Reinforcement of opening - Nozzle #14

Asme VIII Div. 2 Ed. 2007 - Metric Units

Design temperature	T =	250 °C	482 °F

Shell material: **SA-516 70 - Plate**

Nozzle material: **SA-106 B - Smls. pipe**

Pad material: **SA-516 70 - Plate**

Shell allowable stress:	S =	144 MPa	20885.43 psi
Shell allowable stress at room temperature:	S_0 =	175 MPa	253816 psi
Nozzle allowable stress:	Sn =	132 MPa	19144.98 psi
Nozzle allowable stress at room temperature:	Sn_0 =	161 MPa	2335107 psi
Pad allowable stress:	Sp =	144 MPa	20885.43 psi
Pad allowable stress at room temperature:	Sp_0 =	175 MPa	253816 psi
Internal pressure	Pi =	2.5 MPa	362.59 psi
Static head	Ph =	0 MPa	0 psi
Calculation pressure	$P = Pi + Ph$ =	2.5 MPa	362.59 psi
Shell thickness	t =	18 mm	0.709 in
Nozzle inside diameter	d =	304.81 mm	12 in
Nozzle outside diameter	OD =	323.85 mm	12.75 in
Nozzle joint efficiency	E =	1	
Nozzle corrosion allowance	c_n =	1 mm	0.039 in
Nozzle wall undertolerance	c_n' =	1.19 mm	0.047 in
Nozzle position:			Hillside / Axial
Nozzle connection:			Set in
Nozzle thickness	tn =	9.52 mm	0.375 in
Width of the reinforcing pad	W =	150 mm	5.906 in
Thickness of the reinforcing pad	te =	18 mm	0.709 in
Nozzle inside radius	$Rn = d/2 + c_n + c_n'$ =	154.6 mm	6.086 in
Shell inside diameter	Di =	1500 mm	59.055 in
Effective radius of the shell	$Reff = 0.5 \cdot Di + c + c'$ =	751.25 mm	29.577 in
Weld leg length of the outside nozzle fillet weld	$L41$ =	10 mm	0.394 in
Weld leg length of the pad to vessel fillet weld	$L42$ =	10 mm	0.394 in
Weld leg length of the inside nozzle fillet weld	$L43$ =	0 mm	0 in
	$LR1 = \sqrt{(Reff \cdot (t-c-c') + W}$ =	262.18 mm	10.322 in
	$LR2 = \sqrt{((Reff+t-c-c')(t-c-c'+te))}$ =	163.36 mm	6.432 in
	$LR3 = 2Rn$ =	309.19 mm	12.173 in
Effective length along the vessel wall	$LR = min[L_{R1}, L_{R2}, L_{R3}$ =	163.36 mm	6.432 in
	$LH1 = t-c-c' + te + \sqrt{(Rn \cdot (tn-cn-cn'))}$ =	68.41 mm	2.693 in
	$LH2 = L_{pr1} + t-c-c'$ =	400 mm	15.748 in
	$LH3 = 8 \cdot (t-c-c' + te)$ =	278 mm	10.945 in
Effective length along the nozzle wall outside the vessel	$LH = Min[L_{H1}, L_{H2}, L_{H3}]$ =	68.41 mm	2.693 in
Effective thickness	$teff = (t-c-c')(((t-c-c') \cdot LR + A5 \cdot frp)/((t-c-c') \cdot LR))$ =	33.28 mm	1.31 in
	$LI1 = \sqrt{(Rn \cdot (tn-cn-cn'))}$ =	0 mm	0 in
	$LI2 = L_{pr2}$ =	0 mm	0 in
	$LI3 = 8 \cdot (t-c-c' + te)$ =	0 mm	0 in
Effective length along the nozzle wall inside the vessel	$LI = Min[LI1, LI2, LI3]$ =	0 mm	0 in
	$dn = 2R_n$ =	309.19 mm	12.173 in
	$\lambda = min[\{(dn+tn-cn-cn')/(\sqrt{((Di+teff) \cdot teff)})\}, 12]$ =	1.4	
Area contributed by the vessel wall	$A1 = (t-c-c') \cdot LR \cdot max[(\lambda/5)^{0.85}, 1]$ =	2736.4 mm²	4.24 in²
Area contributed by the nozzle outside the vessel wall	$A2 = (tn-cn-cn') \cdot LH$ =	5015 mm²	0.78 in²
Nozzle material factor	$frn = Sn / S$ =	0.917	

Pad material factor	$frp = S_p / S =$	1	
Area contributed by the nozzle inside the vessel wall	$A3 = (t_n-2c_n-c_n')\cdot LI =$	0 mm²	0 in²
Area contributed by the outside nozzle fillet weld	$A41 = 0.5\cdot L_{41}^2 =$	50 mm²	0.08 in²
Area contributed by the pad to vessel fillet weld	$A42 = 0.5\cdot L_{42}^2 =$	50 mm²	0.08 in²
Area contributed by the inside nozzle fillet weld	$A43 = 0.5\cdot L_{43}^2 =$	0 mm²	0 in²
	$A5a = W\cdot t_e =$	2700 mm²	4.19 in²
	$A5b = LR\cdot t_e =$	2940.6 mm²	4.56 in²
Area contributed by the reinforcing pad	$A5 = min[A5_a, A5_b] =$	2700 mm²	4.19 in²
Total area	$AT = A1+frn(A2+A3)+A41+A42+A43+frp\cdot A5 =$	5996 mm²	9.29 in²
Axial offset	$Dx =$	400 mm	15.748 in
	$\theta 1 = Acos(Dx / Reff) =$	57.83 °	57.83 °
	$\theta 2 = Acos((Dx+Rn)/ Reff) =$	42.42 °	42.42 °
Radius of the nozzle opening	$Rnc = max[Reff\cdot(\theta_1-\theta_2)/2, Rn] =$	154.6 mm	6.086 in
Nozzle radius for force calculation	$Rxn = (tn-cn-cn')/ ln[(Rn+tn-cn-cn')/Rn] =$	158.23 mm	6.23 in
Shell radius for force calculation	$Rxs = teff / ln[(Reff+teff)/Reff] =$	767.77 mm	30.227 in
Force from internal pressure in the nozzle	$fN = P\cdot Rxn\cdot(LH-t+c+c') =$	20437 N	4594.36 lbf
Force from internal pressure in the shell	$fS = P\cdot Rxs\cdot(LR+tn-cn-cn') =$	327635 N	73655.25 lbf
Discontinuity force from internal pressure	$fY = P\cdot Rxs\cdot Rnc =$	296733 N	66708.21 lbf
Average primary membrane stress	$\sigma avg = (fN + fS + fY)/ AT =$	107.539 MPa	15597.14 psi
General primary membrane stress	$\sigma circ = P \cdot Rxs / teff =$	57.679 MPa	8365.68 psi
Maximum local primary membrane stress	$PL=max[(2\sigma_{avg}-\sigma_{circ}),\sigma_{circ}] =$	157.398 MPa	22828.6 psi
Internal pressure allowable stress	$Sallow = 1.5SE =$	198 MPa	28717.46 psi
			PL ≤ Sallow Ok
Area resisting pressure	$Ap = Rxn\cdot(LH-t+c+c')+Rxs\cdot(LR+tn-cn-cn'+Rnc) =$	2579218 mm²	399.78 in²
Maximum allowable working pressure	$Pmax =$	3.142 MPa	455.65 psi

Strength of nozzle attachment welds

Discontinuity force factor	$ky = (Rnc + tn - cn - cn')/ Rnc =$	1.047	
Pad to shell weld length	$L\tau p = \pi/2\cdot\sqrt{((Rnc+tn-cn-cn'+W)^2+(Rn+tn-cn-cn'+W)^2/2)} =$	489.97 mm	19.29 in
Nozzle to shell weld length	$L\tau = \pi/2\cdot\sqrt{((Rnc+tn-cn-cn')^2+(Rn+tn-cn-cn')^2/2)} =$	254.35 mm	10.014 in
Throat dimension of the outside nozzle fillet weld	$L41T = 0.7071 \cdot L41 =$	7.07 mm	0.278 in
Throat dimension for the pad to vessel fillet weld	$L42T = 0.7071 \cdot L42 =$	7.07 mm	0.278 in
Throat dimension for inside nozzle fillet weld	$L43T = 0.7071 \cdot L43 =$	0 mm	0 in
Welds force	$fwelds = min[fY\cdot ky, 1.5Sn(A2+A3)] =$	99290 N	2232132 lbf
Discontinuity force	$fws = (fwelds\cdot ky\cdot(t-c-c')\cdot S)/((t-c-c')\cdot S+te\cdot Sp) =$	50129 N	11269.33 lbf
Discontinuity force	$fwp = (fwelds\cdot ky\cdot te\cdot Sp)/((t-c-c')\cdot S+te\cdot Sp) =$	53869 N	12110.33 lbf
Shear stress	$\tau 1 = fws/(L\tau\cdot(0.6\cdot tw1+0.49\cdot L43T)) =$	19.61 MPa	2844.24 psi
Shear stress	$\tau 2 = fwp/(L\tau\cdot(0.6\cdot te+0.49\cdot L41T)) =$	14.847 MPa	2153.4 psi
Shear stress	$\tau 3 = fwp/(L\tau p\cdot 0.49\cdot L42T) =$	31.732 MPa	4602.32 psi
Shear stress	$\tau n = (PL-P\cdot Rn/(tn-cn-cn'))\cdot te/(1.4\cdot(tn-cn-cn')) =$	183.597 MPa	26628.53 psi
			Max[τ1,τ2,τ3] ≤ S Ok
			τn ≤ 1.5·Sn Ok

Hydrostatic test

Shell allowable stress:	Sh =	247 MPa	35824.31 psi
Nozzle allowable stress:	Shn =	228 MPa	33068.6 psi
Pad allowable stress:	Shp =	247 MPa	35824.31 psi
Hydraulic test pressure	Pt =	3.791 MPa	549.9 psi
Static head	Ph =	0.011 MPa	1.62 psi
Calculation pressure	$P = Pt + Ph$ =	3.803 MPa	55152 psi
Nozzle thickness	tn =	9.52 mm	0.375 in
Width of the reinforcing pad	W =	150 mm	5.906 in
Thickness of the reinforcing pad	te =	18 mm	0.709 in
Nozzle inside radius	$Rn = d/2 + cn'$ =	153.6 mm	6.047 in
Shell inside diameter	Di =	1500 mm	59.055 in
Effective radius of the shell	$Reff = 0.5 \cdot Di + c'$ =	750.25 mm	29.537 in
Weld leg length of the outside nozzle fillet weld	$L41$ =	10 mm	0.394 in
Weld leg length of the pad to vessel fillet weld	$L42$ =	10 mm	0.394 in
Weld leg length of the inside nozzle fillet weld	$L43$ =	0 mm	0 in
	$LR1 = \sqrt{(Reff \cdot (t-c') + W}$ =	265.4 mm	10.449 in
	$LR2 = \sqrt{((Reff+t-c')(t-c'+te))}$ =	165.7 mm	6.524 in
	$LR3 = 2Rn$ =	307.19 mm	12.094 in
Effective length along the vessel wall	$LR = min[LR1, LR2, LR3]$ =	165.7 mm	6.524 in
	$LH1 = t-c' + te + \sqrt{(Rn \cdot (tn-cn'))}$ =	7152 mm	2.816 in
	$LH2 = Lpr1 + t-c'$ =	400 mm	15.748 in
	$LH3 = 8 \cdot (t-c' + te)$ =	286 mm	1126 in
Effective length along the nozzle wall outside the vessel	$LH = Min[LH1, LH2, LH3]$ =	7152 mm	2.816 in
Effective thickness	$teff = (t-c')(((t-c') \cdot LR+A5 \cdot frp)/((t-c') \cdot LR))$ =	34.04 mm	1.34 in
	$LI1 = \sqrt{(Rn \cdot (tn-cn'))}$ =	0 mm	0 in
	$LI2 = Lpr2$ =	0 mm	0 in
	$LI3 = 8 \cdot (t-c' + te)$ =	0 mm	0 in
Effective length along the nozzle wall inside the vessel	$LI = Min[LI1, LI2, LI3]$ =	0 mm	0 in
	$dn = 2Rn$ =	307.19 mm	12.094 in
	$\lambda = min[\{(dn+tn-cn')/(\sqrt{((Di+teff) \cdot teff)})\}, 12]$ =	1.38	
Area contributed by the vessel wall	$A1 = (t-c') \cdot LR \cdot max[(\lambda/5)^{0.85}, 1]$ =	29411 mm²	4.56 in²
Area contributed by the nozzle outside the vessel wall	$A2 = (tn-cn') \cdot LH$ =	595.8 mm²	0.92 in²
Nozzle material factor	$frn = Sn / S$ =	0.923	
Pad material factor	$frp = Sp / S$ =	1	
Area contributed by the nozzle inside the vessel wall	$A3 = (tn-cn') \cdot LI$ =	0 mm²	0 in²
Area contributed by the outside nozzle fillet weld	$A41 = 0.5 \cdot L41^2$ =	50 mm²	0.08 in²
Area contributed by the pad to vessel fillet weld	$A42 = 0.5 \cdot L42^2$ =	50 mm²	0.08 in²
Area contributed by the inside nozzle fillet weld	$A43 = 0.5 \cdot L43^2$ =	0 mm²	0 in²
	$A5a = W \cdot te$ =	2700 mm²	4.19 in²
	$A5b = LR \cdot te$ =	2982.6 mm²	4.62 in²
Area contributed by the reinforcing pad	$A5 = min[A5a, A5b]$ =	2700 mm²	4.19 in²
Total area	$AT = A1+frn(A2+A3)+A41+A42+A43+frp \cdot A5$ =	62911 mm²	9.75 in²
Axial offset	Dx =	400 mm	15.748 in
	$\theta 1 = Acos(Dx / Reff)$ =	57.78 °	57.78 °
	$\theta 2 = Acos((Dx+Rn) / Reff)$ =	42.45 °	42.45 °
Radius of the nozzle opening	$Rnc = max[Reff \cdot (\theta 1-\theta 2)/2, Rn]$ =	153.6 mm	6.047 in
Nozzle radius for force calculation	$Rxn = (tn-cn') / ln[(Rn+tn-cn')/Rn]$ =	157.72 mm	6.21 in
Shell radius for force calculation	$Rxs = teff / ln[(Reff+teff)/Reff]$ =	767.15 mm	30.203 in
Force from internal pressure in the nozzle	$fN = P \cdot Rxn \cdot (LH-t+c')$ =	32249 N	7249.78 lbf

Force from internal pressure in the shell	$fS = P \cdot R_{xs} \cdot (LR + t_n - c_n') =$	507667 N	114128.18 lbf
Discontinuity force from internal pressure	$fY = P \cdot R_{xs} \cdot R_{nc} =$	448060 N	100727.84 lbf
Average primary membrane stress	$\sigma avg = (fN + fS + fY) / AT =$	157.044 MPa	22777.3 psi
General primary membrane stress	$\sigma circ = P \cdot R_{xs} / t_{eff} =$	85.686 MPa	12427.7 psi
Maximum local primary membrane stress	$PL = max[(2\sigma_{avg} - \sigma_{circ}), \sigma_{circ}] =$	228.402 MPa	33126.89 psi
Internal pressure allowable stress	$Sallow = 1.5SE =$	342 MPa	49602.89 psi
			PL ≤ Sallow Ok
Maximum allowable working pressure	$Pmax =$	5.683 MPa	824.2 psi

Strength of nozzle attachment welds

Discontinuity force factor	$ky = (Rnc + t_n - c_n') / Rnc =$	1.054	
Pad to shell weld length	$L\tau p = \pi/2 \cdot \sqrt{((R_{nc} + t_n - c_n' + W)^2 + (R_n + t_n - c_n' + W)^2/2)} =$	489.97 mm	19.29 in
Nozzle to shell weld length	$L\tau = \pi/2 \cdot \sqrt{((R_{nc} + t_n - c_n')^2 + (R_n + t_n - c_n')^2/2)} =$	254.35 mm	10.014 in
Throat dimension of the outside nozzle fillet weld	$L41T = 0.7071 \cdot L41 =$	7.07 mm	0.278 in
Throat dimension for the pad to vessel fillet weld	$L42T = 0.7071 \cdot L42 =$	7.07 mm	0.278 in
Throat dimension for inside nozzle fillet weld	$L43T = 0.7071 \cdot L43 =$	0 mm	0 in
Welds force	$fwelds = min[fY \cdot ky, 1.5Sn(A2+A3)] =$	203749 N	45804.51 lbf
Discontinuity force	$fws = (f_{welds} \cdot ky \cdot (t - c') \cdot S) / ((t - c') \cdot S + te \cdot Sp) =$	106648 N	23975.48 lbf
Discontinuity force	$fwp = (f_{welds} \cdot ky \cdot te \cdot Sp) / ((t - c') \cdot S + te \cdot Sp) =$	108150 N	24313.16 lbf
Shear stress	$\tau 1 = fws / (L\tau \cdot (0.6 \cdot t_{w1} + 0.49 \cdot L43T)) =$	39.37 MPa	5710.2 psi
Shear stress	$\tau 2 = fwp / (L\tau \cdot (0.6 \cdot te + 0.49 \cdot L41T)) =$	29.808 MPa	4323.24 psi
Shear stress	$\tau 3 = fwp / (L\tau p \cdot 0.49 \cdot L42T) =$	63.706 MPa	9239.79 psi
Shear stress	$\tau n = (PL - P \cdot R_n / (t_n - c_n')) \cdot te / (1.4 \cdot (t_n - c_n')) =$	244.311 MPa	35434.37 psi
			Max[τ1,τ2,τ3] ≤ S Ok
			τn ≤ 1.5·Sn Ok