Pressure Vessel Engineering Ltd.

120 Randall Drive, Suite B
Waterloo, Ontario, Canada
N2V 1C6

Tel. 519-880-9808
Fax 519-880-9810
info@pveng.com
www.pveng.com

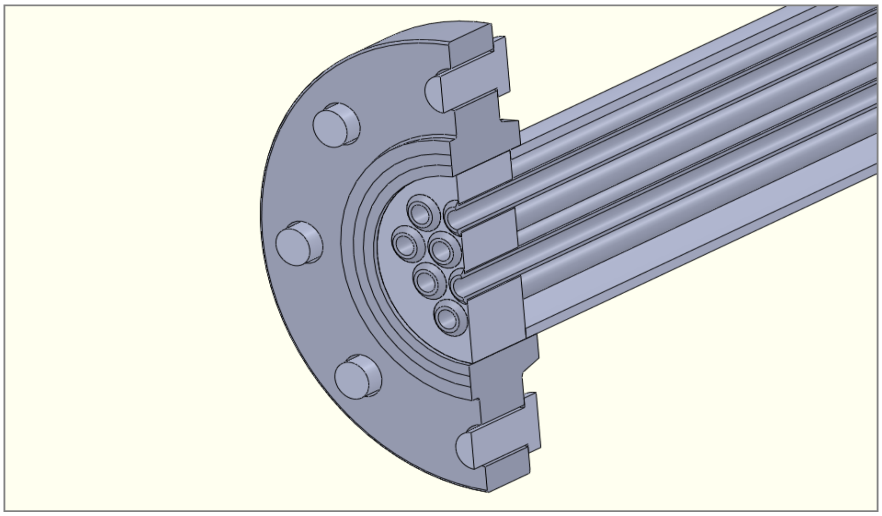
Finite Element Analysis (FEA) Report

Sample Job #23

Fixed Tubesheet

ABC-123-456

April 1, 2009



PVE-3377

Cameron Moore

Laurence Brundrett P. Eng.

Contents **Page**

Revision(s)

Rev	Description	Date	By
0	Release	3-31-09	CM
1			
2			

Executive Summary

Project Information:

Sample Job #23	Customer
Fixed Tubesheet	Vessel / Component(s)
ABC-123-456	Part Number
PVE-3377	Job
SolidWorks CosmosWorks 2008	FEA Program Used
6-Apr-2009	Date

Max Pressure (psi) TS:1300, SS:400	@Temperature (F) TS:200, SS:400	Maximum Allowed Working Pressure
Max Operating Temp (F) TS:200, SS:400	@ Pressure (psi) TS:1300, SS:400	Maximum Design Metal Temperature

Goal:

This report is to investigate the stresses acting on a fixed tubesheet heat exchanger with both tube side and shell side design pressures applied. The design temperatures are also applied to all components to generate the actual thermal loads acting on the exchanger.

Summary Conclusions:

Materials

Material strength properties used in this report are obtained from ASME IID, Table 1A. Stress classification limits are calculated to VIII-2 rules using ASME IID allowables for VIII-1. The tubesheet material is SA-516 70.

Model Information

The model used in this report represents a quarter of the heat exchanger due to symmetry. The mesh size has been refined to 0.250" for all components and refined to 0.166" on the tubes. A 2nd order, tetrahedral solid mesh is used for this model.

Restraints & Loads

Symmetry restraints are applied on the two cutting planes to prevent rigid body motion X and Z axes. A fixed point keeps the model from moving in the Y axis. Tube side and shell side pressures and temperatures have been applied as well as the bolt and gasket loads on the flange.

Results

The shell of the heat exchanger upward in the y axis. The stresses on the tubes, tubesheet and shell are below the corresponding material's allowable stress except at peak areas. A cycle life analysis shows a cycle life of 14,590 cycles.

Analysis Conclusion:

This fixed tubesheet heat exchanger is suitable for Section VIII-I service using Section VIII-II stress classifications.

Material Stress Limits ver 4.00 ASME VIII-2 Fig 4-130.1

Material:

SA-333 Gr 6	**Material**
Shell	**Application**

Strength Properties:

ASME VIII-IID, 2007 Edition 2008 Addenda	**Source** of strength properties
400	**T** [ºF] temperature
14,600	**Sm** [psi] basic allowable stress at temperature T
29,900	**Sy** [psi] yield stress at temperature T (optional)
1.0	**k** [] - stress intensity k factor
1.00	**E1** [] - weld efficiency factor
1.00	**E2** [] - casting efficiency factor

FEA Properties:

ASME VIII-IID, 2007 Edition 2008 Addenda	**Source** of FEA properties
27,800,000	**E** [psi] - modulus of elasticity (at temperature)
0.28	**v** [] - Poison's ratio
7.00E-06	**Coef** [in/in/ºF]- coefficient of thermal expansion (for thermal stress studies only)

Stress Limits:

Pm = k*E1*E2*Sm general primary membrane stress intensity limit

1*1*1*14600 = **14,600**

Pl = 1.5*k*E1*E2*Sm local membrane stress intensity limit

1.5*1*1*1*14600 = **21,900**

Pl+Pb = 1.5*k*E1*E2*Sm primary membrane + primary bending stress intensity limit

1.5*1*1*1*14600 = **21,900**

Pl+Pb+Q = Max(3*E1*E2*Sm,2*E1*E2*Sy) primary + secondary stress intensity

MAX(3*1*1*14600,2*1*1*29900) = **59,800**

Pl+Pb+Q+F = Use fatigue curves peak stress intensity limit

Comments:

(1) Sy material property is not required, more conservative Pl+Pb+Q limits might be computed without it.
(2) Refer to VIII-2 Table AD-150.1 for k values
(3) The thermal expansion coeficient is only required for studies including thermal stresses
(4) Refer to VIII-2 App 4-130 and following for the Pm, Pl, Q and F stress limits
(5) Refer to VIII-2 App 4-130 Table 4-120.1 for the correct application of the calculated stress limits
(6) Use IID tables 2A and 2B for Sm for VIII-2 studies
(7) Use IID tables 1A and 2A for Sm values (S) for VIII-1 studies
(8) Use B31.1 Table A for Sm values for B31.1 studies
(9) Use B31.3 Table A for Sm values for B31.3 studies

Material Stress Limits ver 4.00 ASME VIII-2 Fig 4-130.1

Material:

SA-334 Gr 6	**Material**
Tubes	**Application**

Strength Properties:

ASME VIII-IID, 2007 Edition 2008 Addenda	**Source** of strength properties
400	**T** [ºF] temperature
14,600	**Sm** [psi] basic allowable stress at temperature T
29,900	**Sy** [psi] yield stress at temperature T (optional)
1.0	**k** [] - stress intensity k factor
1.00	**E1** [] - weld efficiency factor
1.00	**E2** [] - casting efficiency factor

FEA Properties:

ASME VIII-IID, 2007 Edition 2008 Addenda	**Source** of FEA properties
27,800,000	**E** [psi] - modulus of elasticity (at temperature)
0.28	**v** [] - Poison's ratio
7.00E-06	**Coef** [in/in/ºF]- coefficient of thermal expansion (for thermal stress studies only)

Stress Limits:

Pm = k*E1*E2*Sm general primary membrane stress intensity limit

1*1*1*14600 = **14,600**

Pl = 1.5*k*E1*E2*Sm local membrane stress intensity limit

1.5*1*1*1*14600 = **21,900**

Pl+Pb = 1.5*k*E1*E2*Sm primary membrane + primary bending stress intensity limit

1.5*1*1*1*14600 = **21,900**

Pl+Pb+Q = Max(3*E1*E2*Sm,2*E1*E2*Sy) primary + secondary stress intensity

MAX(3*1*1*14600,2*1*1*29900) = **59,800**

Pl+Pb+Q+F = Use fatigue curves peak stress intensity limit

Comments:

(1) Sy material property is not required, more conservative Pl+Pb+Q limits might be computed without it.
(2) Refer to VIII-2 Table AD-150.1 for k values
(3) The thermal expansion coeficient is only required for studies including thermal stresses
(4) Refer to VIII-2 App 4-130 and following for the Pm, Pl, Q and F stress limits
(5) Refer to VIII-2 App 4-130 Table 4-120.1 for the correct application of the calculated stress limits
(6) Use IID tables 2A and 2B for Sm for VIII-2 studies
(7) Use IID tables 1A and 2A for Sm values (S) for VIII-1 studies
(8) Use B31.1 Table A for Sm values for B31.1 studies
(9) Use B31.3 Table A for Sm values for B31.3 studies

Material Stress Limits ver 4.00 ASME VIII-2 Fig 4-130.1

Material:

SA-516 Gr 70	**Material**
Tubesheet	**Application**

Strength Properties:

ASME VIII-IID, 2007 Edition 2008 Addenda	**Source** of strength properties
400	**T** [ºF] temperature
20,000	**Sm** [psi] basic allowable stress at temperature T
32,500	**Sy** [psi] yield stress at temperature T (optional)
1.0	**k** [] - stress intensity k factor
1.00	**E1** [] - weld efficiency factor
1.00	**E2** [] - casting efficiency factor

FEA Properties:

ASME VIII-IID, 2007 Edition 2008 Addenda	**Source** of FEA properties
29,400,000	**E** [psi] - modulus of elasticity (at temperature)
0.28	**v** [] - Poison's ratio
6.40E-06	**Coef** [in/in/ºF]- coefficient of thermal expansion (for thermal stress studies only)

Stress Limits:

Pm = k*E1*E2*Sm   general primary membrane stress intensity limit

1*1*1*20000 = **20,000**

Pl = 1.5*k*E1*E2*Sm   local membrane stress intensity limit

1.5*1*1*1*20000 = **30,000**

Pl+Pb = 1.5*k*E1*E2*Sm   primary membrane + primary bending stress intensity limit

1.5*1*1*1*20000 = **30,000**

Pl+Pb+Q = Max(3*E1*E2*Sm,2*E1*E2*Sy)   primary + secondary stress intensity

MAX(3*1*1*20000,2*1*1*32500) = **65,000**

Pl+Pb+Q+F = Use fatigue curves   peak stress intensity limit

Comments:

(1) Sy material property is not required, more conservative Pl+Pb+Q limits might be computed without it.
(2) Refer to VIII-2 Table AD-150.1 for k values
(3) The thermal expansion coeficient is only required for studies including thermal stresses
(4) Refer to VIII-2 App 4-130 and following for the Pm, Pl, Q and F stress limits
(5) Refer to VIII-2 App 4-130 Table 4-120.1 for the correct application of the calculated stress limits
(6) Use IID tables 2A and 2B for Sm for VIII-2 studies
(7) Use IID tables 1A and 2A for Sm values (S) for VIII-1 studies
(8) Use B31.1 Table A for Sm values for B31.1 studies
(9) Use B31.3 Table A for Sm values for B31.3 studies

Material Stress Limits ver 4.00 ASME VIII-2 Fig 4-130.1

Material:

SA-105	**Material**
Flange	**Application**

Strength Properties:

ASME VIII-IID, 2007 Edition 2008 Addenda	**Source** of strength properties
400	**T** [ºF] temperature
20,000	**Sm** [psi] basic allowable stress at temperature T
30,800	**Sy** [psi] yield stress at temperature T (optional)
1.0	**k** [] - stress intensity k factor
1.00	**E1** [] - weld efficiency factor
1.00	**E2** [] - casting efficiency factor

FEA Properties:

ASME VIII-IID, 2007 Edition 2008 Addenda	**Source** of FEA properties
29,400,000	**E** [psi] - modulus of elasticity (at temperature)
0.28	**v** [] - Poison's ratio
6.40E-06	**Coef** [in/in/ºF]- coefficient of thermal expansion (for thermal stress studies only)

Stress Limits:

Pm = k*E1*E2*Sm general primary membrane stress intensity limit

1*1*1*20000 = **20,000**

Pl = 1.5*k*E1*E2*Sm local membrane stress intensity limit

1.5*1*1*1*20000 = **30,000**

Pl+Pb = 1.5*k*E1*E2*Sm primary membrane + primary bending stress intensity limit

1.5*1*1*1*20000 = **30,000**

Pl+Pb+Q = Max(3*E1*E2*Sm,2*E1*E2*Sy) primary + secondary stress intensity

MAX(3*1*1*20000,2*1*1*30800) = **61,600**

Pl+Pb+Q+F = Use fatigue curves peak stress intensity limit

Comments:

(1) Sy material property is not required, more conservative Pl+Pb+Q limits might be computed without it.
(2) Refer to VIII-2 Table AD-150.1 for k values
(3) The thermal expansion coeficient is only required for studies including thermal stresses
(4) Refer to VIII-2 App 4-130 and following for the Pm, Pl, Q and F stress limits
(5) Refer to VIII-2 App 4-130 Table 4-120.1 for the correct application of the calculated stress limits
(6) Use IID tables 2A and 2B for Sm for VIII-2 studies
(7) Use IID tables 1A and 2A for Sm values (S) for VIII-1 studies
(8) Use B31.1 Table A for Sm values for B31.1 studies
(9) Use B31.3 Table A for Sm values for B31.3 studies

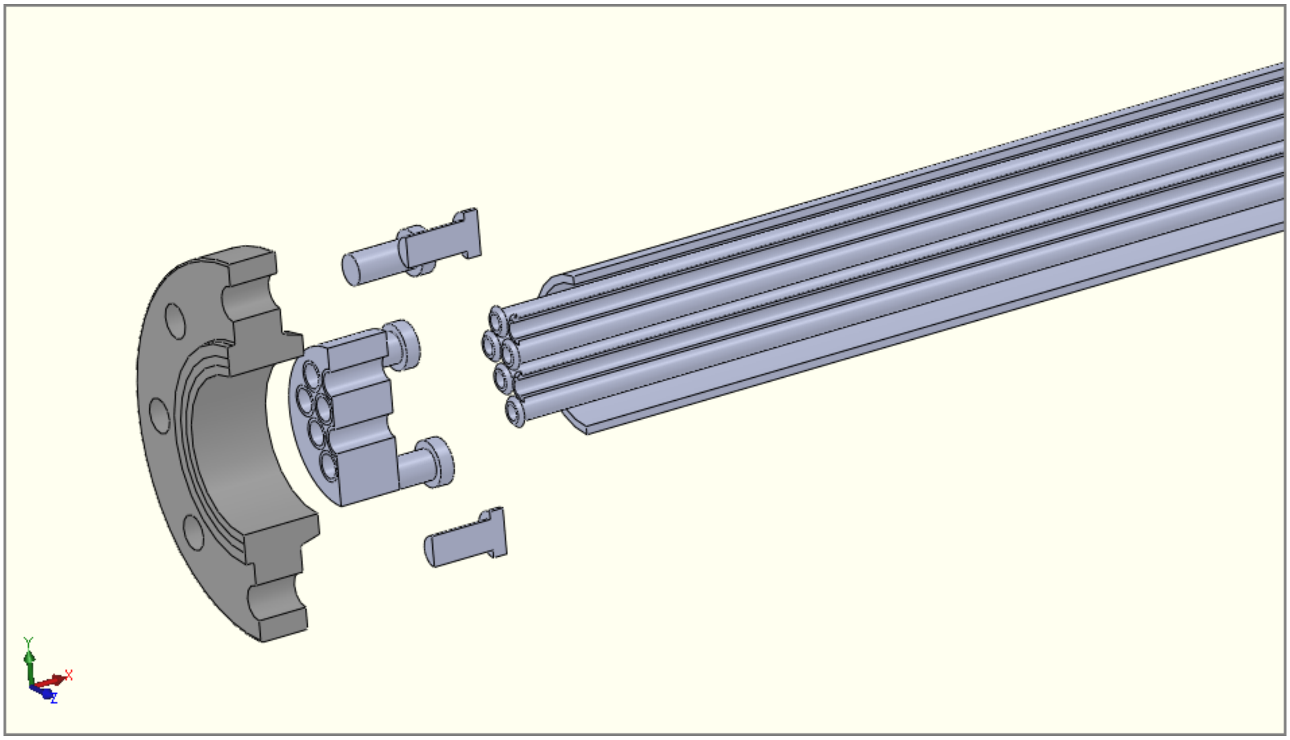


Fig-A A quarter section of the heat exchanger is modelled. A slip on flange is welded at the fixed tubesheet with bolts modelled in to simulate the bending forces acting on the tubesheet.

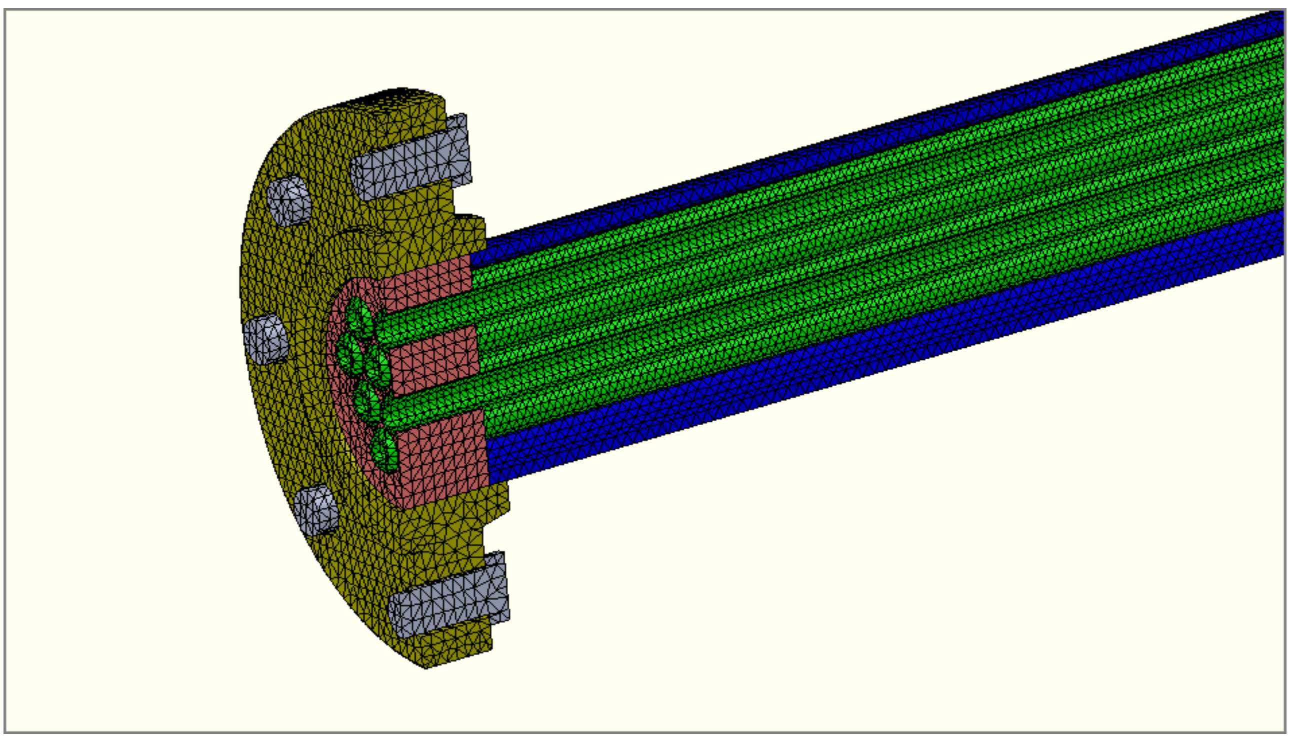


Fig-B A global mesh size of 1/4" has been used on all components except for the tube. Because of the thin wall of the tubes, the mesh has been refined to 0.166" which allows for one element through the wall.

Restraints and Loads Ver 4.06

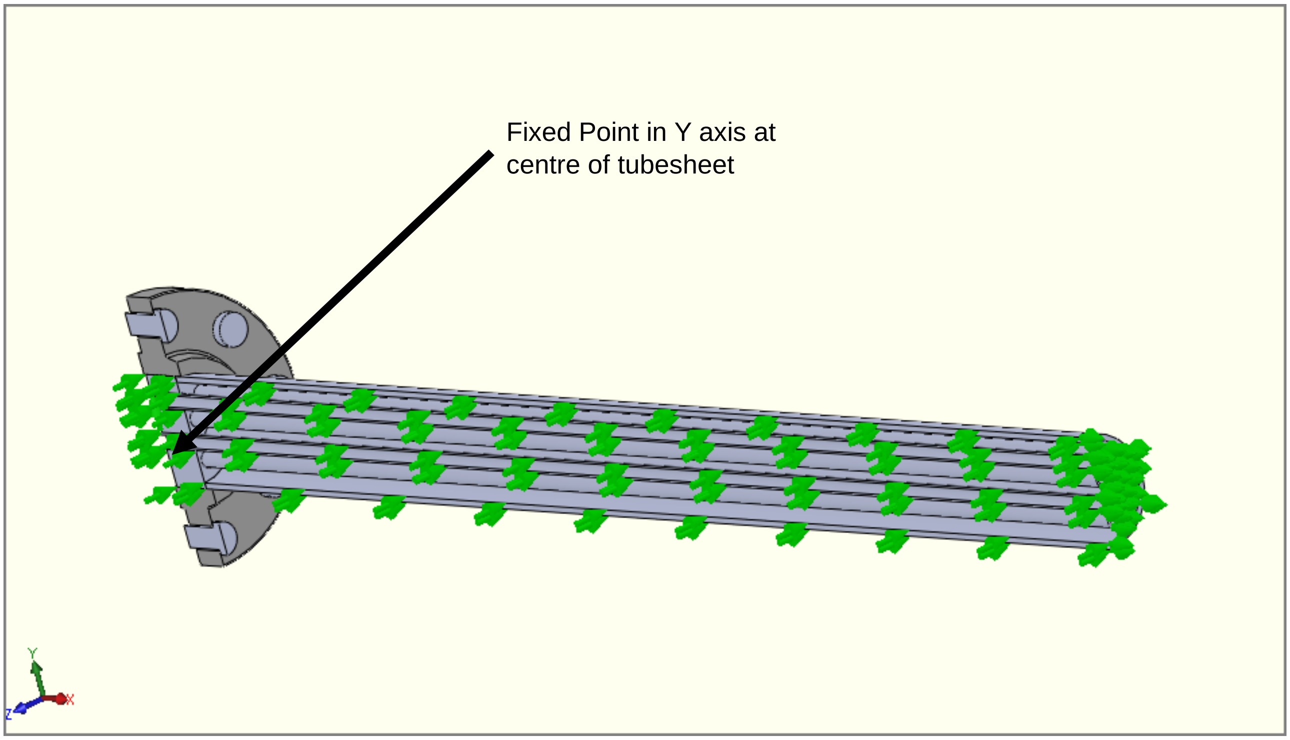


Fig-A A view of the symmetry restraints applied to the model. Symmetry restraints are applied to all of the cut plane edges to provide realistic results and simulate the complete model.

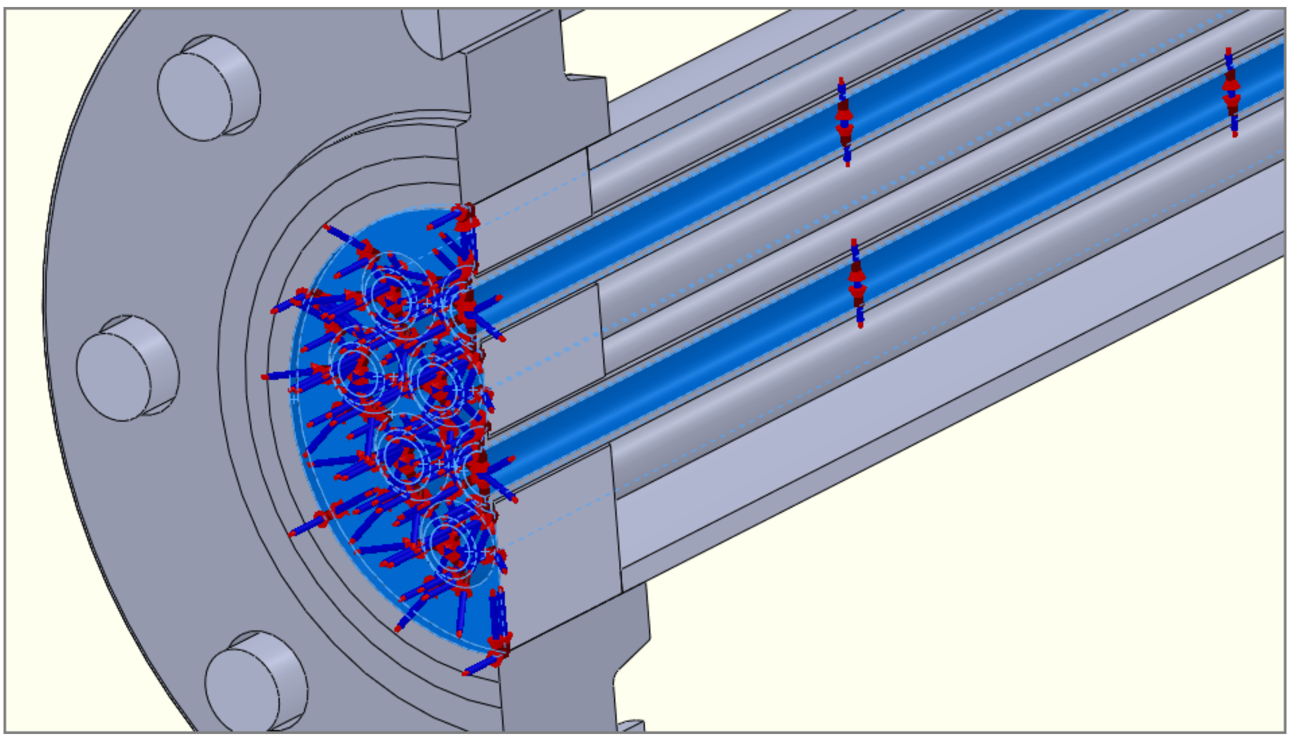


Fig-B A view of 1300 psi and 200°F applied to the tube side faces.

Applied Gasket Load on Flange <- Description

Dimensions and Conditions:

4.500 <- B - ID, uncorroded
0.237 <- tn, nozzle wall thickness
0.583 <- g1 - hub thickness
1300.0 <- P, internal operating pressure

6.188 <- GOD - gasket OD
4.500 <- GID - gasket ID
0.50 <- m - gasket factor
0 <- gy - gasket factor y

8.500 <- varC - bolt circle dia
0.875 <- BoltOD, bolt size
8.0 <- Nbolt, number of bolts

Material Properties:

SA-193 B7 <- Bolting Material
25,000 <- Sb - allowable bolt stress at DESIGN temp
25,000 <- Sba - allowable bolt stress at ASSEMBLY temp

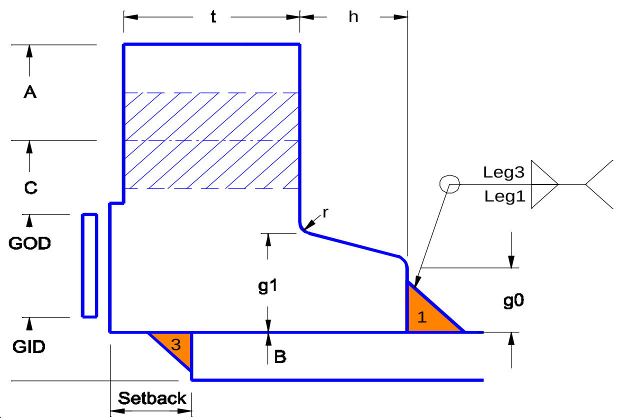


Fig 2-4 (3)

Calculated Dimensions:

g0 =	g0-corr	= 0-0		g0 = ***0.000***
gOne =	g1 - corr	= 0.583-0		gOne = ***0.583***
B =	B+2*corr	= 4.5+2*0	*Corroded ID*	B = ***4.500***
varN =	(GOD-GID)/2	= (6.188-4.5)/2	*Gasket Width in Contact*	varN = ***0.844***
b0 =	varN / 2	= 0.844 / 2	*gasket seating width*	b0 = ***0.422***
varb =	min(Sqrt(b0)/2,b0)	= min(Sqrt(0.422)/2,0.422)	*eff seating width*	varb = ***0.325***
varG =	max(GOD-2*varb,(GOD-GID)/2 + GID)		*gasket load reaction diameter*	varG = ***5.538***
=	max(6.188-2*0.325,(6.188-4.5)/2 + 4.5)			

Flange Loads (VIII App 2-5):

H =	0.785*varG^2*P	= 0.785*5.538^2*1300	*end load*	H = ***31,318***
HP =	2*varb*3.14*varG*m*P	= 2*0.325*3.14*5.538*0.5*1300	*contact load*	HP = ***7,343***
HD =	pi/4 * B^2 * P	= pi/4 * 4.5^2 * 1300	*end load*	HD = ***20,676***
HT =	H - HD	= 31318 - 20676	*face load*	HT = ***10,643***
Wm1 =	H + HP	= 31318 + 7343	*bolt load*	Wm1 = ***38,662***
Wm2 =	pi*varb*varG*gy	= pi*0.325*5.538*0	*seating load*	Wm2 = ***0***
Am =	max(Wm1/Sb, Wm2/Sba)	= max(38662/25000, 0/25000)	*req bolt area*	Am = ***1.546***
Ab =	Root*Nbolt	= 0.431*8 ***7/8-9 UNC 2A***		Ab = ***3.448***

Total Bolt Loads - lbs - (app 2-5):

W =	(Am + Ab)*Sba/2	= (1.546 + 3.448)*25000/2	*seating conditions*	W = ***62,431***
HG =	W - H	= 62431 - 31318	*operating conditions*	HG = ***31,112***

Flange Moment Arms - inch - (Table App 2-6 - loose flanges):

mhD =	(varC-B)/2	= (8.5-4.5)/2	*end pressure*	mhD = ***2.000***
mhT =	(mhD+mhG)/2	= (2+1.481)/2	*face pressure*	mhT = ***1.740***
mhG =	(varC-varG)/2	= (8.5-5.538)/2	*gasket load*	mhG = ***1.481***

Summary of Combined Operating & Seating Loads and Locations

Load	Magnitude (lbs)	Acting Rad (in)	(lbs/in)	
HT	*5,321*	*2.510*	337.48	Gasket face pressure (Operating)
HG+W	*46,772*	*2.769*	2688.12	Inside Gasket load + Bolt Preload (Seating + Operating)
HD	*10,338*	*2.250*	731.25	End pressure (Operating)
HT+HG+HG'+W	*124,862*	*4.250*	4675.84	Bolt reaction balancing load (Seating +Operating)

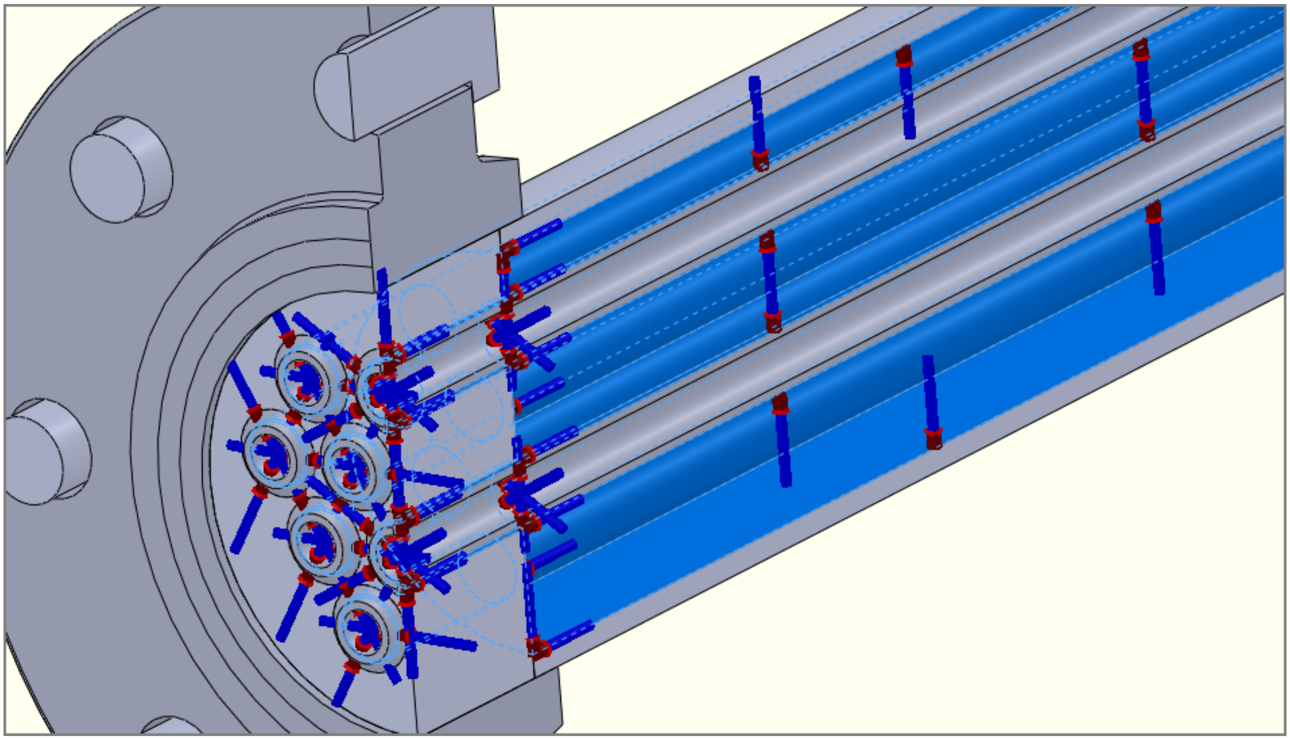


Fig-A A view of the 400 psi and 400°F applied to the shell side faces. Note that all external faces are set to ambient temperature and pressure.

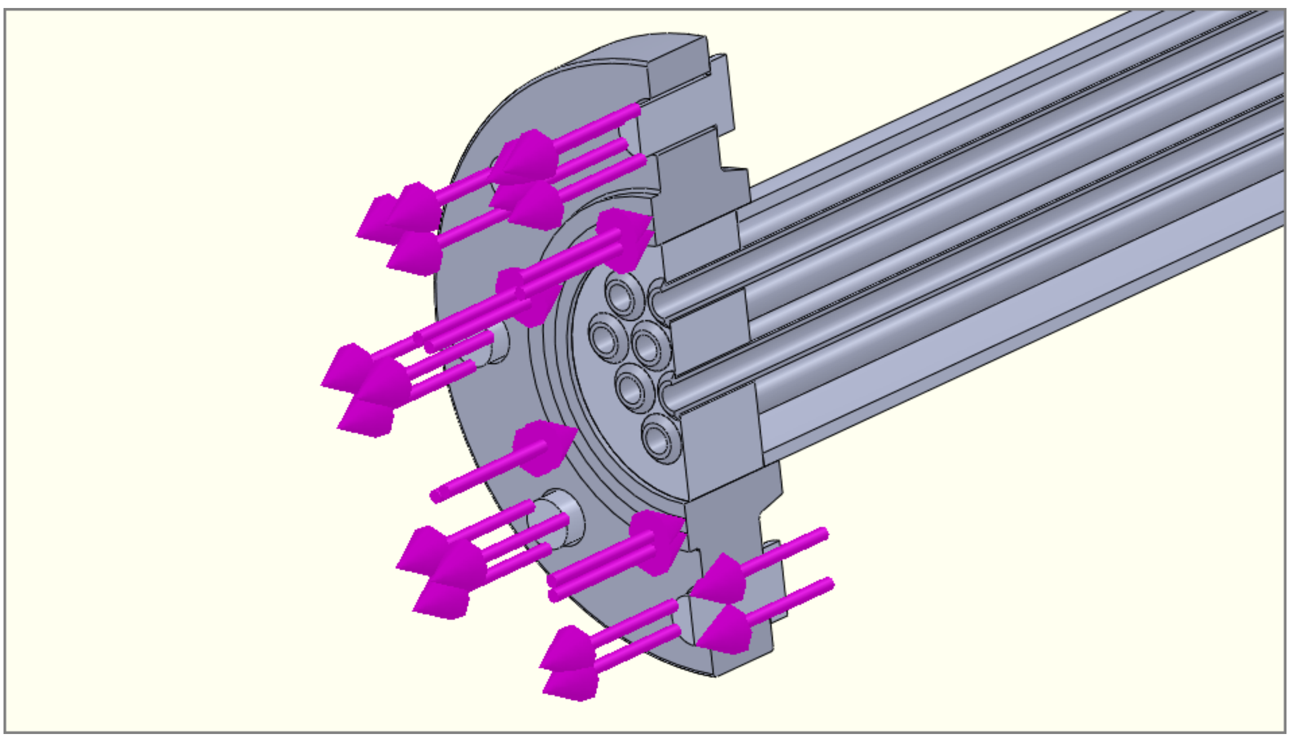


Fig-B Gasket loads and bolt loads are applied on the flange as shown. Refer to the previous page for load calculations.

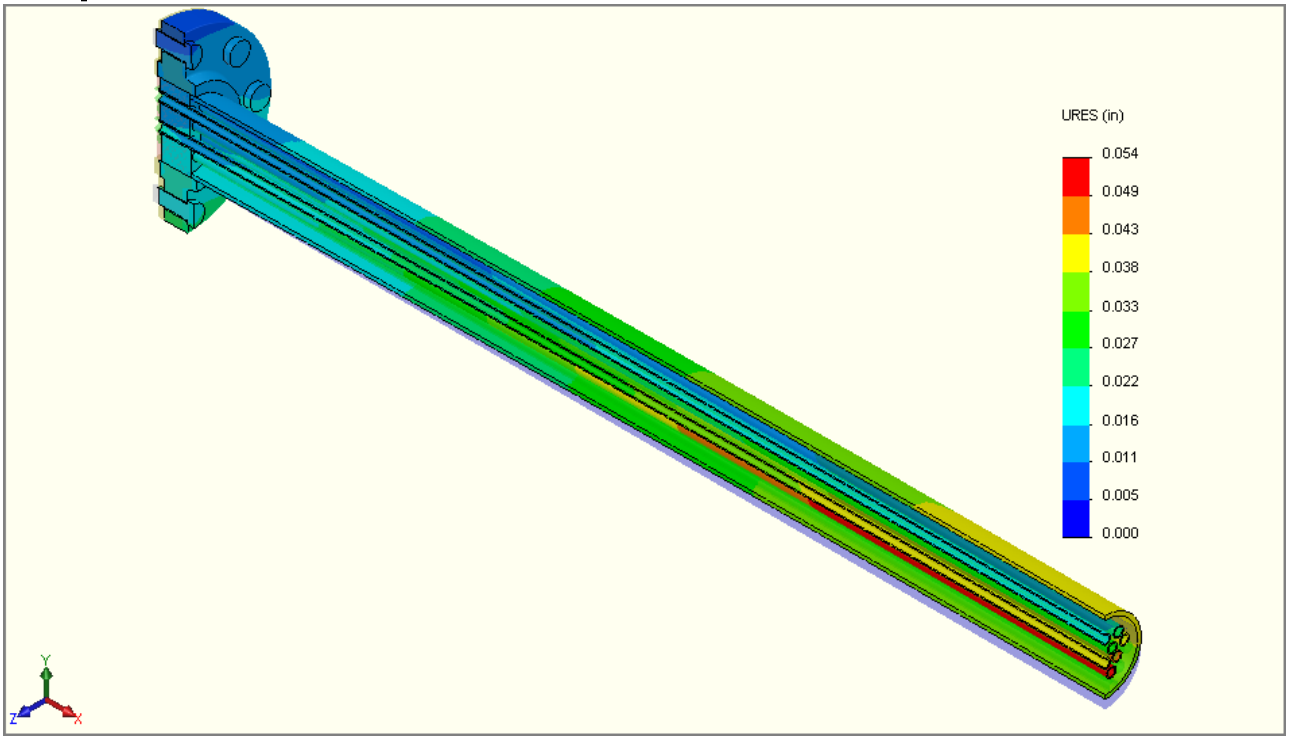


Fig-A A view of the displacement plot with superimposed original geometry. Results are magnified 50X. The shell bends upward in the Y axis.

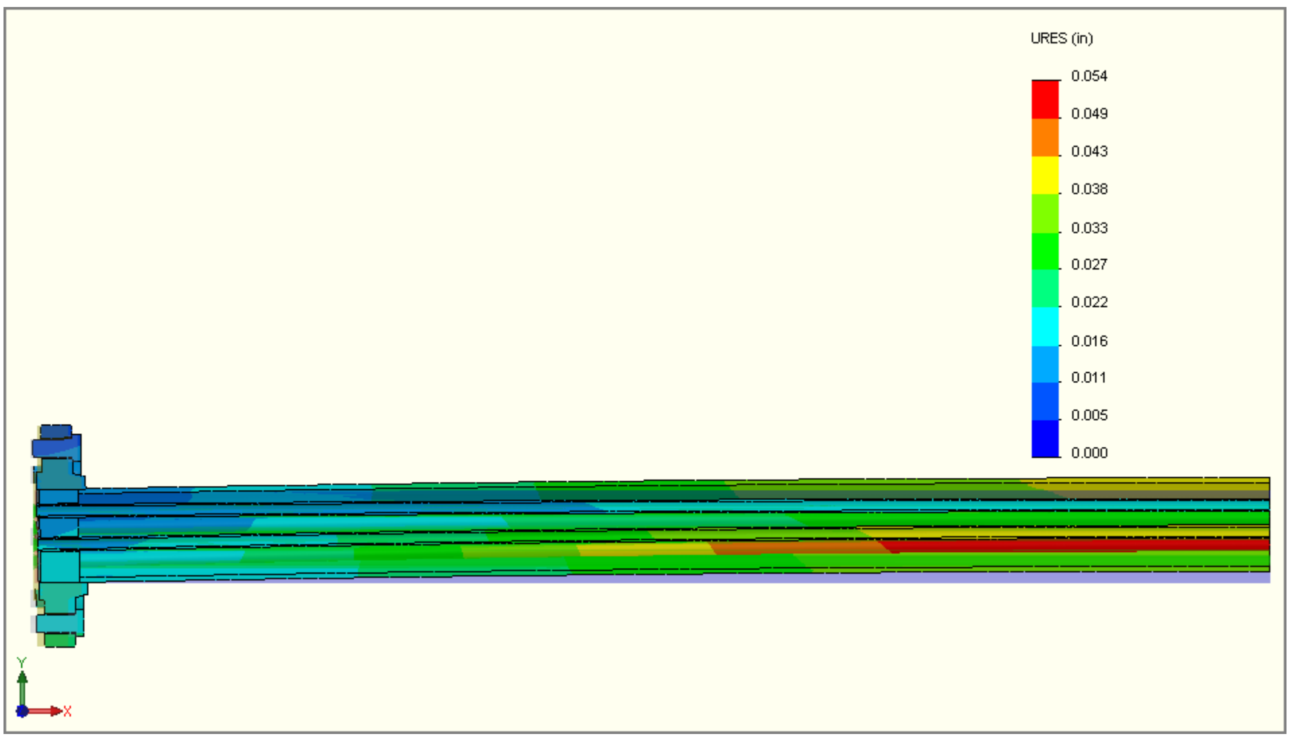


Fig-B View showing the displacement in the XY plane.

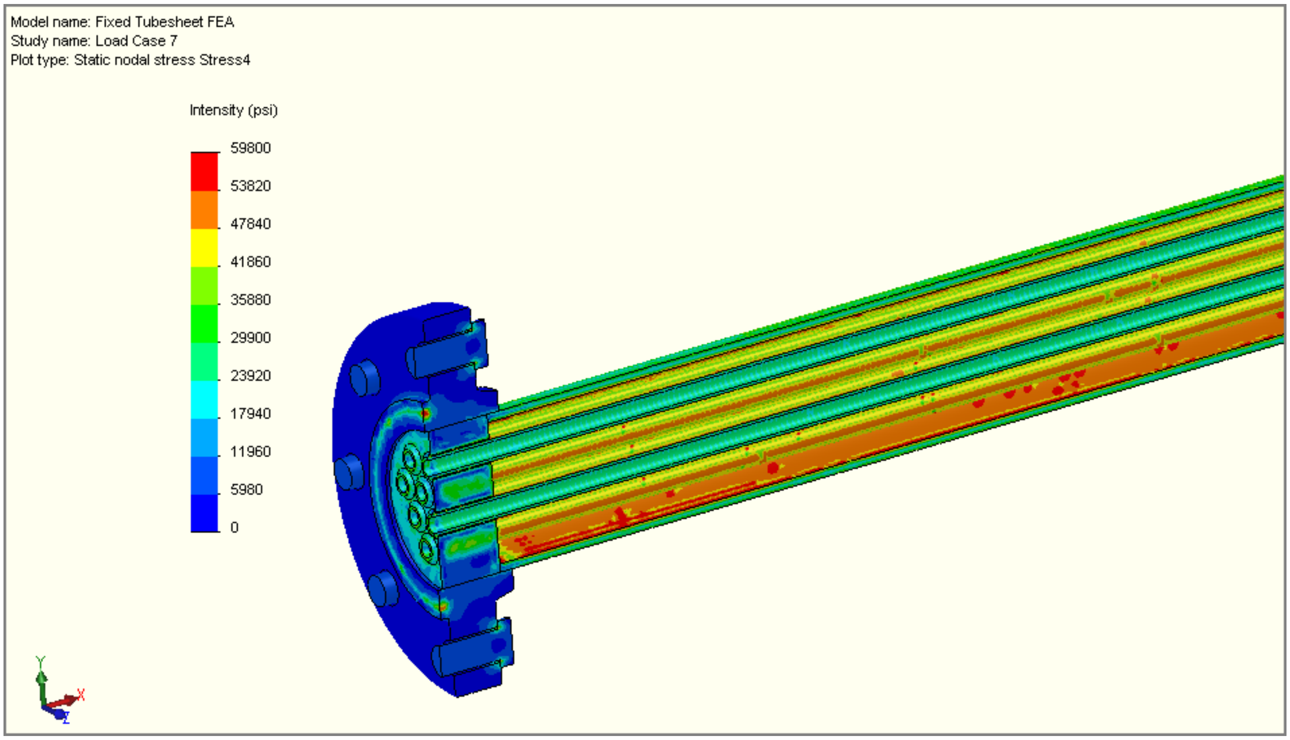


Fig-A A view of the membrane stress plot (Intensity) capped at the allowable stress of 59,800 psi for SA-333 and SA-334. Two times the yield stress of 29,900 psi is allowed for thermal loadings. See next page for cycle life analysis.

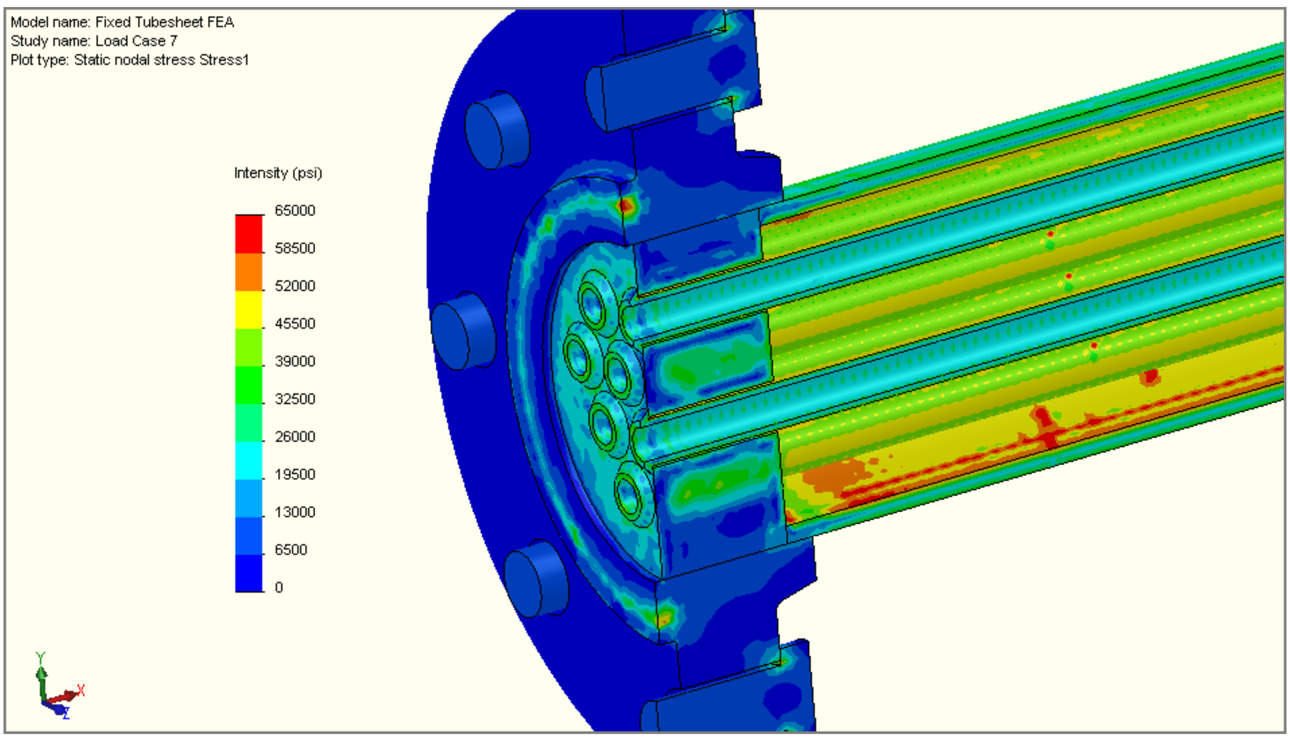


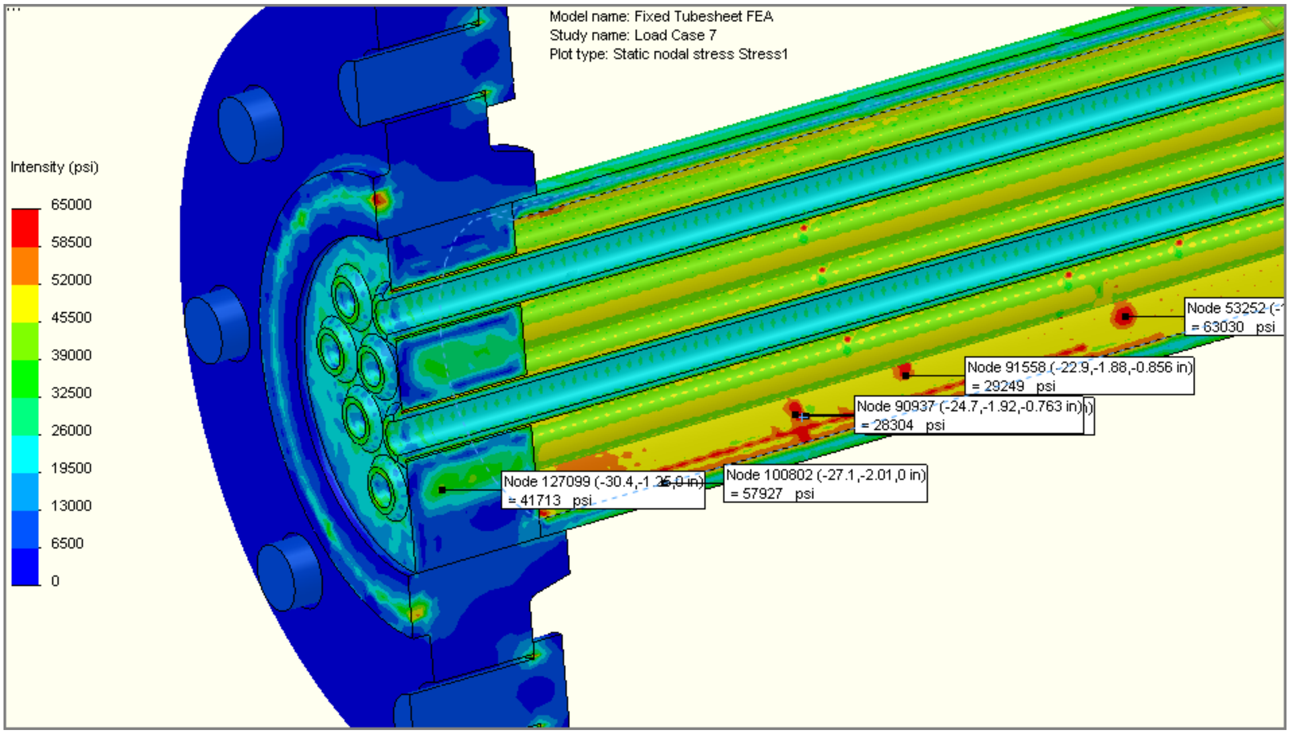
Fig-B A closeup view of the tubesheet. Stress intensity plot is capped at the allowable stress of 65,000 psi for SA-516 70. Two times the yield stress of 32,500 psi is allowed for thermal loadings. Stresses are below the 65,000 psi allowable.

Cycle Life ver 4.04

ASME VIII-2 2004 Ed. 2006 Add, Appx. 5

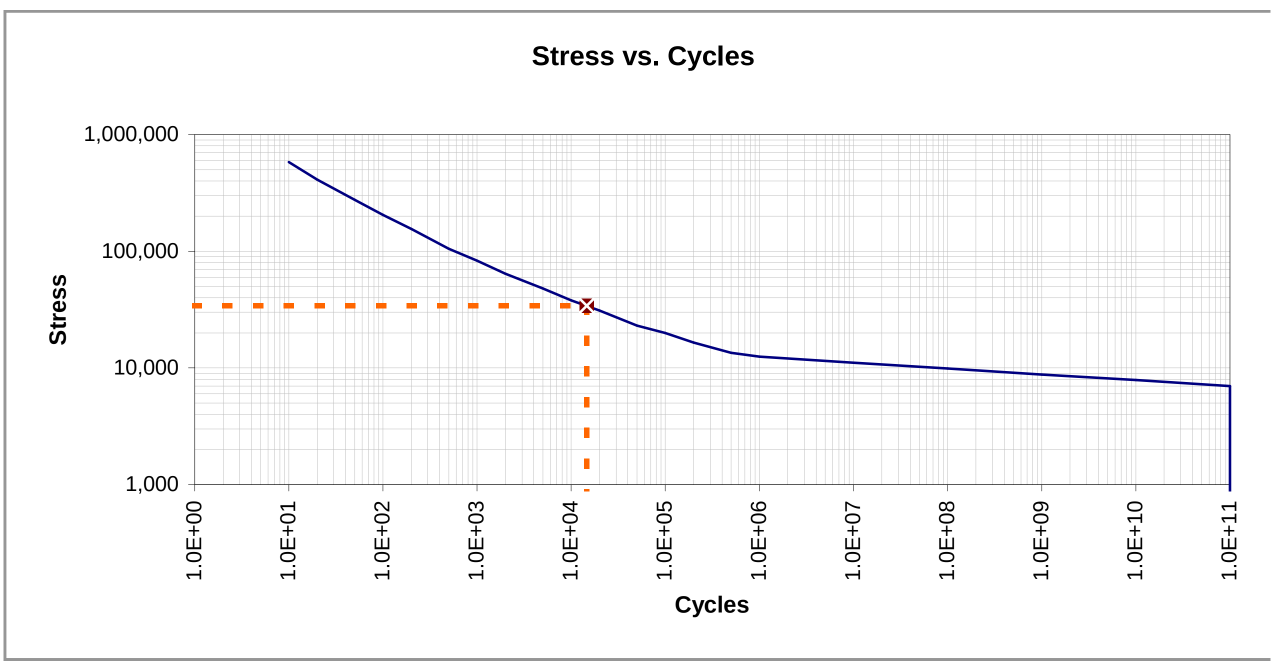
For carbon, low alloy, series 4XX, high alloy steels and high tensile steels for temperatures not exceeding 700ºF and N<= 10^6, UTS<= 80ksi

Fig 5-110.1 80ksi	**graph** - Select graph
63,030	**Str** [psi] - Enter stress value
27,800,000	**ET** [psi] - Modulus of elasticity at operating temp



The Life Cycle Analysis was performed for the highest general stress (63,030 psi) on the shell. The resultant cycle life is 14,590 cycles. This is acceptable since its above the 10,000 cycles required.

Salt [psi] = 1/2 * Str	1/2 * 63030 =	**31,515**
EG [psi] = PVELookup("EgTable","Lookup","Eg","CL_Fig51101_80ksi")		**30,000,000**
Se [psi] = Salt*EG/ET	31515*30000000/27800000 =	**34,009**



Cycles = PVELookup("CL_Fig51101_80ksi","CycleLifeLookup",Se) **14,590**

Reference List:

Please refer to the following links for additional information;

Including reference components in an FEA to provide appropriate boundary and load conditions.
http://www.pveng.com/documents/content_80.pdf

The use and effects of 2nd order integration elements.
http://www.pveng.com/documents/content_151.pdf

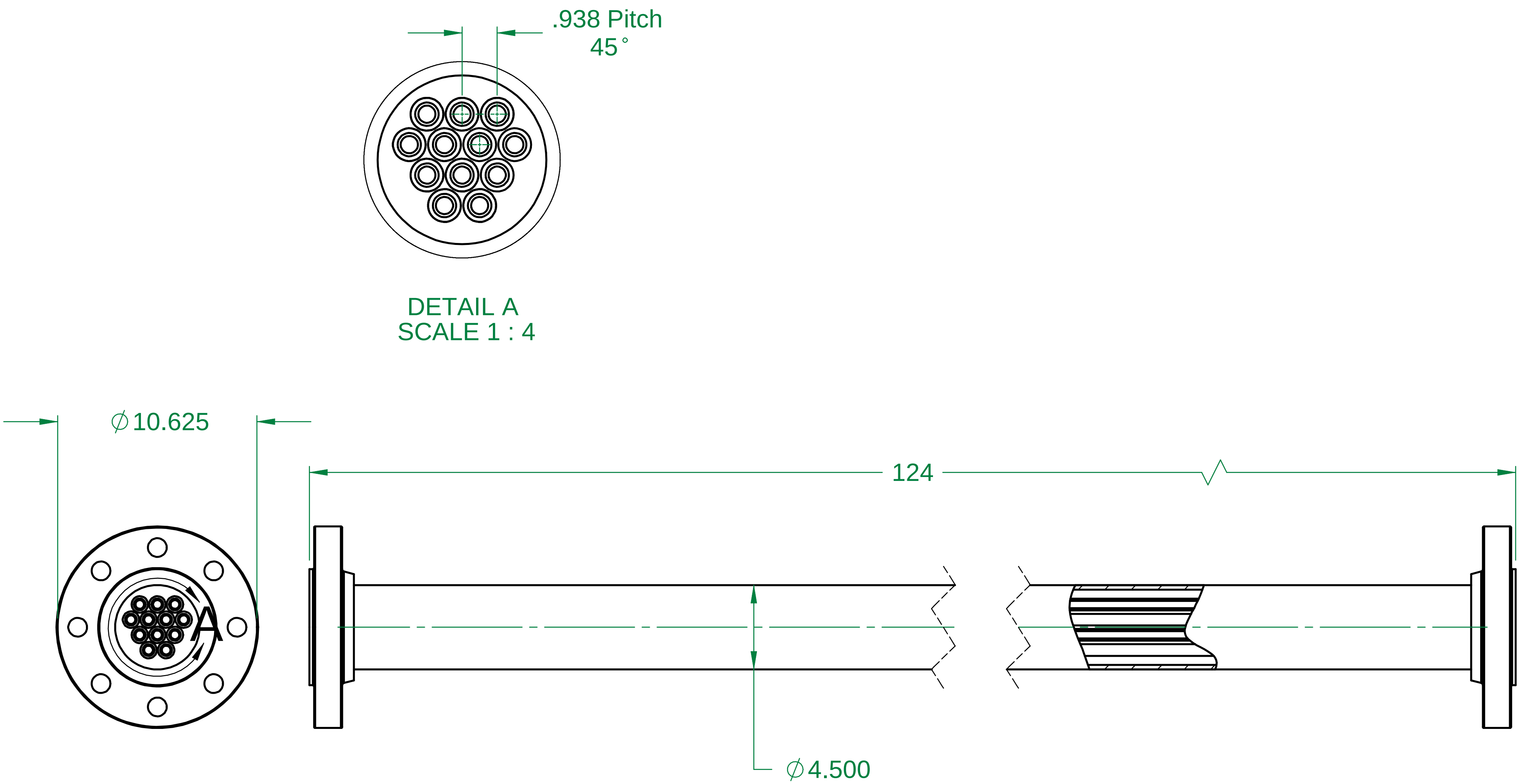
Mesh Refinement Using the Error Function Results for Areas at Discontinuities.
http://www.pveng.com/documents/content_250.pdf

Mesh Refinement Using the Error Function Results for Areas near Discontinuities.
http://www.pveng.com/documents/content_251.pdf

Error Plots for Bolt Heads and Surface to Surface Contacts Areas.
http://www.pveng.com/documents/content_248.pdf

FEA Software Validation - A comparison to theoretical results.
http://www.pveng.com/documents/content_249.pdf

CosmosWorks Validation Examples.
http://www.pveng.com/documents/content_247.pdf



REV	DESCRIPTION	DATE	APVD
REVISIONS			

UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN INCHES

INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

TOLERANCES APPLY AS SHOWN BELOW

0 PL DEC	± 0.2
1 PL DEC	± 0.1
2 PL DEC	± 0.01
3 PL DEC	± 0.005
ANGLES	± .1°
SURFACE ROUGHNESS	32 µ in

THIRD ANGLE PROJECTION

MATERIAL: -

FINISH:

SolidWorks MAINTAINED DATA CHANGES SHALL BE INCORPORATED ELECTRONICALLY BY THE DESIGN ACTIVITY

PROPRIETARY

CUSTOMER: XYZ

PROJECT: PVE-3377

DRAWN BY	DATE
C. Moore	4/1/09
CHECKED BY	DATE
APPROVED	DATE

PVEng
Pressure Vessel Engineering
120 Randall Drive, Suite B Waterloo, Ontario N2V 1C6
P: 519-880-9808 F: 519-880-9810
http://www.pveng.com info@pveng.com

TITLE

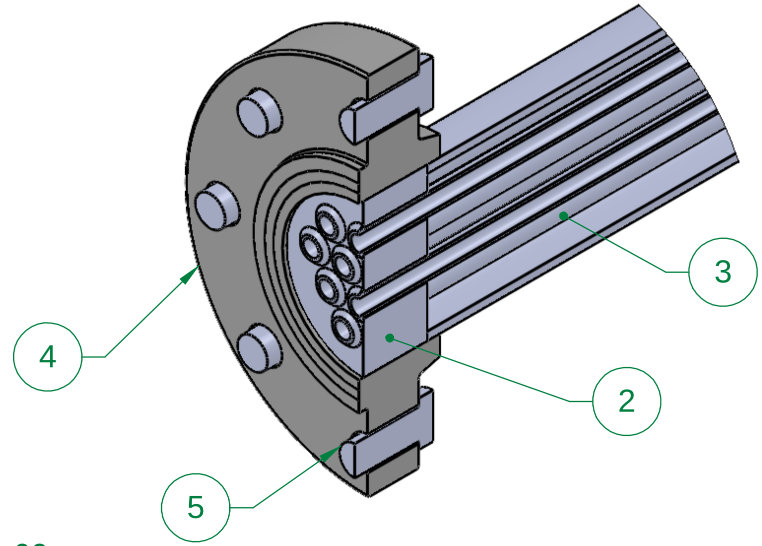
Fixed Tubesheet Heat Exchanger

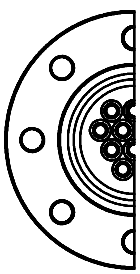
SIZE	DRAWING NO	REVISION
A	PVE-3377	0

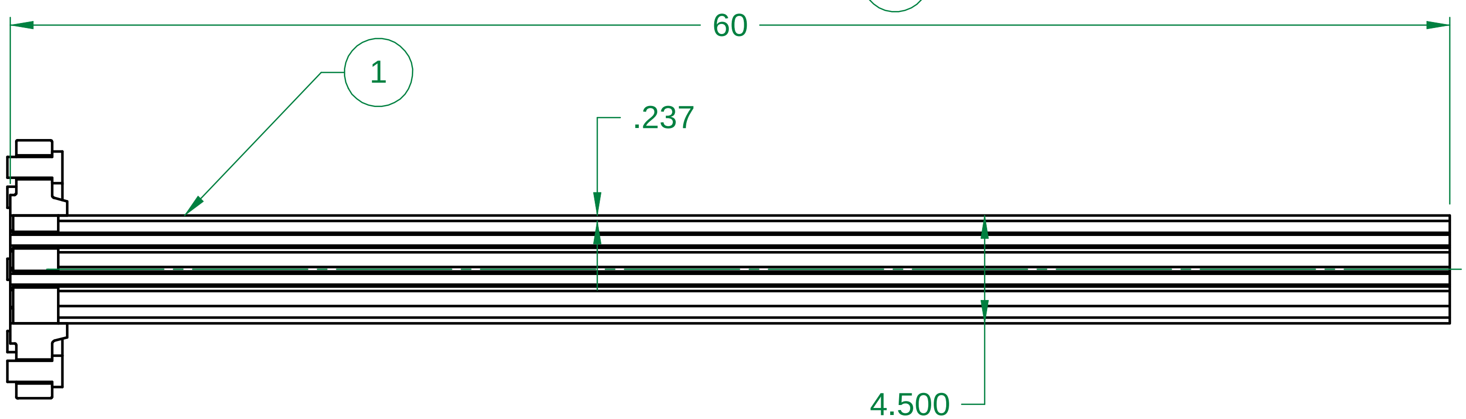
SCALE 1:8 | WEIGHT 76.613 lbs | SHEET 1 OF 2

BOM Table

Item NO.	Description	Qty	Material
1	Shell	1	SA-333 Gr 6
2	Tubesheet	2	SA-516 Gr 70
3	Tubes	12	SA-334 Gr 6
4	Flange - RFSO ASME B16.5	2	SA-105
5	Bolt: 7/8-9 UNC	8	SA-193 B7







REV	DESCRIPTION	DATE	APVD

REVISIONS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES

INTERPRET DIMENSIONS AND TOLERANCES
PER ASME Y14.5M-1994

TOLERANCES APPLY AS SHOWN BELOW

0 PL DEC	± 0.2
1 PL DEC	± 0.1
2 PL DEC	± 0.01
3 PL DEC	± 0.005
ANGLES	± .1°
SURFACE ROUGHNESS	32 µ in

THIRD ANGLE PROJECTION

MATERIAL:
-

FINISH:

SolidWorks MAINTAINED DATA
CHANGES SHALL BE INCORPORATED
ELECTRONICALLY BY THE DESIGN ACTIVITY

CUSTOMER
XYZ

PROJECT
PVE-3377

DRAWN BY	DATE
C. Moore	4/1/09
CHECKED BY	DATE
APPROVED	DATE

PVEng
Pressure Vessel Engineering
120 Randall Drive, Suite B Waterloo, Ontario N2V 1C6
P: 519-880-9808 F: 519-880-9810
http://www.pveng.com info@pveng.com

TITLE
Fixed Tubesheet Heat Exchanger

SIZE
A

DRAWING NO
PVE-3377

REVISION
0

SCALE
1:8

WEIGHT
76.613 lbs