Piping Stress Analysis of a Hypothetical Oil Refinery Plant Having Separate Suction & Discharge Lines

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Abstract— In this study, a hypothetical simulation model is analyzed under varying uncertainty conditions; the key features of overlapping and functional interaction affect the performance measures of development time and effort. Findings indicate that, first and foremost, whether or not overlapping occurs, increasing functional interaction eventually leads to a sound system. A selective overview of group & individual process behaviors of a combined suction & discharge cycles of a hypothetical oil refinery plant is suggested. The pipe material is Carbon fiber reinforced plastic which is chosen because of its excellent length to weight ratio & it serves as an integral part the system which involves tank piping. This model uses psychologically legitimate & theoretically grounded models for time & decision rules. The results of preliminary simulation experiments suggest that the model is sensitive to structural & pay- off density & precisely replicates ideal free distributions. Pipe network models allow the modeling of storage tanks in which the working fluid (here, Naphtha) surface is inconsistent with inflow & outflow. Stress analysis of CFRP material shows that the maximum stresses are within allowable material strength. From the trials, it can be accomplished that, with proper design parameters, CFRP can take the design load similar to that of steel & other alloys
.***Key words:*** Simulation model, Suction & Discharge cycles, Carbon Fiber Reinforced Plastic (CFRP), Tank Piping, Pipe Network, Modeling & Analysis

I. INTRODUCTION

Piping Stress analysis is a term applied to calculations, which address the static and dynamic loading resulting from the effects of gravity, temperature changes, internal and external pressures, changes in fluid flow rate and seismic activity. Codes and standards establish the minimum requirements of stress analysis.

Purpose of piping stress analysis is to ensure :

- Safety of piping and piping components.
- Safety of connected equipment and supporting structure.
- Piping deflections are within the limits.
- Safety of plants
- Safety of environment
- Equipment Design
- Structural design

A. Design Codes Used In Stress Analysis

- ASME B 31.1 – This is the design code used for power piping design.
- ASME B 31.3 – For process piping this code is used
- ASME B 31.4 – For cross country liquid transportation pipeline this code is used.
- ASME B 31.5 – This design code is used for refrigerant piping.
- ASME B 31.8 – This design code is used for cross country gas transportation pipeline

B. Design Codes W.R.T. Plant Life Cycle

The reasons one does a pipe stress analysis on a piping system are many such as:

- The cold and hot conditions are below the allowable values
- To ensure the piping is well supported with used pipe supports and it does not slump or deflect under its own weight
- To ensure that the deflections are fully controlled when thermal and/or other loads are exerted
- To ensure that the loads and moments inflicted on machinery and vessels by the thermal growth of the attached piping accessories are not excessive

C. Modeling Of Pipes & Pipe Systems

The piping system can be modeled under various software such as CAESAR II, CAEPIPE, AUTOPIPE, ANSYS, etc. for analysis purposes. The model is constructed from piping isometric drawings/ General Agreement drawings, piping & valve specifications. Once the system is exactly modeled, under a given set of boundary conditions (temperature, pressure, etc.) comprehensive stress calculations are done, modifications to the model are made to ensure compliance with the above requirements

D. Stress Analysis Report

Following are the main constituents of a stress analysis report:

1) Basis for Analysis
2) List of load cases
3) Static Analysis Input Listing
4) Stress Isometrics
5) Stress Report
6) Displacement Report
7) Restraint Summary

E. Basis for Static Analysis

The basis for static analysis is done when lines are analyzed at operating & design conditions, allowable loads for static equipment are as per codes, the transverse deflection will be limited to 25 mm, for supports, default stiffness value of CAESAR II is considered if not otherwise cited, the vertical deflection due to sustained loads will be limited to 15mm & the number of thermal load cycles is considered to be 7000

II. LITERATURE REVIEW

In order to study the behaviour of CFRP pipes used in utility piping the literature related to the flexibility analysis, fatigue

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& failure analysis of the various components of various kinds of systems has been studied. Houssam Toutanji, Sean Dempsey proposed that fiber reinforced polymer composites (FRPC) have established a strong position as an effective mean for the repair and rehabilitation of infrastructure. However, the use of FRP in the repair and rehabilitation of pipelines is a new concept that has the potential to improve the way we repair pipelines. This paper showed the benefits of using FRPC and the profit to provide stress expressions on the interaction between the different stresses exerted on pipe walls and the effects of FRPC sheets on the circumferential stresses of damaged pipe walls. The effects of three different FRPC sheets: Glass FRP (GFRP), Aramid FRP (AFRP), and Carbon FRP (CFRP) on the performance of pipe walls were compared analytically.

Results showed that carbon fiber composites perform better than glass or aramid in improving the ultimate internal pressure capacity of pipes and therefore, significantly enhance the strength, durability, and corrosive properties. R Andrews, M. C. Weisenberger stated a report on carbon nanotube polymer composites. The state of research into carbon nanotube/ polymer- matrix composites for mechanical reinforcement is critically reviewed with emphasis on recent advances in CNT composite toughness. Particular interest is also given to interfacial bonding of carbon nanotubes to polymer matrices as it applies to stress transfer from the matrix to the CNT. Mohammadreza Tavakkolizadeh, Hamid Saadatmanesh proposed fatigue strength of steel girders strengthened with carbon fiber reinforced polymer patch. The Fatigue sensitivity details in aging steel girders are one of the common problems that structural engineers are facing today. The design characteristics of steel members can be enhanced significantly by epoxy bonding carbon fiber reinforced polymers (CFRP) laminates to the critically stressed tension areas. They presented the results of a study on the retrofitting of notched steel beams with CFRP patches for medium cycle fatigue loading (R=0.1). A total of 21 specimens made of S127x4.5 A36 steel beams were prepared and tested. The steel beams were tested under four point bending with the loading rate of between 5 and 10 Hz. Different constant stress ranges between 69 and 379 MPa were considered. The length and thickness of the patch were kept the same for all the retrofitted specimens. In addition to the number of cycles to failure, changes in the stiffness and crack initiation and growth were monitored during each experiment. The results showed that the CFRP patch not only tends to extend the fatigue life of a detail more than three times, but also decreases the crack growth rate significantly.

III. METHODOLOGY

A hypothetical model of an oil refinery plant is generated on Intergraph Caesar II representing system dynamics in terms of suction & discharge lines, pipe supports, pipe material, and conditions of pressure, temperature & loads. CAESAR II follows some specific piping code requirement, i.e. ASME B31.1 or ASME B31.3 or other relevant power or process piping code. A stress analysis report is generated showing basis for analysis, list of load cases, static analysis input listing, stress isometrics, stress report, displacement report & restraint summary. The process flow diagram is constructed showing the flow of the working fluid in the system.

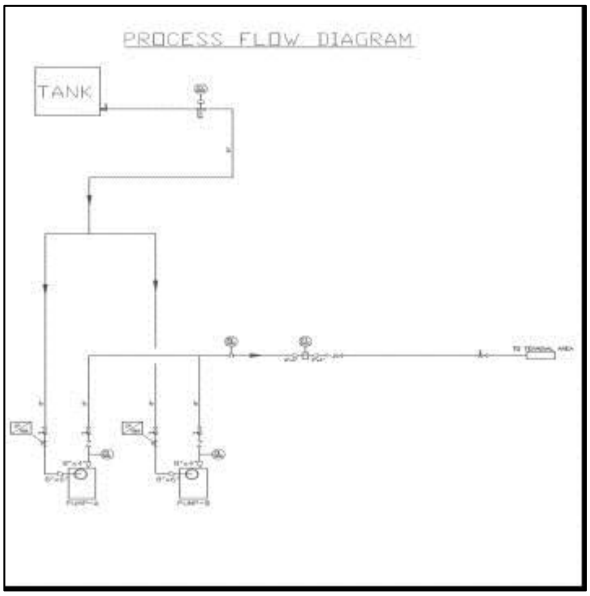

Fig. 1 : Process flow diagram

Various critical tests are performed in order to check the efficiency of the system & the impact of the material used for pipe i.e. CFRP. Piping stress analysis is one of the most crucial tests involved which address the static & dynamic loading resulting from the effects of gravity, temperature changes, pressures (internal & external), changes in fluid flow rate & seismic activity (if any).

After calculation for basis for static analysis, succeeding points are conceived. Lines are analyzed at operating & design conditions. Allowable loads for static equipment are as per design codes. The transverse deflection will be limited to 25mm in general. For supports, default stiffness value of CAESAR II is considered if not otherwise cited. The vertical deflection due to sustained loads will be limited to 15mm. The number of thermal load cycles is considered to be 7000. A load case description is obtained including the restraint summary: loads on restraints

A. *Load Case Definition Key*

1) CASE 1 (HYD) WW+HP
2) CASE 2 (OPE) W+T1+P1
3) CASE 3 (OPE) W+T2+P1
4) CASE 4 (OPE) W+T3+P1
5) CASE 5 (OPE) W+T4+P1
6) CASE 6 (OPE) W+T5+P2
7) CASE 7 (OPE) W+D1+T1+P1
8) CASE 8 (OPE) W+D1+T2+P1
9) CASE 9 (OPE) W+D1+T3+P1
10) CASE 10 (OPE) W+D1+T4+P1
11) CASE 11 (OPE) W+D1+T5+P2
12) CASE 12 (SUS) W+P1
13) CASE 13 (SUS) W+P2

Stress isometrics are received for pump suction

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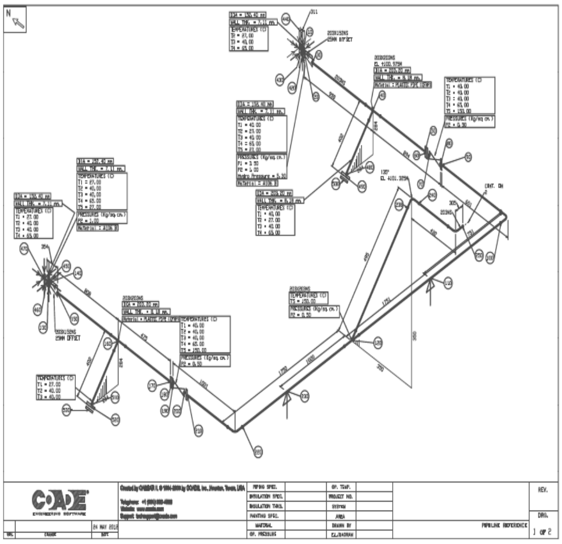

Fig. 2: Stress isometrics for pump suction sheet 1 of 2

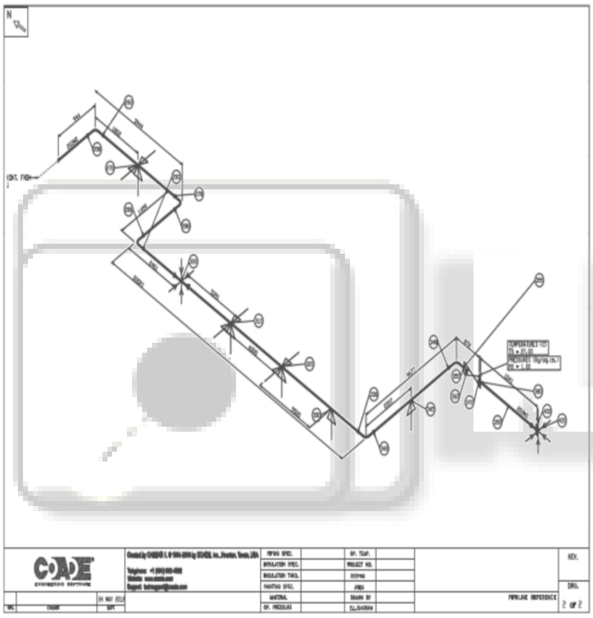

Fig. 3: Stress isometrics for pump suction sheet 2 of 2

A displacement report is obtained showing the nodal movements on CASE 2 (OPE) W+T1+P1.

Now, the listing of load cases for pump discharge is taken as follows:

1) CASE 1 (HYD) WW+HP
2) CASE 2 (OPE) W+T1+P1
3) CASE 3 (OPE) W+T2+P1
4) CASE 4 (OPE) W+T3+P1
5) CASE 5 (OPE) W+T4+P1
6) CASE 6 (OPE) W+T5+P2
7) CASE 7 (SUS) W+P1
8) CASE 8 (SUS) W+P2
9) CASE 9 (EXP) L9=L2-L7
10) CASE 10 (EXP) L10=L3-L7
11) CASE 11 (EXP) L11=L4-L7
12) CASE 12 (EXP) L12=L5-L7
13) CASE 13 (EXP) L13=L6-L8

Stress isometrics for pump discharge are taken out. Stress summary report is obtained showing highest stresses at various loads. Load case definition key is shown as:

1) CASE 7 (SUS) W+P1
2) CASE 8 (SUS) W+P2
3) CASE 9 (EXP) L9=L2-L7
4) CASE 10 (EXP) L10=L3-L7
5) CASE 11 (EXP) L11=L4-L7
6) CASE 12 (EXP) L12=L5-L7
7) CASE 13 (EXP) L13=L6-L8

Piping Code: Multiple Codes

BS 7159 = BS 7159 (1989)

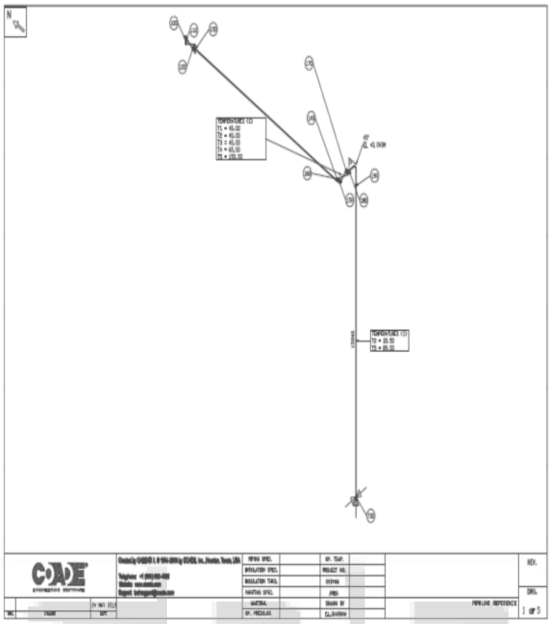

Fig. 4: Stress isometrics for pump discharge sheet 1 of 5

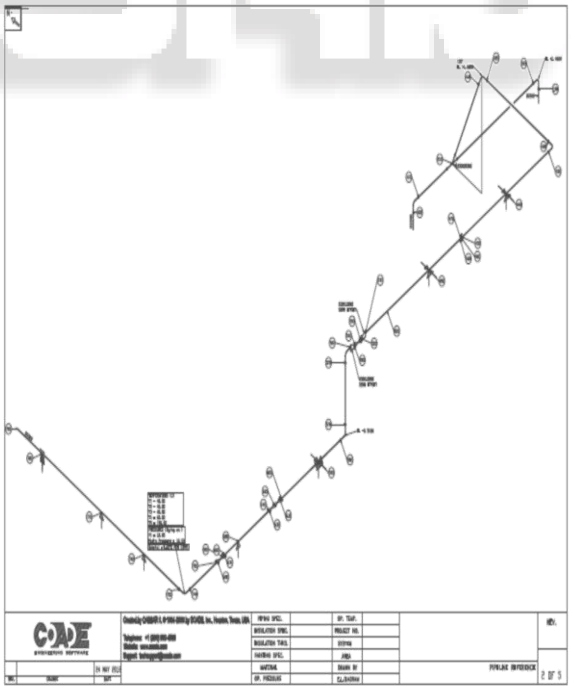

Fig. 5: Stress isometrics for pump discharge sheet 2 of 5

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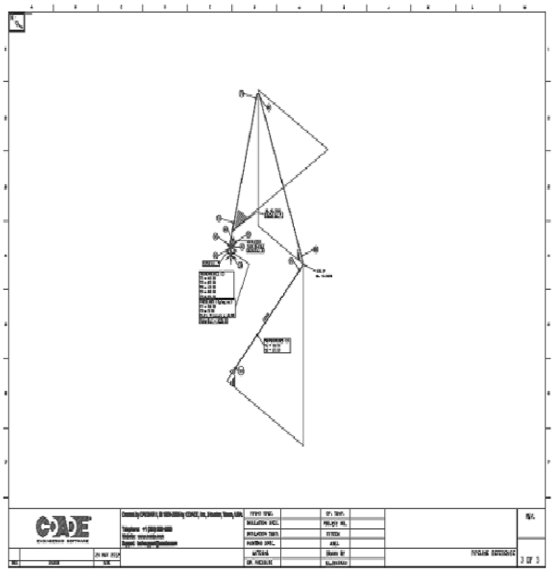

Fig. 6: Stress isometrics for pump discharge sheet 3 of 5

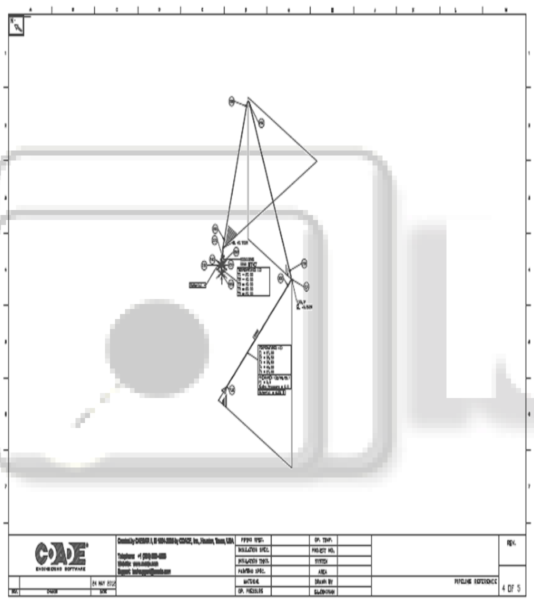

Fig.7: Stress isometrics for pump discharge sheet 4 of 5

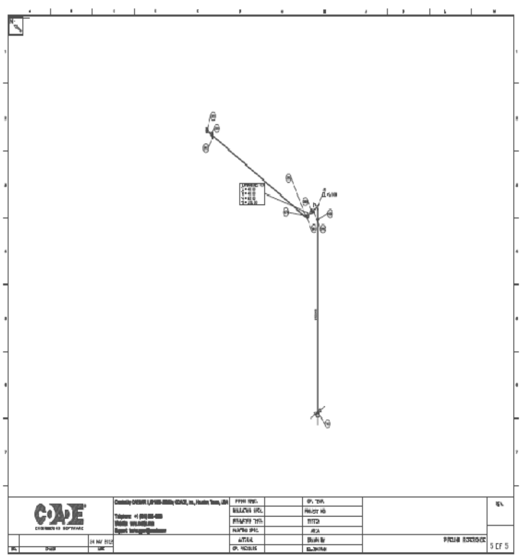

Fig. 8: Stress isometrics for pump discharge sheet 5 of 5

The load cases are now considered where code stress check has passed.Various parameters such as highest stresses (lb per square inch), code stress ratio (%), code stress, axial stress, bending stress, torsion stress, hoop stress, 3D max intensity, etc. are considered. After this, a restraint summary report showing loads on restraints is carried out.

1) CASE 1 (HYD) WW+HP
2) CASE 2 (OPE) W+T1+P1
3) CASE 3 (OPE) W+T2+P1
4) CASE 4 (OPE) W+T3+P1
5) CASE 5 (OPE) W+T4+P1
6) CASE 6 (OPE) W+T5+P2
7) CASE 7 (SUS) W+P1
8) CASE 8 (SUS) W+P2

A final displacement report is taken out for nodal movements for discharge case on CASE 2 (OPE) W+T1+P1.

IV. RESULTS

The modeling framework has responded successfully to the various crucial tests & analysis. The CFRP pipe has passed all the critical tests such as stress/strain & displacement tests. All the values are under permissible limits. Loads on pump suction & discharge nozzles are as per code API- 610 & loads on tank nozzle are as per code API- 650. The maximum vertical deflection was taken out to be 15mm which was safely passed by CFRP pipes made up of nominal pipe size of 6 & 8mm .The stresses at steam out, sustained & expansion case are within allowable limits. CAESAR II has successfully performed the tests & has shown the allowable values under maximum values as per B31.3. The code stress compliance for both suction & discharge cases are shown in the respective tables

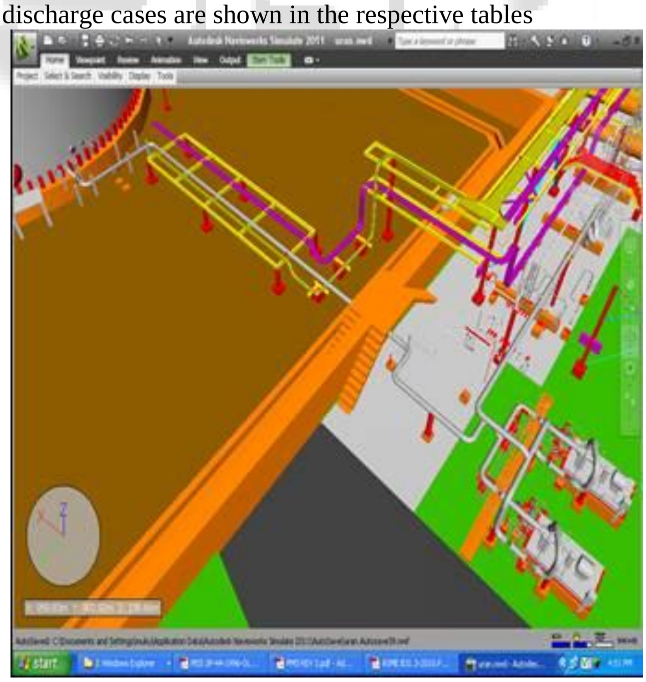

Fig. 9: Snapshot of the hypothetical oil refinery plant

A. Code Compliance: Suction

- CASE 12 (SUS) W+P1
- Piping Code: Multiple Codes
- BS 7159 = BS 7159
- B31.3 = B31.3 -2006

- *** CODE COMPLIANCE EVALUATION PASSED ***
- Highest Stresses: (lb./sq.in.)
- Code Stress Ratio (%) is 22.9 at Node 400 LOADCASE: 12 (SUS) W+P1
- Code Stress: 4574.0 Allowable: 20000.0
- Axial Stress: 391.9 @Node 30 LOADCASE: 12 (SUS) W+P1
- Bending Stress: 4201.1 @Node 400 LOADCASE: 12 (SUS) W+P1
- Torsion Stress: 248.2 @Node 350 LOADCASE: 12 (SUS) W+P1
- Hoop Stress: 2165.9 @Node 40 LOADCASE: 12 (SUS) W+P1
- 3D Max Intensity: 4600.9 @Node 400 LOADCASE: 12 (SUS) W+P1

Load Case	From Node	Code Stress lb./sq.in.	Allowable Stress lb./sq.in.	To Node	Code Stress lb./sq.in.	Allowable Stress lb./sq.in.	Piping Code
12 (SUS)	400	4574.0	20000.0	405	4560.0	20000.0	BS 7159

Table 1(a): Code compliance: suction

B. *Code compliance: discharge*

- CASE 7 (SUS) W+P1
- Piping Code: Multiple Codes
- B31.3 = B31.3 -2006
- BS 7159 = BS 7159
- *** CODE COMPLIANCE EVALUATION PASSED ***
- Highest Stresses: (lb./sq.in.)
- Code Stress Ratio (%) is 19.8 at Node 569 LOADCASE: 7 (SUS) W+P1
- Code Stress: 3950.8 Allowable: 20000.0
- Axial Stress: 1343.7 @Node 270 LOADCASE: 7 (SUS) W+P1
- Bending Stress: 1268.1 @Node 550 LOADCASE: 7 (SUS) W+P1
- Torsion Stress: 122.5 @Node 200 LOADCASE: 7 (SUS) W+P1
- Hoop Stress: 3950.6 @Node 569 LOADCASE: 7 (SUS) W+P1
- 3D Max Intensity: 2929.2 @Node 210 LOADCASE: 7 (SUS) W+P1

Load Case	From Node	Code Stress lb./sq.in.	Allowable Stress lb./sq.in.	To Node	Code Stress lb./sq.in.	Allowable Stress lb./sq.in.	Piping Code
7 (SUS)	569	3950.8	20000.0	570	3882.5	20000.0	BS 7159

Table 2: Code stress compliance: discharge

V. CONCLUSION

Following are the conclusions made on the basis of testing and analysis of the hypothetical oil refinery plant (system):

- Stresses at sustained, expansion & steam out case are within allowable limits.
- Loads on Pump Suction & Discharge nozzles are as per code API- 610.
- Loads on Tank nozzle are as per code API-650.
- Vertical deflection due to sustained loads is within allowable.

Simulations are carried out successfully and thus give significant contributions to the innovative climate and the productivity of project. In an oil refinery plant, the proper labeling of pipes, valves, flanges and instrumentation in production and refining industry is critical. A real-time model has been created and pilot runs are made after checking the accuracy, stability and efficiency of the product. The final product with necessary changes has been delivered for the commercialization purpose.

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