, \tau_3] \le S$ | (4.5.188) |

| | |
|---|---|
| **Division 2 4.5.14 Strength of Nozzle Attachment Welds** | |
| **Corroded\New** | |
| **Discontinuity force factor** | |
| $k_y$ = (6 + 0.375) / 6 = | 1.0625 |
| **Weld length resisting discontinuity force** | |
| $L_\tau = \pi / 2*[((6 + 0.375)^2 + (6 + 0.375)^2) / 2]^{0.5}$ = | 10.0138" |
| $L_{\tau p} = \pi / 2*[((6 + 0.375 + 3)^2 + (6 + 0.375 + 3)^2) / 2]^{0.5}$ = | 14.7262" |
| **Weld throat dimensions** | |
| $L_{41T}$ = 0.7071*0.25 = | 0.1768" |
| $L_{42T}$ = 0.7071*0.1875 = | 0.1326" |
| **Design P** | |
| **Average shear stress in weld** | |
| $f_{welds}$ = min[ 18,187.83*1.0625, 1.5*17,100*(0.795 + 0) , $\pi$ / 4*100*$6^2$*$1.0625^2$ ] = | 3,191.91 $lb_f$ |
| $f_{ws}$ = 3,191.91*0.37*18,800 / (0.37*18,800 + 0.25*18,800) = | 1,904.85 $lb_f$ |
| $f_{wp}$ = 3,191.91*0.25*18,800 / (0.37*18,800 + 0.25*18,800) = | 1,287.06 $lb_f$ |
| $\tau_1$ = 1,904.85 / [10.0138*(0.6*0.37 + 0.49*0)] = | 857 psi |
| $\tau_2$ = 1,287.06 / [10.0138*(0.6*0.25 + 0.49*0.1768)] = | 543 psi |
| $\tau_3$ = 1,287.06 / [14.7262*0.49*0.1326] = | 1,345 psi |
| $\tau$ = max[ 857, 543, 1,345] = | 1,345 psi |
| $\tau$ = 1,345 psi $\leq$ S = 18,800 psi | |
| **MAWP** | |
| **Average shear stress in weld** | |
| $f_{welds}$ = min[ 32,014.12*1.0625, 1.5*17,100*(0.795 + 0) , $\pi$ / 4*176.02*$6^2$*$1.0625^2$ ] = | 5,618.38 $lb_f$ |
| $f_{ws}$ = 5,618.38*0.37*18,800 / (0.37*18,800 + 0.25*18,800) = | 3,352.9 $lb_f$ |
| $f_{wp}$ = 5,618.38*0.25*18,800 / (0.37*18,800 + 0.25*18,800) = | 2,265.48 $lb_f$ |
| $\tau_1$ = 3,352.9 / [10.0138*(0.6*0.37 + 0.49*0)] = | 1,508 psi |
| $\tau_2$ = 2,265.48 / [10.0138*(0.6*0.25 + 0.49*0.1768)] = | 956 psi |
| $\tau_3$ = 2,265.48 / [14.7262*0.49*0.1326] = | 2,368 psi |
| $\tau$ = max[ 1,508, 956, 2,368] = | 2,368 psi |
| $\tau$ = 2,368 psi $\leq$ S = 18,800 psi | |

| Division 2 4.3.3.1 Design Thickness for Internal Pressure | |
|---|---|
| $t_d$ = D / 2 * (exp[P / (S*E)] - 1) + Corrosion | (4.3.1) |
| **Operating Hot & Corroded** | |
| $t_d$ = 12 / 2 * (exp[(100 + 0) / (17,100*1)] - 1) + 0 = | 0.0352" |
| **Operating Cold & Corroded** | |
| $t_r$ = 12 / 2 * (exp[(144.02 + 0) / (17,100*1)] - 1) = | 0.0507" |

| Division 2 4.3.3.1 Maximum Pressure Circumferential Stress | |
|---|---|
| $P_{max}$ = S*E*ln[$D_o$ / D] | (4.3.1) |
| **MAWP** | |
| $P_{max}$ = 17,100*1*ln[12.75 / 12] - 0 = | 1,036.68 psi |

**Saddle #1**

| ASME Section VIII Division 1, 2013 Edition (Code Case 2695) | | |
|---|---|---|
| **Saddle Material** | | |
| **Saddle Construction** | Centered web | |
| **Welded to Vessel** | Yes | |
| **Saddle Allowable Stress** | 20,000 psi | |
| **Saddle Yield Stress** | 38,000 psi | |
| **Foundation Allowable Stress** | 1,658 psi | |
| **Design Pressure** | **Left Saddle** | **Right Saddle** |
| **Operating** | 144.02 psi | |
| **Test** | 4.12 psi | 7.59 psi |
| **Dimensions** | | |
| **Saddle distance to datum** | 13.1875" | |
| **Tangent To Tangent Length, L** | 196" | |
| **Saddle seperation, $L_s$** | 165.625" | |
| **Vessel Mean Radius, $R_m$** | 30.3145" | |
| **Tangent Distance Left, $a_l$** | 15.1875" | |
| **Tangent Distance Right, $a_r$** | 15.1875" | |
| **Saddle Height, $H_s$** | 42.375" | |
| **Saddle Contact Angle, $\theta$** | 120° | |
| **Web Plate Thickness, $t_s$** | 0.375" | |
| **Base Plate Length, E** | 54.0667" | |
| **Base Plate Width, F** | 9" | |
| **Base Plate Thickness, $t_b$** | 0.375" | |
| **Number of Stiffening Ribs, n** | 4 | |
| **Largest Stiffening Rib Spacing, $d_i$** | 17.7514" | |
| **Stiffening Rib Thickness, $t_w$** | 0.375" | |
| **Saddle Width, b** | 8" | |
| **Reinforcing Plate** | | |
| **Material** | SA-516 70 (II-D p. 22, ln. 6) | |
| **Thickness, $t_r$** | 0.375" | |
| **Width, $b_1$** | 11" | |
| **Contact Angle, $\theta_1$** | 132° | |
| **Bolting** | | |

| Material | | |
|---|---|---|
| **Bolt Allowable Shear** | 15,000 psi | |
| **Description** | 1 inch series 8 threaded | |
| **Corrosion on root** | 0" | |
| **Anchor Bolts per Saddle** | 2 | |
| **Base coefficient of friction** | 0.45 | |
| **Weight** | | |
| | **Operating, Corroded** | **Hydrotest** |
| **Weight on Left Saddle** | 2,521 lb | 13,700 lb |
| **Weight on Right Saddle** | 2,310 lb | 13,456 lb |
| **Weight of Saddle Pair** | 578 lb | |

| Reinforcing Plate Requirements | | |
|---|---|---|
| $b_1 \geq \min[(b + 1.56*(R_m*t)^{0.5}), 2*a]$ | | (4.15.1) |
| $\theta_1 \geq \theta + \theta / 12$ | | (4.15.2) |
| **Operating** | | |
| $b_1 \geq \min[(8 + 1.56*(30.3145*0.371)^{0.5}), 2*15.1875]$ | 13.2316" | Not OK |
| $\theta_1 \geq 120 + 120 / 12$ | 130° | OK |

| 4.15.3.3 Longitudinal Stress | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Load** | **Condition** | **Saddle** | **Bending + Pressure at Saddle (psi)** | | | | **Bending + Pressure between Saddle (psi)** | | | |
| | | | $\sigma_3^*$ | **Allowable** | $\sigma_4^*$ | **Allowable** | $\sigma_1$ | **Allowable** | $\sigma_2$ | **Allowable** |
| Weight | Operating | Right Saddle | 5,903 | 18,800 | 5,872 | 18,800 | 5,962 | 18,800 | 5,805 | 18,800 |
| | | Left Saddle | 5,903 | 18,800 | 5,873 | 18,800 | | | | |
| | Test | Right Saddle | 420 | 34,200 | 249 | 34,200 | 713 | 34,200 | -93 | 30,364 |
| | | Left Saddle | 276 | 34,200 | 109 | 34,200 | | | | |
| | Hot Shutdown | Right Saddle | 20 | 18,800 | -11 | 18,800 | 79 | 18,800 | -79 | 18,800 |
| | | Left Saddle | 19 | 18,800 | -11 | 18,800 | | | | |

| 4.15.3.4 Shear Stress | | | | |
|---|---|---|---|---|
| **Load** | **Condition** | **Saddle** | **Shear Stress in Cylindrical Shell (psi)** | |
| | | | $\tau_2$ | **Allowable** |
| Weight | Operating | Right Saddle | 183 | 15,040 |
| | | Left Saddle | 204 | 15,040 |
| | Test | Right Saddle | 1,075 | 27,360 |
| | | Left Saddle | 1,095 | 27,360 |

| 4.15.3.5 Circumferential Stress | | | | | | |
|---|---|---|---|---|---|---|
| **Load** | **Condition** | **Saddle** | **Compressive Circ Membrane Stress In Shell (psi)** | | **Compressive Membrane + Bending Stress at Horn (psi)** | |
| | | | $\sigma_6$ | **Allowable** | $\sigma_7^*$ | **Allowable** |
| Weight | Operating | Right Saddle | -36 | 18,800 | -537 | 23,500 |
| | | Left Saddle | -39 | 18,800 | -580 | 23,500 |
| | Test | Right Saddle | -209 | 34,200 | -3,127 | 34,200 |
| | | Left Saddle | -212 | 34,200 | -3,153 | 34,200 |

| 4.15.3.3 Longitudinal Stress | |
|---|---|
| $M_1 = w*(2*h_2*a / 3 + a^2 / 2 - (R_m^2 - h_2^2) / 4)$ | |
| $M_2 = w*[a^2 / 2 + 2 / 3*h_2*(3 / 8*h_2 + a) - x_0^2 / 2 - R_m^2 / 4]$ | |
| $\sigma_1 = P*R_m / (2*t) - M_2 / (\pi*R_m^2*t)$ | (4.15.6) |
| $\sigma_2 = P*R_m / (2*t) + M_2 / (\pi*R_m^2*t)$ | (4.15.7) |
| $\sigma_3^* = P*R_m / (2*t) - M_1 / (\pi*K_1*R_m^2*t)$ | (4.15.10) |
| $\sigma_4^* = P*R_m / (2*t) + M_1 / (\pi*K_1^{*}*R_m^2*t)$ | (4.15.11) |
| $S_c = \min[ K*t*E_y / (16*R_m) , S*E ]$ | (4.15.12) |

| Weight | | | | |
|---|---|---|---|---|
| Operating | Right Saddle | $M_1 = 22.33*(2*15.23*15.1875 / 3 + 15.1875^2 / 2 - (30.2275^2 - 15.23^2) / 4)$ | -2,213.2 $lb_f$-in | |
| | | $S_c = \min[ 1*0.37*26.0E+06 / (16*30.2275) , 18,800*1 ]$ | 18,800 psi | |
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\sigma_3^* = 144.02*30.2275 / (2*0.37) - -2,213.2 / (\pi*0.1066*30.2275^2*0.37)$ | 5,903 | 18,800 |
| | | $\sigma_4^* = 144.02*30.2275 / (2*0.37) + -2,213.2 / (\pi*0.1923*30.2275^2*0.37)$ | 5,872 | 18,800 |
| | Between Saddles | $x_0 = 2,521 / 22.33 - 2*15.23 / 3 - 15.1875$ | 87.5362" | |
| | | $M_2 = 22.33*[15.1875^2 / 2 + 2 / 3*15.23*(3 / 8*15.23 + 15.1875) - 87.5362^2 / 2 - 30.2275^2 / 4]$ | -83,384.5 $lb_f$-in | |
| | | $S_c = \min[ 1*0.37*26.0E+06 / (16*30.2275) , 18,800*1 ]$ | 18,800 psi | |
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\sigma_1 = 144.02*30.2275 / (2*0.37) - -83,384.5 / (\pi*30.2275^2*0.37)$ | 5,962 | 18,800 |
| | | $\sigma_2 = 144.02*30.2275 / (2*0.37) + -83,384.5 / (\pi*30.2275^2*0.37)$ | 5,805 | 18,800 |
| | Left Saddle | $M_1 = 22.33*(2*15.23*15.1875 / 3 + 15.1875^2 / 2 - (30.3145^2 - 15.23^2) / 4)$ | -2,183.8 $lb_f$-in | |
| | | $S_c = \min[ 1*0.371*26.0E+06 / (16*30.3145) , 18,800*1 ]$ | 18,800 psi | |
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\sigma_3^* = 144.02*30.3145 / (2*0.371) - -2,183.8 / (\pi*0.1066*30.3145^2*0.371)$ | 5,903 | 18,800 |
| | | $\sigma_4^* = 144.02*30.3145 / (2*0.371) + -2,183.8 / (\pi*0.1923*30.3145^2*0.371)$ | 5,873 | 18,800 |
| | Right Saddle | $M_1 = 125.54*(2*15.23*15.1875 / 3 + 15.1875^2 / 2 - (30.2275^2 - 15.23^2) / 4)$ | -12,441 $lb_f$-in | |
| | | $S_c = \min[ 1.35*0.37*29.4E+06 / (16*30.2275) , 34,200*1 ]$ | 30,364 psi | |
| | | | | |

| | | | | |
|---|---|---|---|---|
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\sigma_3^* = 7.59*30.2275 / (2*0.37) - -12{,}441 / (\pi*0.1066*30.2275^2*0.37)$ | 420 | 34,200 |
| | | $\sigma_4^* = 7.59*30.2275 / (2*0.37) + -12{,}441 / (\pi*0.1923*30.2275^2*0.37)$ | 249 | 34,200 |
| | **Between Saddles** | $x_0 = 13{,}700 / 125.54 - 2*15.23 / 3 - 15.1875$ | 83.7843" | |
| | | $M_2 = 125.54*[15.1875^2 / 2 + 2 / 3*15.23*(3 / 8*15.23 + 15.1875) - 83.7843^2 / 2 - 30.2275^2 / 4]$ | -428,371.4 $lb_f$-in | |
| | | $S_c = \min[\ 1.35*0.37*29.4E{+}06 / (16*30.2275)\ ,\ 34{,}200*1\ ]$ | 30,364 psi | |
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\sigma_1 = 7.59*30.2275 / (2*0.37) - -428{,}371.4 / (\pi*30.2275^2*0.37)$ | 713 | 34,200 |
| | | $\sigma_2 = 7.59*30.2275 / (2*0.37) + -428{,}371.4 / (\pi*30.2275^2*0.37)$ | -93 | 30,364 |
| | **Left Saddle** | $M_1 = 125.54*(2*15.23*15.1875 / 3 + 15.1875^2 / 2 - (30.3145^2 - 15.23^2) / 4)$ | -12,275.7 $lb_f$-in | |
| | | $S_c = \min[\ 1.35*0.371*29.4E{+}06 / (16*30.3145)\ ,\ 34{,}200*1\ ]$ | 30,359 psi | |
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\sigma_3^* = 4.12*30.3145 / (2*0.371) - -12{,}275.7 / (\pi*0.1066*30.3145^2*0.371)$ | 276 | 34,200 |
| | | $\sigma_4^* = 4.12*30.3145 / (2*0.371) + -12{,}275.7 / (\pi*0.1923*30.3145^2*0.371)$ | 109 | 34,200 |
| **Hot Shutdown** | **Right Saddle** | $M_1 = 22.33*(2*15.23*15.1875 / 3 + 15.1875^2 / 2 - (30.2275^2 - 15.23^2) / 4)$ | -2,213.2 $lb_f$-in | |
| | | $S_c = \min[\ 1*0.37*26.0E{+}06 / (16*30.2275)\ ,\ 18{,}800*1\ ]$ | 18,800 psi | |
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\sigma_3^* = 0*30.2275 / (2*0.37) - -2{,}213.2 / (\pi*0.1066*30.2275^2*0.37)$ | 20 | 18,800 |
| | | $\sigma_4^* = 0*30.2275 / (2*0.37) + -2{,}213.2 / (\pi*0.1923*30.2275^2*0.37)$ | -11 | 18,800 |
| | **Between Saddles** | $x_0 = 2{,}521 / 22.33 - 2*15.23 / 3 - 15.1875$ | 87.5362" | |
| | | $M_2 = 22.33*[15.1875^2 / 2 + 2 / 3*15.23*(3 / 8*15.23 + 15.1875) - 87.5362^2 / 2 - 30.2275^2 / 4]$ | -83,384.5 $lb_f$-in | |
| | | $S_c = \min[\ 1*0.37*26.0E{+}06 / (16*30.2275)\ ,\ 18{,}800*1\ ]$ | 18,800 psi | |
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\sigma_1 = 0*30.2275 / (2*0.37) - -83{,}384.5 / (\pi*30.2275^2*0.37)$ | 79 | 18,800 |
| | | $\sigma_2 = 0*30.2275 / (2*0.37) + -83{,}384.5 / (\pi*30.2275^2*0.37)$ | -79 | 18,800 |
| | **Left Saddle** | $M_1 = 22.33*(2*15.23*15.1875 / 3 + 15.1875^2 / 2 - (30.3145^2 - 15.23^2) / 4)$ | -2,183.8 $lb_f$-in | |

| | | | | |
|---|---|---|---|---|
| | | $S_c$ = min[ 1*0.371*26.0E+06 / (16*30.3145) , 18,800*1 ] | 18,800 psi | |
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\sigma_3^*$ = 0*30.3145 / (2*0.371) - -2,183.8 / ($\pi$*0.1066*30.3145²*0.371) | 19 | 18,800 |
| | | $\sigma_4^*$ = 0*30.3145 / (2*0.371) + -2,183.8 / ($\pi$*0.1923*30.3145²*0.371) | -11 | 18,800 |

| **4.15.3.4 Shear Stress** | | | | |
|---|---|---|---|---|
| T = Q - w*(a + 2*$h_2$ / 3) | | | (4.15.5) | |
| $\tau_2 = K_2$*T / ($R_m$*t) | | | (4.15.14) | |
| **Weight** | | | | |
| **Operating** | **Right Saddle** | T = 2,310 - 22.33*(15.1875 + 2*15.23 / 3) | 1,744.04 $lb_f$ | |
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\tau_2$ = 1.1707*1,744.04 / (30.2275*0.37) | 183 | 15,040 |
| | **Left Saddle** | T = 2,521 - 22.33*(15.1875 + 2*15.23 / 3) | 1,955.04 $lb_f$ | |
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\tau_2$ = 1.1707*1,955.04 / (30.3145*0.371) | 204 | 15,040 |
| **Test** | **Right Saddle** | T = 13,456 - 125.54*(15.1875 + 2*15.23 / 3) | 10,274.61 $lb_f$ | |
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\tau_2$ = 1.1707*10,274.61 / (30.2275*0.37) | 1,075 | 27,360 |
| | **Left Saddle** | T = 13,700 - 125.54*(15.1875 + 2*15.23 / 3) | 10,518.61 $lb_f$ | |
| | | | **Stress (psi)** | **Allowable (psi)** |
| | | $\tau_2$ = 1.1707*10,518.61 / (30.3145*0.371) | 1,095 | 27,360 |

<table>
<tr><th colspan="5">4.15.3.5 Circumferential Stress</th></tr>
<tr><td colspan="4">$x_1, x_2 = 0.78*(R_m*t)^{0.5}$</td><td>(4.15.22)</td></tr>
<tr><td colspan="4">$\sigma_6 = -K_5*Q*k / (t*(b + x_1 + x_2))$</td><td>(4.15.23)</td></tr>
<tr><td colspan="4">$\sigma_7^* = -Q / (4*t*(b + x_1 + x_2)) - 12*Q*K_7*R_m / (L*t^2)$</td><td>(4.15.25)</td></tr>
<tr><th colspan="5">Weight</th></tr>
<tr><td rowspan="8">Operating</td><td rowspan="4">Right Saddle</td><td>$x_1, x_2 = 0.78*(30.2275*0.37)^{0.5}$</td><td colspan="2">2.6085"</td></tr>
<tr><td></td><td>Stress (psi)</td><td>Allowable (psi)</td></tr>
<tr><td>$\sigma_6 = -0.7603*2{,}310*0.1 / (0.37*(8 + 2.6085 + 2.6085))$</td><td>-36</td><td>18,800</td></tr>
<tr><td>$\sigma_7^* = -2{,}310 / (4*0.37*(8 + 2.6085 + 2.6085)) - 12*2{,}310*0.0134*30.2275 / (196*0.37^2)$</td><td>-537</td><td>23,500</td></tr>
<tr><td rowspan="4">Left Saddle</td><td>$x_1, x_2 = 0.78*(30.3145*0.371)^{0.5}$</td><td colspan="2">2.6158"</td></tr>
<tr><td></td><td>Stress (psi)</td><td>Allowable (psi)</td></tr>
<tr><td>$\sigma_6 = -0.7603*2{,}521*0.1 / (0.371*(8 + 2.6158 + 2.6158))$</td><td>-39</td><td>18,800</td></tr>
<tr><td>$\sigma_7^* = -2{,}521 / (4*0.371*(8 + 2.6158 + 2.6158)) - 12*2{,}521*0.0133*30.3145 / (196*0.371^2)$</td><td>-580</td><td>23,500</td></tr>
<tr><td rowspan="8">Test</td><td rowspan="4">Right Saddle</td><td>$x_1, x_2 = 0.78*(30.2275*0.37)^{0.5}$</td><td colspan="2">2.6085"</td></tr>
<tr><td></td><td>Stress (psi)</td><td>Allowable (psi)</td></tr>
<tr><td>$\sigma_6 = -0.7603*13{,}456*0.1 / (0.37*(8 + 2.6085 + 2.6085))$</td><td>-209</td><td>34,200</td></tr>
<tr><td>$\sigma_7^* = -13{,}456 / (4*0.37*(8 + 2.6085 + 2.6085)) - 12*13{,}456*0.0134*30.2275 / (196*0.37^2)$</td><td>-3,127</td><td>34,200</td></tr>
<tr><td rowspan="4">Left Saddle</td><td>$x_1, x_2 = 0.78*(30.3145*0.371)^{0.5}$</td><td colspan="2">2.6158"</td></tr>
<tr><td></td><td>Stress (psi)</td><td>Allowable (psi)</td></tr>
<tr><td>$\sigma_6 = -0.7603*13{,}700*0.1 / (0.371*(8 + 2.6158 + 2.6158))$</td><td>-212</td><td>34,200</td></tr>
<tr><td>$\sigma_7^* = -13{,}700 / (4*0.371*(8 + 2.6158 + 2.6158)) - 12*13{,}700*0.0133*30.3145 / (196*0.371^2)$</td><td>-3,153</td><td>34,200</td></tr>
</table>

<table>
<tr><th colspan="5">4.15.3.6 Saddle Support</th></tr>
<tr><td colspan="4">$F_h$ = Q*(1 + cos[β] - 0.5*sin$^2$[β]) / (π - β + sin[β]*cos[β])</td><td>(4.15.42)</td></tr>
<tr><td colspan="5">$A_e$ = ($H_{eff}$*$t_s$ + $t_r$*$b_1$)</td></tr>
<tr><td colspan="5">$\sigma_{SS}$ = $F_h$ / $A_e$</td></tr>
<tr><th colspan="5">Weight</th></tr>
<tr><td rowspan="8">Operating</td><td rowspan="4">Right Saddle</td><td>$F_h$ = 2,310*(1 + cos[120] - 0.5*sin$^2$[120]) / (π - 2.0944 + sin[120]*cos[120])</td><td colspan="2">470.14 $lb_f$</td></tr>
<tr><td>$A_e$ = (10.0758*0.375 + 0.375*11)</td><td colspan="2">7.9 in$^2$</td></tr>
<tr><td></td><td>Stress (psi)</td><td>Allowable (psi)</td></tr>
<tr><td>$\sigma_{SS}$ = 470.14 / 7.9</td><td>59</td><td>13,333</td></tr>
<tr><td rowspan="4">Left Saddle</td><td>$F_h$ = 2,521*(1 + cos[120] - 0.5*sin$^2$[120]) / (π - 2.0944 + sin[120]*cos[120])</td><td colspan="2">513.08 $lb_f$</td></tr>
<tr><td>$A_e$ = (10.1048*0.375 + 0.375*11)</td><td colspan="2">7.91 in$^2$</td></tr>
<tr><td></td><td>Stress (psi)</td><td>Allowable (psi)</td></tr>
<tr><td>$\sigma_{SS}$ = 513.08 / 7.91</td><td>65</td><td>13,333</td></tr>
<tr><td rowspan="8">Test</td><td rowspan="4">Right Saddle</td><td>$F_h$ = 13,456*(1 + cos[120] - 0.5*sin$^2$[120]) / (π - 2.0944 + sin[120]*cos[120])</td><td colspan="2">2,738.59 $lb_f$</td></tr>
<tr><td>$A_e$ = (10.0758*0.375 + 0.375*11)</td><td colspan="2">7.9 in$^2$</td></tr>
<tr><td></td><td>Stress (psi)</td><td>Allowable (psi)</td></tr>
<tr><td>$\sigma_{SS}$ = 2,738.59 / 7.9</td><td>347</td><td>34,200</td></tr>
<tr><td rowspan="4">Left Saddle</td><td>$F_h$ = 13,700*(1 + cos[120] - 0.5*sin$^2$[120]) / (π - 2.0944 + sin[120]*cos[120])</td><td colspan="2">2,788.25 $lb_f$</td></tr>
<tr><td>$A_e$ = (10.1048*0.375 + 0.375*11)</td><td colspan="2">7.91 in$^2$</td></tr>
<tr><td></td><td>Stress (psi)</td><td>Allowable (psi)</td></tr>
<tr><td>$\sigma_{SS}$ = 2,788.25 / 7.91</td><td>352</td><td>34,200</td></tr>
</table>

<table>
<tr><th colspan="2">Shear stress in anchor bolting, one end slotted</th></tr>
<tr><td>Maximum seismic or wind base shear</td><td>0 $lb_f$</td></tr>
<tr><td>Thermal expansion base shear = W*μ = 2,810*0.45</td><td>1,264.5 $lb_f$</td></tr>
<tr><td>Corroded root area for a 1 inch series 8 threaded bolt (2 per saddle )</td><td>0.551 in$^2$</td></tr>
<tr><td>Bolt shear stress = 1,264.5 / (0.551*1*2)</td><td>1,147 psi</td></tr>
<tr><td colspan="2">Anchor bolt stress is acceptable (<= 15,000 psi)</td></tr>
</table>

| Shear stress in anchor bolting, transverse | |
|---|---|
| Maximum seismic or wind base shear | 0 $lb_f$ |
| Corroded root area for a 1 inch series 8 threaded bolt (2 per saddle ) | 0.551 $in^2$ |
| Bolt shear stress = 0 / (0.551*2*2) | 0 psi |
| Anchor bolt stress is acceptable (<= 15,000 psi) | |

| Web plate buckling check (Escoe pg 251) | |
|---|---|
| $S_c = K_i*\pi^2*E / (12*(1 - 0.3^2)*(d_i / t_s)^2)$ | |
| $S_c = \min[ S_c , S ]$ | |
| $b_e = d_i*t_s / (d_i*t_s + 2*t_w*(b - 1))$ | |
| $F_b = n*(A_s + 2*b_e*t_s)*S_c$ | |
| **Results** | |
| $S_c = 1.28*\pi^2*29.0E{+}06 / (12*(1 - 0.3^2)*(17.7514 / 0.375)^2)$ | 14,972 psi |
| $S_c$ = min[ 14,972 , 20,000 ] | 14,972 psi |
| $b_e$ = 17.7514*0.375 / (17.7514*0.375 + 2*0.375*(8 - 1)) | 0.5591" |
| $F_b$ = 4*(2.8594 + 2*0.5591*0.375)*14,972 | 196,355.04 $lb_f$ |
| Saddle loading of 13,989 $lb_f$ is <= $F_b$; satisfactory. | |

| Primary bending + axial stress in the saddle due to end loads (assumes one saddle slotted) | |
|---|---|
| $\sigma_b = V*(H_s - x_o)*y / I + Q / A$ | |
| $\sigma_b$ = 0*(42.375 - 25.1509)*4 / 64.0659 + 2,521 / 31.191 | 81 psi |
| The primary bending + axial stress in the saddle <= 20,000 psi; satisfactory. | |

| Secondary bending + axial stress in the saddle due to end loads (includes thermal expansion, assumes one saddle slotted) | |
|---|---|
| $\sigma_b = V*(H_s - x_o)*y / I + Q / A$ | |
| $\sigma_b$ = 1,264.5*(42.375 - 25.1509)*4 / 64.0659 + 2,521 / 31.191 | 1,441 psi |
| The secondary bending + axial stress in the saddle < 2*$S_y$= 76,000 psi; satisfactory. | |

| Saddle base plate thickness check (Roark sixth edition, Table 26, case 7a) | |
|---|---|
| $t_b = (\beta_1*q*b^2 / (1.5*S_a))^{0.5}$ | |
| $t_b = (3*29*4.3125^2 / (1.5*20{,}000))^{0.5}$ | 0.2312" |
| The base plate thickness of 0.375 in is adequate. | |

| Foundation bearing check | |
|---|---|
| $S_f = Q_{max} / (F*E)$ | |
| $S_f$ = 13,989 / (9*54.0667) | 29 psi |

Concrete bearing stress ≤ 1,658 psi ; satisfactory.