Stress Analysis of Different Reinforcement PAD for Nozzle Opening in Pressure Vessel

Jargal Faisal M.
P.G. Student
Department of Mechanical Engineering
SVMIT – Bharuch

B. C. Patel
Assistant Professor
Department of Mechanical Engineering
SVMIT – Bharuch

M. A. Jamnu
Assistant Professor
Department of Applied Mechanics
Government Engineering College-Godhra

R. A. Mistry
Deputy General Manager
Essar Learning Centre, Essar Steel India Ltd.,
Hazira, Surat

Abstract

This paper presents the comparative stress analysis of pressure vessels which are subjected to internal fluid pressure. The area of shell wall near nozzle opening is seriously affected due to stress concentration which may cause the failure of pressure vessels. To minimize the stress concentration conventionally circular reinforcement pad is provided for shell wall. Depending upon the usage of pressure vessels, too much care is required in analysis of pressure vessels. Here an attempt is made to carryout comparative stress analysis. A pressure vessel having 7700mm internal diameter and 32mm thickness is selected for analysis. Nozzle diameters are taken 600,700,800,900,1000,1100 and 1200mm. CREO PARAMETRIC 3.0 is used to create geometry and ANSYS Workbench has been used for stress analysis. Here analysis is carried out for different models i.e. without reinforcement pad i.e. opening only and with circular as well as elliptical reinforcement pad. Further analysis is carried out for two models having maximum effect of reinforcement pad. A detailed comparative stress analysis has been carried out which shows that if elliptical reinforcement pad is used in place of circular reinforcement pad the saving in area required is about 30% to 50% which eventually reduce the cost of fabrication of pressure vessels.
Keywords: Pressure vessel, Nozzle, Stress concentration, Circular Reinforcement pad, Elliptical Reinforcement pad, Comparative Stress Analysis

I. INTRODUCTION

Pressure vessels are very important structures for different industries as they are used as industrial compressed receiver or storage tanks. They are subjected to high pressures & temperatures of constant or of cycling nature, the fluid being stored may undergo a change of state inside the pressure vessel. So, the analysis of pressure vessels requires great care because rupture of pressure vessels may result in loss of life and property.

A. *Stress Concentration:*

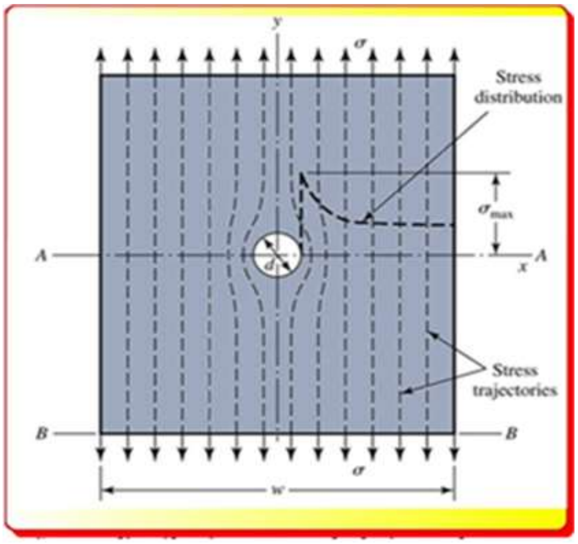


Fig. 1: Stress distribution near a hole

The cylindrical shell which is subjected to uniform pressure is subjected to non-uniform pressure distribution near the openings which are provided for nozzle. The maximum stress is much larger compared to nominal stress. This causes the rise in the stress distribution around the hole, to study the effect of stress concentration and magnitude of localized stresses, a dimensionless factor called Stress Concentration Factor (SCF), is used to calculate the stress rising around hole. This factor is ratio between the maximum average stress generated in the critical zone of discontinuity and the stress produce over the cross section of that zone. K_t as defined by Eq. is used.

$$K_t = \sigma_{max} / \sigma_{nominal}$$

B. *Importance of Pad Reinforcement*

Fig. 2: Reinforcement Pad

To minimize the effect of concentrated stress in the vicinity of hole, an extra hollow plate is provided near the opening, which is called REINFORCEMENT PAD. Generally circular pad is provided for the opening. The stress distribution around the opening is not same in both the directions. So it becomes costly to provide circular pad. An Elliptical pad may be provided to optimize the required reinforcement.

II. BRIEF OVERVIEW OF SOME RESEARCH

The importance of pressure vessels has gained attention of many researches since long. Number of experimental, analytical and software related work has been done. From this Literature following findings have been carried out.

The opening for nozzle creates the geometric discontinuity for the pressure vessels cylinder, which causes the stress distribution alteration near the vicinity of discontinuity in the cylindrical wall. It can be observed that the maximum stress occurs at the junction of Pressure Vessel and the nozzle. High stress concentration is developed at this location due to abrupt change in the geometry and the consequent change in stress flow. The value of stress after opening is different at each and every point in the vicinity of hole.

The stress value depends on the distance from the center as well as on the angle from the polar axis of hole. The raised stress is expressed in terms of stress concentration factor K_t which is the ratio of maximum stress σ_{max} at a point to the nominal tangential stress σ_t. The maximum value of stress is about 3 times the nominal value of stress under the action of the internal pressure i.e the value of K_t is about 3.The effect of opening is observed upto about 3 times the hole diameter from the center of hole along the longitudinal direction of vessel.

It is concluded that the location and size of the hole depends on the size of the cylinder. The optimum location is where the Von Misses stress is minimum and also the hole size should be such that the Von Misses stresses are minimum around the vicinity of the hole. The application of reinforcement reduces the concentrated stress in the affected area. Circular pad reinforcement is generally provided to overcome the stress concentration.

III. OBJECTIVES OF PRESENT WORK

- By reviewing various literature papers of stress concentration on nozzle it is found that various types of analysis and experiments have been carried out by changing nozzle location and shell thickness to find out stress concentration factor. So following objectives were decided for the present study
- To analyze the effect of opening for nozzle in pressure vessels for different diameter of nozzle.
- To investigate the effect of Circular Reinforcement pad on stress concentration for nozzle by varying the nozzle diameter and pad thickness.
- To investigate the effect of Elliptical Reinforcement pad on stress concentration for nozzle by varying the nozzle diameter and pad thickness.
- To carryout comparative analysis for optimization of circular and elliptical reinforcement pad.

IV. MODEL ANALYSIS OF PRESSURE VESSEL

Static analysis has been used to carry out stress analysis. The geometric modeling work has been done in CREO PARAMETRIC 3.0 and the remaining work has been done in ANSYS Work bench.

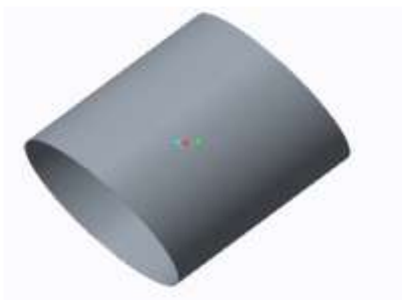
Table – 1
Material Properties

Modulus of elasticity	200×10^3 N/mm^2
Poisson's ratio	*0.3*
Density	7850 Kg/m^3
Yield stress	250 N/mm^2

A. *Concept of modeling shell in ANSYS:*

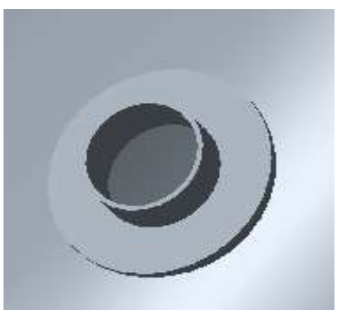
Here for the shell subjected to internal pressure four types of cases are taken into consideration

- CASE – I – Shell without hole
- CASE – II – Shell with hole
- CASE – III – Shell with hole covered with circular pad reinforcement
- CASE – IV – Shell with hole covered with elliptical pad reinforcement



CASE – I – Shell without hole

CASE – II – Shell with hole



CASE – III – Shell with hole covered with circular pad reinforcement

CASE – IV – Shell with hole covered with elliptical pad reinforcement

Fig. 3: Different models of opening in shell wall

Further stress analysis has been carried out for the models in which the effect of pad reinforcement has been encountered maximum. In these analyses along with the above cases the following two cases has been considered for comparative analysis.

- CASE – 1 - Stress analysis in the shell using 28mm thick circular reinforcement pad
- CASE – 2 - Stress analysis in the shell using 28mm thick elliptical reinforcement pad having major to minor axis ratio 2 : 1.25 and 1.5 : 1.25

Further the above models have been verified for stress analysis using different element type.

B. *Modeling Data*

Table – 2
Modeling data

Inside diameter of cylinder	*7700 mm*
Wall thickness of cylinder	*32 mm*
Length of cylinder	*8000 mm*
Half-length of cylinder	*4000 mm*
Diameter of nozzle	*600mm,700mm,800mm,900mm,1000mm,1100mm,1200mm*
Inside height of nozzle	*300mm*
Design pressure(Internal)	*0.517 MPa*

V. STRESS ANALYSIS IN SHELL WALL FOR DIFFERNT CASES

A. Stress Analysis in the Shell Wall Without Hole

$\sigma_{nominal}$ = 80.67 MPa

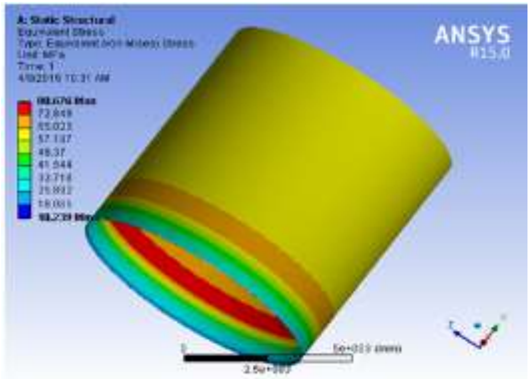


Fig. 4: Model of Pressure Vessel without Hole

B. Stress analysis in the Shell Wall with Different Sizes of Hole for Nozzle

1) Calculation for Stress Concentration for different nozzle diameter

a) Stress concentration factor for nozzle diameter for 600 mm

Diameter	*600 mm*
$\sigma_{nominal}$	*80.67 MPa*
σ_{max}	*140.11 MPa*
K_t	*1.73*

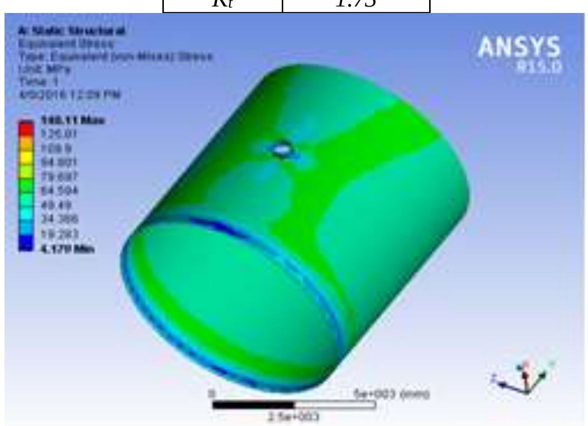


Fig. 5: Von-misses stress plot of pressure vessel for nozzle diameter 600 mm

– Stress distribution in longitudinal direction of cylinder

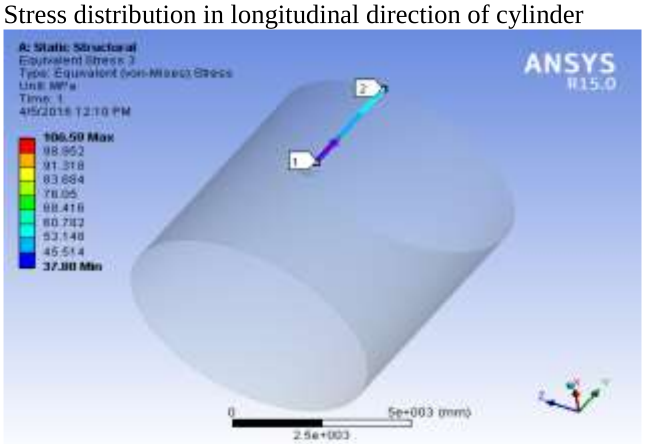


Fig. 6: Stress distribution in Longitudinal direction of cylinder-600 mm nozzle

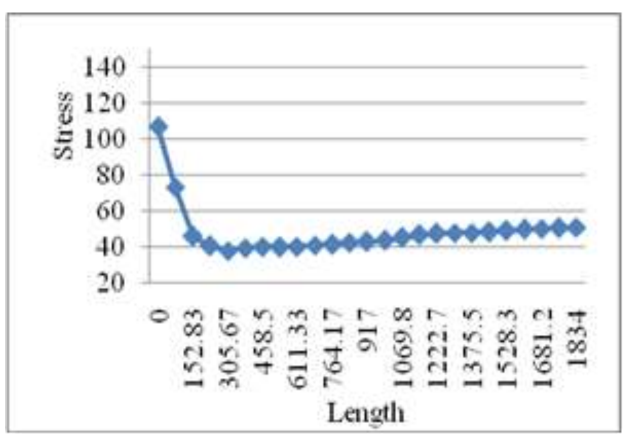


Fig. 7: Stress distribution in Longitudinal direction of cylinder

– Stress distribution in transverse direction of cylinder

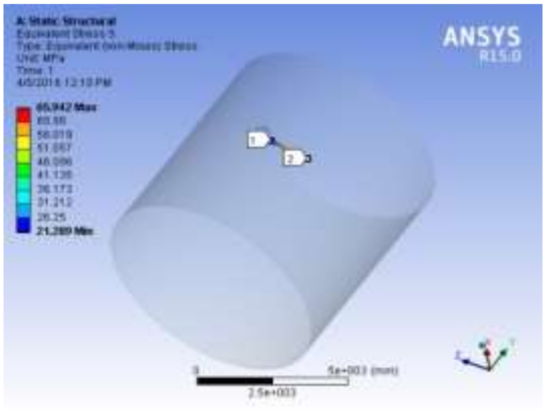


Fig. 8: Stress distribution in transverse direction of cylinder

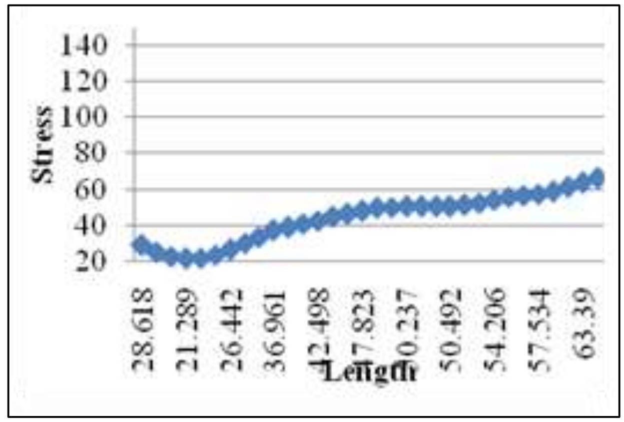


Fig. 9: Stress distribution in transverse direction of cylinder

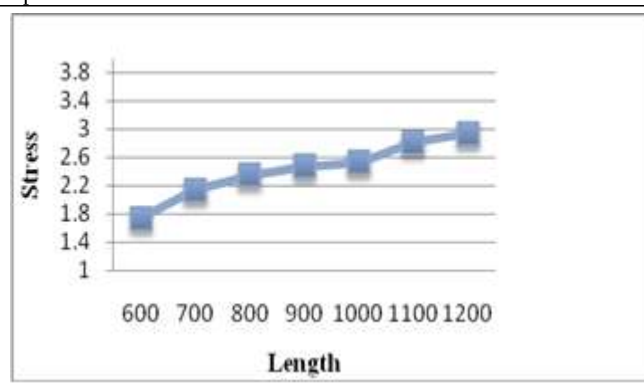
Here maximum Stress is 140.11 MPa at the edge of hole at an angle of 90° or 270° to the polar axis of hole which is 73.4 % higher than nominal value.

Same procedure for modeling and analysis has been carried out models with nozzle opening size 700 to 1200 without reinforcement pad and with circular / elliptical reinforcement pad and following results have been derived.

C. *FEA result summary of pressure vessel with different diameter of nozzle*

Table – 3
FEA result summary of pressure vessel with different diameter of nozzle

Diameter	*Max.stress(Mpa)*	*SCF*
600	*140.11*	*1.73*
700	*172.54*	*2.13*
800	*188.79*	*2.34*
900	*199.54*	*2.47*
1000	*203.41*	*2.52*
1100	*226.76*	*2.81*
1200	*236.56*	*2.93*

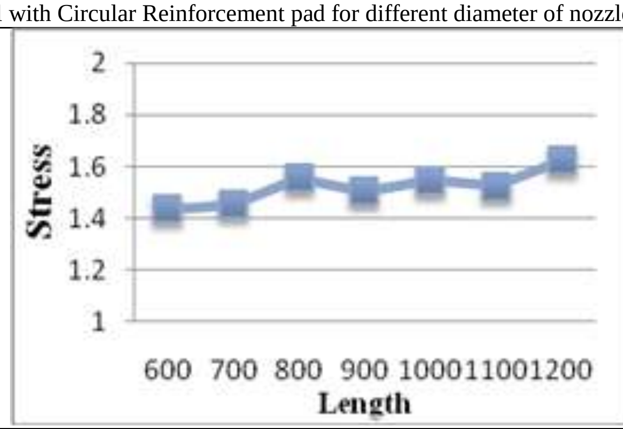


D. *Stress analysis in the shell wall with different sizes of hole with reinforcement pad for nozzle*

2) Calculation for Stress Concentration with Circular Reinforcement pad for different nozzle diameter

Table – 3
FEA result summary of pressure vessel with Circular Reinforcement pad for different diameter of nozzle

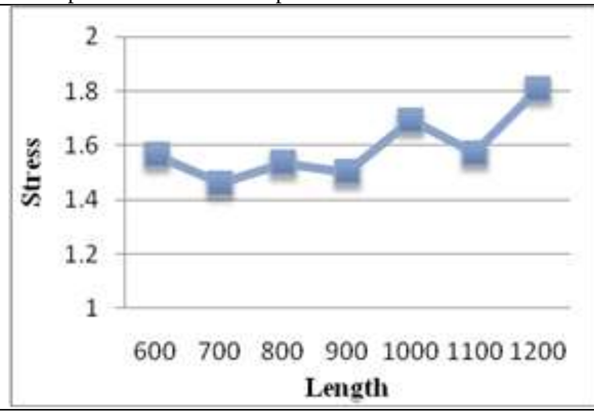
Diameter	*Max.stress(Mpa)*	*SCF*
600	*115.77*	*1.43*
700	*117.28*	*1.45*
800	*125.53*	*1.55*
900	*121.27*	*1.50*
1000	*124.69*	*1.54*
1100	*122.97*	*1.52*
1200	*131.04*	*1.62*



3) Calculation for Stress Concentration with Elliptical Reinforcement pad for different nozzle diameter

Table – 4
FEA result summary of pressure vessel with Elliptical Reinforcement pad for different diameter of nozzle

Diameter	*Max.Stress (Mpa)*	*SCF*
600	*126.24*	*1.56*
700	*117.84*	*1.46*
800	*123.76*	*1.53*
900	*121.12*	*1.50*
1000	*136.51*	*1.69*
1100	*126.76*	*1.57*
1200	*145.91*	*1.80*



From the above results of stress analysis two models viz. 900mm and 1100mm diameter which have given maximum effect of reinforcement pad have been selected for further analysis. Another pad thickness of 28mm was selected for comparative stress analysis. The models were prepared using different dimensions of circular as well as elliptical reinforcement pad. For circular pad the diameter was taken as 2D and 1.5D and for elliptical pad the ratio of major to minor axis was taken as 2D : 1.25D and 1.5D : 1.25D. After complete stress analysis of all models the detailed comparative analysis has been prepared.

VI. DISCUSSION ON ANALYSIS RESULTS

The opening for nozzle creates the geometric discontinuity for the pressure vessels cylinder, which affects the stress distribution near the vicinity of discontinuity in the cylindrical wall. It can be observed that the maximum stress occurs at the junction of Pressure Vessel and the nozzle. As the diameter of opening is increased the concentrated stress value is also increased at each and every point in the vicinity of hole. The stress value depends on the distance from the center as well as on the angle from the polar axis of hole. Value of stress is highest at the edge of hole at an angle of 90^o or 270^o to the polar axis of the hole i.e. in longitudinal direction of vessel.

Due to creation of the opening the stress value rises in the multiplication of stress concentration factor Kt which varies from 1.7 to 2.9 depending upon the diameter of opening for the shell without pad reinforcement. The rise in stress is observed about 74% to 200%. To minimize the effect of stress concentration, pad reinforcement becomes necessary to be provided.

Due to application of circular pad reinforcement the rise in stress is observed about 44% to 64% and the stress concentration factor is 1.43 to 1.62. Circular pad reinforcement reduces the rise in stress about 18% to 46%.

Due to application of elliptical pad reinforcement the rise in stress is observed about 56% to 80% and the stress concentration factor is 1.56 to 1.80.Elliptical pad reinforcement reduces the rise in stress about 10% to 44%.

The rise of stress is almost in the longitudinal direction of vessel and in the transverse direction the rise is nominal. The difference in stress reduction due to application of pad reinforcement is nearly same and thus elliptical pad may be effectively provided in place of circular pad reinforcement. The provision of elliptical reinforcement reduces the area of pad to be provided.
If the provided elliptical pad is having major axis as 2D and minor axis as 1.25D then there will be saving of 50% with respect to circular pad reinforcement. The difference in stress values for 28mm thick reinforcement pad is observed 0.03% to 13.67 with respect to 32mm. Elliptical reinforcement pad using major to minor axis ratio 1.5:1.25 gives the stress values which show minor difference between 1.73% to 8.10%. Elliptical reinforcement pad using major to minor axis ratio 1.5:1.25 gives lesser area to be provided for pad compared to 2: 1.25 which is around 42%.

VII. CONCLUSION

Pressure vessels are very important structures for chemical industries, petroleum industries as well as nuclear power plants. They are generally used as industrial compressed receiver or storage tanks. As they are subjected to high pressures & temperatures of constant or of cycling nature, the fluid being stored may undergo a change of state inside the pressure vessel. So, the analysis of pressure vessels requires great care because rupture of pressure vessels may result in loss of life and property.

Generally for provision of nozzles opening is created in shell wall of pressure vessel. From the analysis it can be observed that the maximum stress occurs at the junction of Pressure Vessel and the nozzle due to abrupt change in the geometry. The stress value rises in the multiplication of stress concentration factor Kt which varies from 1.7 to 2.9 depending upon the diameter of opening for the shell without pad reinforcement. Increase in the diameter of opening increases the concentrated stress at each and every point in the vicinity of hole depending on the distance from the center as well as on the angle from the polar axis of hole. The maximum value is at an angle of 90^o or 270^o to the polar axis of the hole i.e. in longitudinal direction of vessel.

To control the rise in stresses reinforcement pad becomes necessary to be provided to minimize the effect of stress concentration. Due to application of circular pad reinforcement reduction of the rise in stress is about 18% to 46%. While it is about 10% to 44% in case of elliptical pad having major to minor axis ratio 2D to 1.25D. As the rise of stress is in the longitudinal direction of vessel and in the transverse direction the rise is nominal, the difference in stress reduction due to application of pad reinforcement is nearly same and thus elliptical pad may be effectively provided in place of circular reinforcement pad. The provision of elliptical reinforcement reduces the area of pad to be provided. If the provided elliptical pad is having major axis as 2D and minor axis as 1.25D then there will be saving of 50% with respect to circular pad reinforcement. From the analysis it is observed that the thickness other than shell thickness is also possible for reinforcement pad.

The 28mm thick reinforcement pad gives around 0.03% to 13.67 differences with respect to 32mm. Which shows that the thickness may be reduced upto safe limit of allowable stresses. Elliptical reinforcement pad using major to minor axis ratio 1.5:1.25 gives minor difference between 1.73% to 8.10% with respect to 2;1.25. Elliptical reinforcement pad using major to minor axis ratio 1.5:1.25 gives lesser area to be provided for pad compared to 2: 1.25 which is around 42%. From this study it can be concluded that elliptical reinforcement pad may be effectively used in place of circular reinforcement pad which will eventually save the area of reinforcement pad around 30% to 50% depending upon the area of opening which eventually reduce the cost of reinforcement pad according to the dimensions of shell and openings required.

REFERENCES

[1] M. Javed Hyder, “Optimization of location and size of opening in a pressure vessel cylinder using ANSYS” Engineering Failure Analysis 15 (2008) 1–19
[2] Dharmit Thakore, “Finite Element Analysis of Pressure Vessel and Nozzle Junction” Revision: 0, Date: 29 March 2013.
[3] Tanweer Alam, “Hole Size and Location Optimization in Pressure Vessel” International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT) – 2016
[4] Mr. Kaushal Shetty, “Elastic Behavior of Cylindrical Vessels with Lateral Nozzle under internal pressure”. International Journal of Engineering Research and Applications (IJERA) Vol. 2, Issue 1, Jan-Feb 2012, pp. 1029-1034
[5] Z.F. sang , “ limit and burst pressures for a cylindrical vessel with a30 deg- lateral(d/D≥0.5)” Journal of pressure vessel technology, February 2005,vol.127/61
[6] Z.F. sang, “limit and burst pressures for a cylindrical shell intersection with intermediate diameter ratio” international journal of pressure vessel and piping 79(2002)341-379
[7] Jorge r. Miranda, “Stress analysis on vessel/nozzle intersections with/without pad reinforcement for cylindrical pressure vessels” 19th International congress of mechanical engineering copyright © 2007 by ABCM November 5-9, 2007, Brasília, DF
[8] J. Fang, “A comparative study of usefulness for pad reinforcement in cylindrical vessels under external load on nozzle” International Journal of Pressure Vessels and Piping 86 (2009) 273–279
[9] Shyam R. Gupta, “Optimize nozzle location for minimization of stress in pressure vessel (optimize angle and location of nozzle for minimization stress without reinforcement)” International Journal of Advance Engineering and Research Development (IJAERD) Volume 1,Issue 6,June 2014, e-ISSN: 2348 – 4470
[10] Norton RL. Machine design, an integrated approach, 2nd ed. Prentice-Hall International, Inc.