Design and Analysis of Nozzle Junction

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Abstract: ***In various tanks, pressure vessels as well as heat exchanger, nozzle is very important & serves as inlet & outlet for process fluid & cooling fluid. Number of nozzle could be one or more depending upon requirement but it tends to lower strength of parent component, which may lead to failure of vessel. In this paper, nozzle is used for inlet & outlet of propane gas as well as cooling water. In order to improve strength at nozzle shell junction, reinforcement pad is used sometimes to prevent failure. So, here nozzle to shell junction is analyzed by considering various areas which affect strength of junction(either improve or degrade strength) & it is predicted that pad is required or not & if pad is required then its dimensions like thickness & diameter is calculated based on ASME Codes. In addition, finite element analysis of junction is done to check stress induced at the junction.***

Keywords: Hexahedron & Tetrahedron meshing**,** Finite Element Analysis, Nozzle Junction, Heat Exchanger

1. Introduction

Pressure vessels are widely applied in many various branches of industry such as chemical and petroleum machine-building, nuclear and power engineering gas, oil and oil-refining industries, aerospace techniques, etc for various purposes. As the name implies these are very important components of processing equipment. Nozzles or various opening are necessary in the pressure vessels or heat exchanger to satisfy certain requirements such as inlet or outlet connection, manholes, vents & drains etc. Welded nozzles connecting a pressure vessel to piping can be placed on the cylindrical shell or channel and the heads of the vessel or tank. [1-2]

Geometrical parameters of nozzle connections may significantly vary even in one pressure vessel. These nozzles cause geometric discontinuity of the vessel wall. So a stress concentration is created around the opening. The junction may fail due to these high stresses. Hence a detailed analysis is required. One of the parts of overall structural analysis for nozzle connections is the stress analysis of two intersecting shells [4, 6]. Due to different loadings applied to these structures, a local stress state of nozzle connection characterized by high stress concentration occurs in intersection region. Internal pressure is primary loading used in the structure analysis for determination of main vessel-nozzle connections. However the effect of external forces and moments applied to nozzle should be taken into consideration in addition to the stresses caused by the internal pressure. External loading usually are imposed by a piping system attached to the nozzle. Values of the loads & moments are calculated by an analysis of piping system [9]

Many works including analytical, experimental & numerical investigations have been devoted to the stress analysis of nozzle connections in pressure vessels, subjected to different external loadings. The codes suggest a procedure to design the junction, but do not provide any methodology to calculate the extended and magnitude of these high stresses. The available analytical solution WRC-107 is limited to simple geometries [5-8]. So, there is need to carry out a detailed finite element analysis of the junction to calculate stresses at the junction & both in the vessel & in the nozzle. ANSYS package is used as a finite element tool [11]

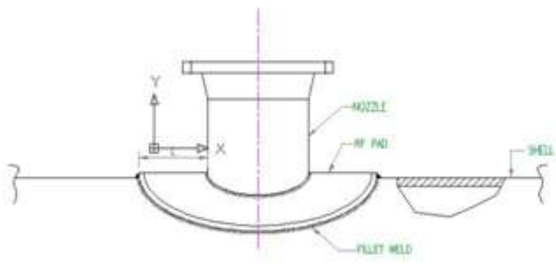

Figure 1: Nozzle attached to shell with pad

Nozzle is a pipe or tube of constant or varying cross sectional area with one flange attached to it, and can be used to direct the fluid. It is frequently used to control the flow rate, speed, direction, mass, shape and the pressure of the stream that emerges from them. In case of heat exchanger, the main use of nozzle is to serve as inlet, outlet or drain part for working fluids. The different nozzle types are:

1) Radial nozzle [7]: A nozzle whose axis is perpendicular in orientation to the connecting parts mainly shell or head is called Radial nozzle.
2) Offset nozzle [7]: A nozzle which has distance from the orientation axis line is called o set nozzle.
3) Angular nozzle [7]: A nozzle which is at some angle from orientation line is called angular nozzle.

2. Objectives of Work

- With the help of CAD software to Create 3D model of pressure vessel & nozzle and to carried out study for given condition of pressure vessel.
- For the purpose of internal design model of nozzle and pressure are analyzed with given conditions.
- FEA analysis is performed according to ASME code Section VIII, Division 2.
- To find out the value of stress in the Nozzle N-12 of liquid Carbon drain Pressure Vessel.

3. Analytical Methodology

The input parameters for left nozzle are as below:
Material: SA-106 B [7]
Allowable stress(S) =137.89 MPa [8]
Shell Diameter (Ds) =600 mm
Wall thickness of shell (Nt) = 9.5 mm [10]
Required wall thickness of wall = 6.9 mm [1]
Internal pressure (P) = 1.78 N/ mm^2
The diameter of nozzle and its outward & inward projection, nominal and internal thickness can be found by following equations.

$$m = \rho av$$

$$lp = \frac{p}{(d+2c)(tn-c)}$$

$$d = Do - 2tn$$

$$ti = N\ wall - 2c$$

Table 2: Nozzle Geometry

Do (mm)	Nwall (mm)	Lp (mm)	Ip (mm)	tn (mm)	ti (mm)	d (mm)
273	9.27	40.21	29	6.27	3.27	260.4

Where,
S= Allowable stress.
Ds= Shell Diameter.
Nt= Wall thickness of shell.
Treq= Required wall thickness of wall.
P= Internal pressure

As per the performance requirements, one or more nozzles are provided at particular location for inlet, outlet or draining of fluids. So, to attach nozzle, hole is made in parent section, whether shell or head. Depending on area removed from section, due to stress-concentration, equipment may fail at this junction. i.e. nozzle to shell junction, nozzle to head junction or any other junction. This failure is dependent on the area available after removal of material as per the size of nozzle. Now, whether the available area is sufficient or not, needs to check and if not found sufficient to withstand stresses, area should be provided in form of reinforcement pad.[5]

The below mentioned formulas [5] gives information whether reinforcement should be provided or not and in specify the amount of reinforcement.
A =Total cross-sectional area removed due to nozzle or required to be reinforced.
A1 =Area in excess thickness in the vessel wall available for reinforcement.
A2 =Area in excess thickness in the nozzle wall available for reinforcement.
A3 =Area available for reinforcement when the nozzle extends inside the vessel wall.
A41 =Cross-sectional area of welds available on outside projection of nozzle.
A42 =Cross-sectional area of welds available on inside projection of nozzle.

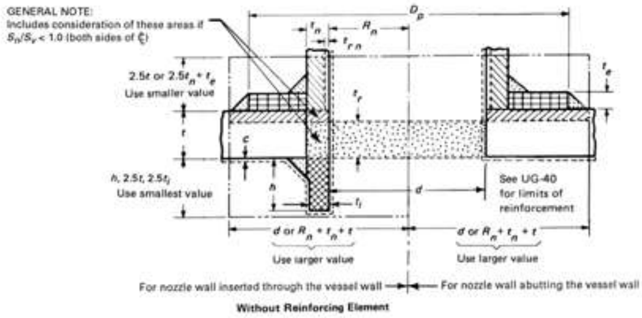

Figure 2: Nomenclature for reinforced openings [5]

A. Area removed due to nozzle opening:
As we know the section of shell is same as pipe and to incorporate nozzle in this pipe kind of section, pipe is cut out as per the outside diameter of nozzle. This creates a hole in the pipe and there is reduction in area leading to stress concentration, due to which, the strength of the pipe is lowered. So, first of all we need to find how much is the reduction in strength due to hole? As it depends on area removed as discussed above, First the removed area is evaluated from equation (1), as per UG-37[5].

$$A = dTreq + 2tnTreq.F(1-fr1) \quad (1)$$

Where,
d = Nozzle inside diameter.
Treq = Required thickness of shell.
tn = Nominal wall thickness.
F = Correction factor which compensates for the variation on internal pres-sure stresses on different planes with respect to axis of vessel.
fr1= strength reduction factor = Sn/Sv
Sn= Allowable stress in nozzle.
Sv= Allowable stress in vessel.

B. Area available due to excess thickness of vessel Wall:
After making hole in pipe, still some excess area is always present in terms of additional thickness [1] provided in vessel wall, which increase strength. The strength available in this area to support the junction is evaluated. So, among various area available one of which is the area provided by additional thickness of shell above the minimum required thickness, which can be found as per UG-37[5] from equation (2) and (3) and maximum amongst two is selected.

$$A_1 = d\,(E_1t - FT_{req}) - 2tn(E_1t - FT_{req})\,(1 - fr_1) \quad (2)$$

$$A_1 = 2(t + tn)\,(E_1\,t - FT_{req}) - 2\,tn(E_1\,t - FT_{req})\,(1 - fr_1) \quad (3)$$

C. Area in excess thickness in the nozzle wall available for reinforcement:
When nozzle extends above vessel wall then same as shell, nozzle is provided with a thickness above the minimum required [2], which will act as reinforcement. The area which it contributes can be found by equation (4) & (5) based on UG 37[5].

$$A_2 = 5(tn - T_{req})\,fr_2t \quad (4)$$

$$A_2 = 5(tn - T_{req})\,fr_2t_n \quad (5)$$

D. Area available for reinforcement when the nozzle extends inside vessel wall
If nozzle extends below the inside diameter of shell, additional thickness provided in nozzle pipe gives some

strength to nozzle-shell junction. So, the area contributed by it to increase joint strength, can be found by following equations based on UG-37[5].

$A3 = n_t t i f r_2$ (6)

$A3 = t i t i f r_2$ (7)

$A3 = 5 l p t i f r_2$ (8)

E.Cross-sectional area of welds available for reinforcement

The nozzle to shell junction is secured by fillet welding, although proper radiography can't be done to check validity or strength of joint but additional material provided in welding also contributes as additional area to increase the strength. Its contribution in the areas giving additional reinforcement can be found from equations (9) and (10) based on UG-37[5]

A41= leg2 fr3 (9)

A41= leg2 fr4 (10)

F. Cross-sectional area of material added -reinforcement:

If the sum of strength provided by the above mentioned areas is not enough, to maintain the integrity and strength of joint, more additional area is provided by means of reinforcement pads. These pads provide enough strength to prevent the rupture. As we know, area of pad comprises of diameter and thickness. So, based on required area, thickness and diameter, pad is fixed by using the equation (11) following UG-37[5].

$A5 = [(Dp - d - 2tn)te\ fr_4]$ (11)

Result Table:

A	A1	A2	A3	A41	A42	A5
1642	832	166	53.46	49	16	526

Based on above areas we got to know that, the area required for reinforcement in terms of reinforcement pad is 383.7 mm^2 or more, which needs to be provided for successful operation of nozzle.

To, provide reinforcing area reinforcement pad of 543 mm outer diameter is used & thickness is determined.

4. 3D Model

The 3D solid work model of this heat Exchanger is created in CAD software Solid works as shown in figure.

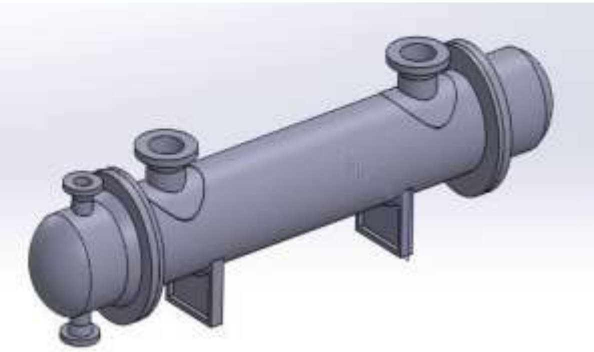

Figure 3: 2D solid work model of Heat Exchanger with fitted nozzle

5. Mesh Model

Meshing is nothing but discretization of object into the small number of parts called as elements. Fig. shows 3D meshed model of Heat Exchanger.

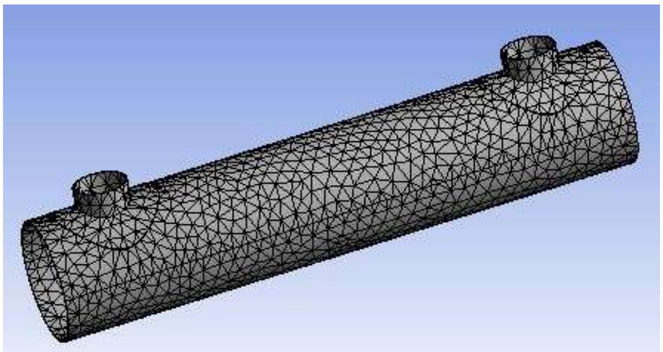

Figure 4: 3D ANSYS Meshed Model

6. Boundary Conditions

For evaluating stresses, it is fixed at both the ends and junctions where welding takes place. An internal pressure of 1.78 $N/mm^2$is applied and this pressure is normal to the shell inner diameter i.e. radially outwards.

7. Static Structural Analysis

Static analysis is used to find parameters like displacements, stresses, trains, and forces in structures or components which is caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. Here, load given to structure is internal pressure and equivalent stress (Von misses plot) is as shown in fig.

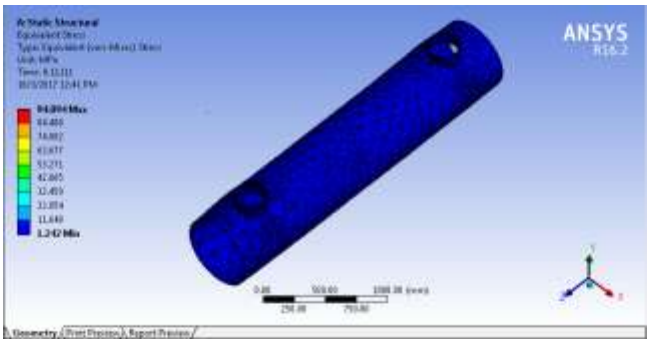

Figure 6: 3D ANSYS result

From above stress plot, it is found that the provided Reinforcement Pad is sufficient to maintain the stresses well below the limit. Induced stress is 6983 Psi or 62 Mpa where as allowable stress is 138 Mpa. [8] So junction will be safe.

8. Result

By using Analytical Methodology we can easily calculate the exact numerical value of induced stress in nozzle junction of a vessel. With the help of numerical equation, mathematical results of a Heat Exchanger are compared with FEA analysis results. Thus, FEA Analysis is used for evaluating the stress level in the nozzle of Heat Exchanger with more accuracy, which is indicating that induced stress 6983 Psi or 62 MPa, which is well below allowable stress.

9. Conclusion

In this way calculations can be performed on nozzle fitted on pressure vessel or Heat Exchanger. Analytical Methodology is followed as per the ASME code & from this analysis it is concluded that Ana1ytical calculations & FEA Analysis results are approximately same. From this analysis, the mechanical design of a Nozzle & Heat Exchanger junction can be easily verified by a third party organization to ensure the quality of a pressure vessel or Heat Exchanger junction.

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Author Profile

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