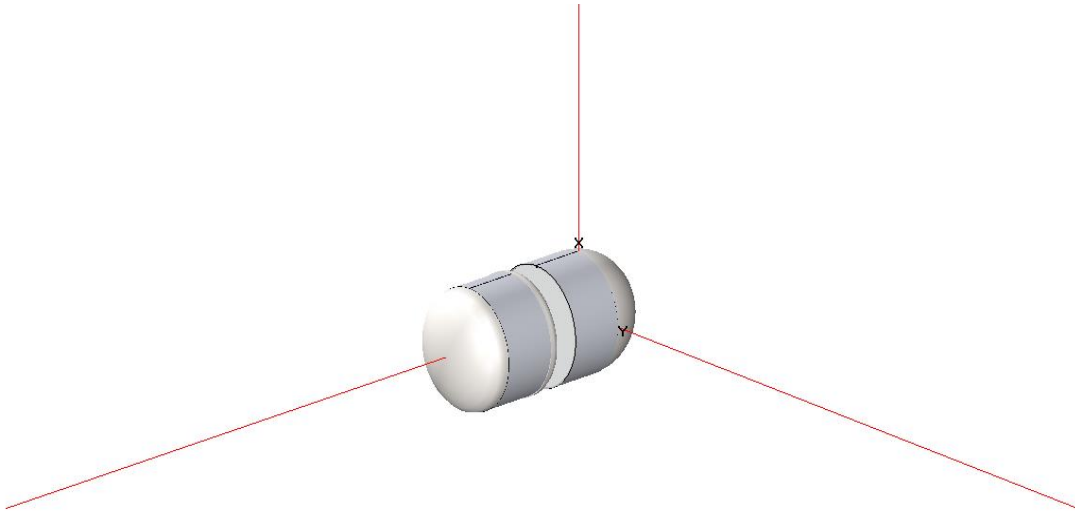


## Pressure Vessel Engineering Ltd.

120 Randall Drive, Suite B

Waterloo, Ontario, Canada

N2V 1C6



## Comparison of Four Head Types

**Item:** Four Heads

**Vessel No:** PVE-3101

**Designer:** Laurence Brundrett

**Date:** Wednesday, August 24, 2016

**Vessel Name:** Four Head Calcs

Reviewed: Michael Tomlinson

### Pressure Summary

Component Summary for Chamber bounded by Flanged and Dished (F&D) Head and Semi Elliptical (SE) Head							
Identifier	P Design (psi)	T Design (°F)	MAWP (psi)	MAP (psi)	MDMT (°F)	MDMT Exemption	Impact Tested
<a href="#">Semi Elliptical (SE) Head</a>	420	100	420.14	420.14	-20	Note 1	No
<a href="#">Straight Flange on Semi Elliptical (SE) Head</a>	420	100	420.17	420.17	-20	Note 2	No
<a href="#">Cylinder for SE and F&amp;D Heads</a>	420	100	420.17	420.17	-20	Note 2	No
<a href="#">Straight Flange on Flanged and Dished (F&amp;D) Head</a>	420	100	740.7	740.7	-55	Note 4	No
<a href="#">Flanged and Dished (F&amp;D) Head</a>	420	100	420.01	420.01	-55	Note 3	No

Chamber Summary for Chamber bounded by Flanged and Dished (F&D) Head and Semi Elliptical (SE) Head	
Design MDMT	-20 °F
Rated MDMT	-20 °F @ 420.01 psi
MAWP hot & corroded	420.01 psi @ 100 °F
MAP cold & new	420.01 psi @ 70 °F
(1) This pressure chamber is not designed for external pressure.	

Component Summary for Chamber bounded by Hemispherical (Hemi) Head and Welded Flat Head							
Identifier	P Design (psi)	T Design (°F)	MAWP (psi)	MAP (psi)	MDMT (°F)	MDMT Exemption	Impact Tested
<a href="#">Welded Flat Head</a>	420	100	420	420	-20	Note 5	No
<a href="#">Cylinder for Flat and Hemi Heads</a>	420	100	420.17	420.17	-20	Note 2	No
<a href="#">Hemispherical (Hemi) Head</a>	420	100	420.22	420.22	-20.1	Note 6	No

Chamber Summary for Chamber bounded by Hemispherical (Hemi) Head and Welded Flat Head	
Design MDMT	-20 °F
Rated MDMT	-20 °F @ 420 psi
MAWP hot & corroded	420 psi @ 100 °F
MAP cold & new	420 psi @ 70 °F
(1) This pressure chamber is not designed for external pressure.	

Notes for MDMT Rating		
Note #	Exemption	Details
1.	<a href="#">Straight Flange</a> governs MDMT	
2.	Material is impact test exempt per UG-20(f)	UCS-66 governing thickness = 0.5 in
3.	<a href="#">Straight Flange</a> governs MDMT	
4.	Material impact test exemption temperature from Fig UCS-66 Curve B = -7°F 30°F MDMT reduction per UCS-68(c) applies. Fig UCS-66.1 MDMT reduction = 46.8°F, (coincident ratio = 0.5615) Rated MDMT of -83.8°F is limited to -55°F by UCS-66(b)(2)	UCS-66 governing thickness = 0.5 in
5.	Head is impact test exempt per UG-20(f)	UCS-66 governing thickness = 0.978 in
6.	Material impact test exemption temperature from Fig UCS-66 Curve B = -20°F Fig UCS-66.1 MDMT reduction = 0.1°F, (coincident ratio = 0.9995)	UCS-66 governing thickness = 0.2474 in

### Thickness Summary

Component Data								
Component Identifier	Material	Diameter (in)	Length (in)	Nominal t (in)	Design t (in)	Total Corrosion (in)	Joint E	Load
<a href="#">Semi Elliptical (SE) Head</a>	SA-516 70	47 ID	12.2447	0.4947*	0.4946	0	1.00	Internal
<a href="#">Straight Flange on Semi Elliptical (SE) Head</a>	SA-516 70	47 ID	1.5	0.5	0.4998	0	1.00	Internal
<a href="#">Cylinder for SE and F&amp;D Heads</a>	SA-516 70	47 ID	24	0.5	0.4998	0	1.00	Internal
<a href="#">Straight Flange on Flanged and Dished (F&amp;D) Head</a>	SA-516 70	47 ID	1.5	0.8901	0.4998	0	1.00	Internal
<a href="#">Flanged and Dished (F&amp;D) Head</a>	SA-516 70	47 ID	8.7863	0.8901*	0.8901	0	1.00	Internal
<a href="#">Welded Flat Head</a>	SA-516 70	47 OD	3.912	3.912	3.912	0	1.00	Internal
<a href="#">Cylinder for Flat and Hemi Heads</a>	SA-516 70	47 ID	24	0.5	0.4998	0	1.00	Internal
<a href="#">Hemispherical (Hemi) Head</a>	SA-516 70	47 ID	23.7474	0.2474*	0.2473	0	1.00	Internal

\*Head minimum thickness after forming

Definitions	
Nominal t	Vessel wall nominal thickness
Design t	Required vessel thickness due to governing loading + corrosion
Joint E	Longitudinal seam joint efficiency
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

Weight (lb) Contributed by Vessel Elements										
Component	Metal New*	Metal Corroded	Insulation	Insulation Supports	Lining	Piping + Liquid	Operating Liquid		Test Liquid	
							New	Corroded	New	Corroded
<a href="#">Semi Elliptical (SE) Head</a>	397.4	397.4	0	0	0	0	0	0	584.5	584.5
<a href="#">Cylinder for SE and F&amp;D Heads</a>	506.8	506.8	0	0	0	0	0	0	1,503	1,503
<a href="#">Flanged and Dished (F&amp;D) Head</a>	602.9	602.9	0	0	0	0	0	0	397.7	397.7
<a href="#">Welded Flat Head</a>	1,920.8	1,920.8	0	0	0	0	0	0	0	0
<a href="#">Cylinder for Flat and Hemi Heads</a>	506.8	506.8	0	0	0	0	0	0	998	998
<a href="#">Hemispherical (Hemi) Head</a>	245.5	245.5	0	0	0	0	0	0	981.1	981.1
<b>TOTAL:</b>	<b>4,180.1</b>	<b>4,180.1</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>4,464.4</b>	<b>4,464.4</b>

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

Weight (lb) Contributed by Attachments									
Component	Body Flanges		Nozzles & Flanges		Packed Beds	Trays	Tray Supports	Rings & Clips	Vertical Loads
	New	Corroded	New	Corroded					
<a href="#">Semi Elliptical (SE) Head</a>	0	0	0	0	0	0	0	0	0
<a href="#">Cylinder for SE and F&amp;D Heads</a>	0	0	0	0	0	0	0	0	0
<a href="#">Flanged and Dished (F&amp;D) Head</a>	0	0	0	0	0	0	0	0	0
<a href="#">Welded Flat Head</a>	0	0	0	0	0	0	0	0	0
<a href="#">Cylinder for Flat and Hemi Heads</a>	0	0	0	0	0	0	0	0	0
<a href="#">Hemispherical (Hemi) Head</a>	0	0	0	0	0	0	0	0	0
<b>TOTAL:</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>

Vessel Totals		
	New	Corroded
Operating Weight (lb)	4,180	4,180
Empty Weight (lb)	4,180	4,180
Test Weight (lb)	8,873	8,873
Capacity** (US gal)	563	563

\*\*The vessel capacity does not include volume of nozzle, piping or other attachments.

Vessel Lift Condition	
Vessel Lift Weight, New (lb)	4,180
Center of Gravity from Datum (in)	28.0711

## Cylinder for SE and F&amp;D Heads

ASME Section VIII Division 1, 2015 Edition				
Component		Cylinder		
Material		SA-516 70 (II-D p. 18, ln. 37)		
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		420	100	-20
Static Liquid Head				
Condition		P <sub>s</sub> (psi)	H <sub>s</sub> (in)	SG
Test horizontal		1.7	47	1
Dimensions				
Inner Diameter		47"		
Length		24"		
Nominal Thickness		0.5"		
Corrosion	Inner	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)	Capacity (US gal)	
New		506.77	180.25	
Corroded		506.77	180.25	
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	Internal pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	<a href="#">0.4998"</a>
Maximum allowable working pressure (MAWP)	<a href="#">420.17 psi</a>
Maximum allowable pressure (MAP)	<a href="#">420.17 psi</a>
Rated MDMT	-20 °F

UCS-66 Material Toughness Requirements	
Governing thickness, t <sub>g</sub> =	0.5"
MDMT =	-20°F
Material is exempt from impact testing per UG-20(f) at the Design MDMT of -20°F.	

Design thickness, (at 100 °F) UG-27(c)(1)

$$\begin{aligned}
 t &= P \cdot R / (S \cdot E - 0.60 \cdot P) + \text{Corrosion} \\
 &= 420 \cdot 23.5 / (20,000 \cdot 1.00 - 0.60 \cdot 420) + 0 \\
 &= \underline{0.4998"}
 \end{aligned}$$

**Maximum allowable working pressure, (at 100 °F) UG-27(c)(1)**

$$\begin{aligned}
 P &= S \cdot E \cdot t / (R + 0.60 \cdot t) - P_s \\
 &= 20,000 \cdot 1.00 \cdot 0.5 / (23.5 + 0.60 \cdot 0.5) - 0 \\
 &= \underline{420.17} \text{ psi}
 \end{aligned}$$

**Maximum allowable pressure, (at 70 °F) UG-27(c)(1)**

$$\begin{aligned}
 P &= S \cdot E \cdot t / (R + 0.60 \cdot t) \\
 &= 20,000 \cdot 1.00 \cdot 0.5 / (23.5 + 0.60 \cdot 0.5) \\
 &= \underline{420.17} \text{ psi}
 \end{aligned}$$

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

$$\begin{aligned}
 \text{EFE} &= (50 \cdot t / R_p) \cdot (1 - R_f / R_o) \\
 &= (50 \cdot 0.5 / 23.75) \cdot (1 - 23.75 / \infty) \\
 &= 1.0526\%
 \end{aligned}$$

The extreme fiber elongation does not exceed 5%.

## Semi Elliptical (SE) Head

ASME Section VIII Division 1, 2015 Edition				
<b>Component</b>		Ellipsoidal Head		
<b>Material</b>		SA-516 70 (II-D p. 18, ln. 37)		
<b>Attached To</b>		Cylinder for SE and F&D Heads		
<b>Impact Tested</b>	<b>Normalized</b>	<b>Fine Grain Practice</b>	<b>PWHT</b>	<b>Optimize MDMT/ Find MAWP</b>
No	No	No	No	No
		<b>Design Pressure (psi)</b>	<b>Design Temperature (°F)</b>	<b>Design MDMT (°F)</b>
<b>Internal</b>		420	100	-20
Static Liquid Head				
<b>Condition</b>		<b>P<sub>s</sub> (psi)</b>	<b>H<sub>s</sub> (in)</b>	<b>SG</b>
<b>Test horizontal</b>		1.7	47	1
Dimensions				
<b>Inner Diameter</b>		47"		
<b>Head Ratio</b>		2		
<b>Minimum Thickness</b>		0.4947"		
<b>Corrosion</b>	<b>Inner</b>	0"		
	<b>Outer</b>	0"		
<b>Length L<sub>sf</sub></b>		1.5"		
<b>Nominal Thickness t<sub>sf</sub></b>		0.5"		
Weight and Capacity				
		<b>Weight (lb)<sup>1</sup></b>	<b>Capacity (US gal)<sup>1</sup></b>	
<b>New</b>		397.37	70.1	
<b>Corroded</b>		397.37	70.1	
Radiography				
<b>Category A joints</b>		Seamless No RT		
<b>Head to shell seam</b>		Full UW-11(a) Type 1		

<sup>1</sup> includes straight flange

Results Summary	
Governing condition	internal pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	<a href="#">0.4946"</a>
Maximum allowable working pressure (MAWP)	<a href="#">420.14</a> psi
Maximum allowable pressure (MAP)	<a href="#">420.14</a> psi
<a href="#">Straight Flange</a> governs MDMT	-20°F

Design thickness for internal pressure, (Corroded at 100 °F) UG-32(c)(1)

$$\begin{aligned}
 t &= P \cdot D / (2 \cdot S \cdot E - 0.2 \cdot P) + \text{Corrosion} \\
 &= 420 \cdot 47 / (2 \cdot 20,000 \cdot 1 - 0.2 \cdot 420) + 0 \\
 &= \underline{0.4945"}
 \end{aligned}$$

**Maximum allowable working pressure, (Corroded at 100 °F) UG-32(c)(1)**

$$\begin{aligned}
 P &= 2SEt / (D + 0.2t) - P_s \\
 &= 2 * 20,000 * 1 * 0.4947 / (47 + 0.2 * 0.4947) - 0 \\
 &= \underline{420.14} \text{ psi}
 \end{aligned}$$

**Maximum allowable pressure, (New at 70 °F) UG-32(c)(1)**

$$\begin{aligned}
 P &= 2SEt / (D + 0.2t) - P_s \\
 &= 2 * 20,000 * 1 * 0.4947 / (47 + 0.2 * 0.4947) - 0 \\
 &= \underline{420.14} \text{ psi}
 \end{aligned}$$

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

$$\begin{aligned}
 EFE &= (75t / R_f) * (1 - R_f / R_o) \\
 &= (75 * 0.5 / 8.24) * (1 - 8.24 / \infty) \\
 &= 4.551\%
 \end{aligned}$$

The extreme fiber elongation does not exceed 5%.



## Flanged and Dished (F&amp;D) Head

ASME Section VIII Division 1, 2015 Edition				
<b>Component</b>		F&D Head		
<b>Material</b>		SA-516 70 (II-D p. 18, ln. 37)		
<b>Attached To</b>		Cylinder for SE and F&D Heads		
<b>Impact Tested</b>	<b>Normalized</b>	<b>Fine Grain Practice</b>	<b>PWHT</b>	<b>Optimize MDMT/ Find MAWP</b>
No	No	No	Yes	No
		<b>Design Pressure (psi)</b>	<b>Design Temperature (°F)</b>	<b>Design MDMT (°F)</b>
<b>Internal</b>		420	100	-20
<b>Static Liquid Head</b>				
<b>Condition</b>		<b>P<sub>s</sub> (psi)</b>	<b>H<sub>s</sub> (in)</b>	<b>SG</b>
<b>Test horizontal</b>		1.7	47	1
<b>Dimensions</b>				
<b>Inner Diameter</b>		47"		
<b>Crown Radius L</b>		48"		
<b>Knuckle Radius r</b>		2.9273"		
<b>Minimum Thickness</b>		0.8901"		
<b>Corrosion</b>	<b>Inner</b>	0"		
	<b>Outer</b>	0"		
<b>Length L<sub>sf</sub></b>		1.5"		
<b>Nominal Thickness t<sub>sf</sub></b>		0.8901"		
<b>Weight and Capacity</b>				
		<b>Weight (lb)<sup>1</sup></b>		<b>Capacity (US gal)<sup>1</sup></b>
<b>New</b>		602.9		47.7
<b>Corroded</b>		602.9		47.7
<b>Radiography</b>				
<b>Category A joints</b>		Seamless No RT		
<b>Head to shell seam</b>		Full UW-11(a) Type 1		

<sup>1</sup> includes straight flange

Results Summary	
Governing condition	internal pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	<u>0.8901"</u>
Maximum allowable working pressure (MAWP)	<u>420.01</u> psi
Maximum allowable pressure (MAP)	<u>420.01</u> psi
<u>Straight Flange</u> governs MDMT	-55°F

Factor M
$M = 1/4 * [3 + (L / r)^{1/2}]$

Corroded	$M = 1/4 * [3 + (48 / 2.9273)^{1/2}]$	1.7623
New	$M = 1/4 * [3 + (48 / 2.9273)^{1/2}]$	1.7623

**Design thickness for internal pressure, (Corroded at 100 °F) Appendix 1-4(d)**

$$\begin{aligned}
 t &= P * L * M / (2 * S * E - 0.2 * P) + \text{Corrosion} \\
 &= 420 * 48 * 1.7623 / (2 * 20,000 * 1 - 0.2 * 420) + 0 \\
 &= \underline{0.8901"}
 \end{aligned}$$

**Maximum allowable working pressure, (Corroded at 100 °F) Appendix 1-4(d)**

$$\begin{aligned}
 P &= 2 * S * E * t / (L * M + 0.2 * t) - P_s \\
 &= 2 * 20,000 * 1 * 0.8901 / (48 * 1.7623 + 0.2 * 0.8901) - 0 \\
 &= \underline{420.01} \text{ psi}
 \end{aligned}$$

**Maximum allowable pressure, (New at 70 °F) Appendix 1-4(d)**

$$\begin{aligned}
 P &= 2 * S * E * t / (L * M + 0.2 * t) - P_s \\
 &= 2 * 20,000 * 1 * 0.8901 / (48 * 1.7623 + 0.2 * 0.8901) - 0 \\
 &= \underline{420.01} \text{ psi}
 \end{aligned}$$

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

$$\begin{aligned}
 \text{EFE} &= (75 * t / R_f) * (1 - R_f / R_o) \\
 &= (75 * 0.8901 / 3.3724) * (1 - 3.3724 / \infty) \\
 &= 19.7955\%
 \end{aligned}$$

## Welded Flat Head

ASME Section VIII Division 1, 2015 Edition				
<b>Component</b>		Welded Cover		
<b>Configuration</b>		Figure UG-34 Sketch (f)		
<b>Material</b>		SA-516 70 (II-D p. 18, ln. 37)		
<b>Attached To</b>		Cylinder for Flat and Hemi Heads		
<b>Impact Tested</b>	<b>Normalized</b>	<b>Fine Grain Practice</b>	<b>PWHT</b>	<b>Optimize MDMT/ Find MAWP</b>
No	No	No	No	No
		<b>Design Pressure (psi)</b>	<b>Design Temperature (°F)</b>	<b>Design MDMT (°F)</b>
<b>Internal</b>		420	100	-20
<b>Static Liquid Head</b>				
<b>Condition</b>		<b>P<sub>s</sub> (psi)</b>	<b>H<sub>s</sub> (in)</b>	<b>SG</b>
<b>Test horizontal</b>		1.7	47	1
<b>Dimensions</b>				
<b>Outer Diameter</b>		47"		
<b>Nominal Thickness</b>		3.912"		
<b>Head Inset</b>		0.5"		
<b>Inner Fillet Weld Leg</b>		0.5"		
<b>Outer Fillet Weld Leg</b>		0.5"		
<b>Corrosion</b>	<b>Inner</b>	0"		
	<b>Outer</b>	0"		
<b>Weight and Capacity</b>				
		<b>Weight (lb)</b>		<b>Capacity (US gal)</b>
<b>New</b>		1,920.75		0
<b>Corroded</b>		1,920.75		0
<b>Radiography</b>				
<b>Category A joints</b>		Seamless No RT		

<b>Results Summary</b>	
Governing condition	internal pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	<a href="#">3.912"</a>
Maximum allowable working pressure (MAWP)	<a href="#">420</a> psi
Maximum allowable pressure (MAP)	<a href="#">420</a> psi
Rated MDMT	-20°F

<b>UCS-66 Material Toughness Requirements</b>	
Governing thickness, t <sub>g</sub> =	0.978"
MDMT =	-20°F

Material is exempt from impact testing per UG-20(f) at the Design MDMT of -20°F.

Figure UG-34 Weld Sizing					
Inner fillet $\geq t_s + C_{i,shell} / 0.7$					
Outer fillet $\geq t_s + C_{o,shell} / 0.7$					
Results					
Inner fillet =	0.5"	$\geq$	$0.5 + 0 / 0.7 =$	0.5"	OK
Outer fillet =	0.5"	$\geq$	$0.5 + 0 / 0.7 =$	0.5"	OK

Factor C from Fig. UG-34, sketch (b-2), (e through g)

$$\begin{aligned} C &= 0.33 * t_r / t_s \\ &= 0.33 * 0.4998 / 0.5 \\ &= 0.3299 \end{aligned}$$

Design thickness, (at 100 °F) UG-34 (c)(2)

$$\begin{aligned} t &= d * \text{Sqr}(C * P / (S * E)) + \text{Corrosion} \\ &= 47 * \text{Sqr}(0.3299 * 420 / (20,000 * 1)) + 0 \\ &= \underline{3.912"} \end{aligned}$$

Maximum allowable working pressure, (at 100 °F)

$$\begin{aligned} C &= 0.33 * t_r / t_s \\ &= 0.33 * 0.4998 / 0.5 \\ &= 0.3299 \\ \text{MAWP} &= (S * E / C) * (t / d)^2 - P_s \\ &= (20,000 * 1 / 0.3299) * (3.912 / 47)^2 - 0 \\ &= \underline{420} \text{ psi} \end{aligned}$$

Maximum allowable pressure, (At 70 °F)

$$\begin{aligned} C &= 0.33 * t_r / t_s \\ &= 0.33 * 0.4998 / 0.5 \\ &= 0.3299 \\ \text{MAP} &= (S * E / C) * (t / d)^2 \\ &= (20,000 * 1 / 0.3299) * (3.912 / 47)^2 \\ &= \underline{420} \text{ psi} \end{aligned}$$

### Hemispherical (Hemi) Head

ASME Section VIII Division 1, 2015 Edition				
<b>Component</b>		Hemispherical Head		
<b>Material</b>		SA-516 70 (II-D p. 18, ln. 37)		
<b>Attached To</b>		Cylinder for Flat and Hemi Heads		
<b>Impact Tested</b>	<b>Normalized</b>	<b>Fine Grain Practice</b>	<b>PWHT</b>	<b>Optimize MDMT/ Find MAWP</b>
No	No	No	No	No
		<b>Design Pressure (psi)</b>	<b>Design Temperature (°F)</b>	<b>Design MDMT (°F)</b>
<b>Internal</b>		420	100	-20
Static Liquid Head				
<b>Condition</b>		<b>P<sub>s</sub> (psi)</b>	<b>H<sub>s</sub> (in)</b>	<b>SG</b>
<b>Test horizontal</b>		1.7	47	1
Dimensions				
<b>Inner Diameter</b>		47"		
<b>Minimum Thickness</b>		0.2474"		
<b>Corrosion</b>	<b>Inner</b>	0"		
	<b>Outer</b>	0"		
Weight and Capacity				
		<b>Weight (lb)</b>	<b>Capacity (US gal)</b>	
<b>New</b>		245.51	117.67	
<b>Corroded</b>		245.51	117.67	
Radiography				
<b>Category A joints - Long Seam</b>		Seamless No RT		
<b>Category A joints - Circ Seam</b>		Full UW-11(a) Type 1		

Results Summary	
Governing condition	Internal pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	<a href="#">0.2473"</a>
Maximum allowable working pressure (MAWP)	<a href="#">420.22 psi</a>
Maximum allowable pressure (MAP)	<a href="#">420.22 psi</a>
Rated MDMT	-20.1 °F

UCS-66 Material Toughness Requirements	
Governing thickness, t <sub>g</sub> =	0.2474"
Exemption temperature from Fig UCS-66 Curve B =	-20°F
t <sub>r</sub> = 420*23.5 / (2*20,000*1 - 0.2*420) =	0.2473"
Stress ratio = t <sub>r</sub> *E* / (t <sub>n</sub> - c) = 0.2473*1 / (0.2474 - 0) =	0.9995
Reduction in MDMT, T <sub>R</sub> from Fig UCS-66.1 =	0.1°F

$\text{MDMT} = \max[\text{MDMT} - T_R, -55] = \max[-20 - 0.1, -55] = -20.1^\circ\text{F}$
Material is exempt from impact testing at the Design MDMT of $-20^\circ\text{F}$ .

**Design thickness, (at 100 °F) UG-32(e)**

$$\begin{aligned}
 t &= P \cdot R / (2 \cdot S \cdot E - 0.20 \cdot P) + \text{Corrosion} \\
 &= 420 \cdot 23.5 / (2 \cdot 20,000 \cdot 1.00 - 0.20 \cdot 420) + 0 \\
 &= \underline{0.2473"}
 \end{aligned}$$

**Maximum allowable working pressure, (at 100 °F) UG-32(e)**

$$\begin{aligned}
 P &= 2 \cdot S \cdot E \cdot t / (R + 0.20 \cdot t) - P_s \\
 &= 2 \cdot 20,000 \cdot 1.00 \cdot 0.2474 / (23.5 + 0.20 \cdot 0.2474) - 0 \\
 &= \underline{420.22} \text{ psi}
 \end{aligned}$$

**Maximum allowable pressure, (at 70 °F) UG-32(e)**

$$\begin{aligned}
 P &= 2 \cdot S \cdot E \cdot t / (R + 0.20 \cdot t) \\
 &= 2 \cdot 20,000 \cdot 1.00 \cdot 0.2474 / (23.5 + 0.20 \cdot 0.2474) \\
 &= \underline{420.22} \text{ psi}
 \end{aligned}$$

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

$$\begin{aligned}
 \text{EFE} &= (75 \cdot t / R_p) \cdot (1 - R_f / R_o) \\
 &= (75 \cdot 0.2474 / 23.6237) \cdot (1 - 23.6237 / \infty) \\
 &= 0.7854\%
 \end{aligned}$$

The extreme fiber elongation does not exceed 5%.