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Design of a Steam Piping System for Dryers in Paper Machine and Checking its Sustainability through Finite Element Analysis Using Caesar II

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Abstract:** Process piping is a form of pipework used to transport materials used in industrial processes and manufacturing. It is specially designed for particular applications to ensure that it will meet health and safety standards, in addition to suiting the needs of a given manufacturing process. The designer of the piping also has to consider issues like the amount of pressure the piping will be subjected to and the width of the piping, when selecting an appropriate construction material for longer life of system. In this project study, by using data like P & ID, 2-D and 3-D piping system is designed by following codes and standards. Finite element analysis is performed with the application of various loading cases to check sustainability of piping system in design service condition. The results of the study show that the primary and secondary stresses are within code allowable limits. Hence system is safe for stresses. Also nodal movements are shown in displacement summary report.

***Keywords:** Process piping, stress analysis, CAESER II, piping layouts, piping design.*

I. INTRODUCTION

Process piping is the system of pipes that transport process fluid like Air, Steam, Water, and industrial gases, Fuels, Chemicals, around an industrial facility involved in manufacture of product or in generation of Power. The term piping includes components like pipe spool, fittings, flanges, valves, bolts, gaskets, bellows etc. Materials selection for achievement of metallurgical stability shall be made on the basis of design condition and to resist possible exposures against fire, corrosion, operating condition, service etc the code followed for this piping is ASME B 31.3. The design, fabrication, installation, erection, commissioning and inspection are carried out as per code ASME B 31.3. [1].

A. Piping Components

1. *Flanges:*

Flanges provide a bolted, separable joint in piping. The most of valves have flanged ends and must have a companion or matching flange attached. A gasket is then inserted between them and the bolts are tightened to form a flanged joint. Flanges are used where there is a clear need for removal of valves or equipment, for access of maintenance. Because all flanged connections are potential leak source, their use should be kept to the minimum needed for safe and reasonably convenient operation and maintenance.

2. *Bolts and gasket:*

Choice of bolting material is governed by service fluid and its temperature. The most commonly used bolts for flanges in refinery piping are the ASTM A193 Gr.B7 Stud bolts which fall into the high strength group. The temperature range is from –

29°C to 454 °C. A gasket is a thin circular disc, made up of soft compressive material. The most of valves have flanged ends and must have a companion or matching flange attached. A gasket is then inserted between them, and the bolts are tightened to form a flanged joint.

3. Valves:

- Valves stop or open and regulate flow. Some of the basic valve types are gate, globe, check, Ball, Plug etc.
- Gate valve: It is usually manually operated and is designed for open or shut operation. Flow can enter either end of the gate body.
- Globe valve: Globe valve is for throttling. Good examples of globe valves are the faucets on washbasin which throttle or adjust the flow to suit a person's needs. Flow must enter the valve and flow up, against the seat and change the direction again to the outlet.
- Check valve: This valve checks flow. It lets flow go one way and will not let it reverse. When we have a check valve in a line, we have made a one-way street. The flow can go one way.

B. Applications of piping

- This type of piping can be used in a wide variety of ways. In food manufacturing, for example, process piping can be used to transport food ingredients to various points on the assembly line.
- Chemical manufacturing facilities use this type of piping to transport components of their

  Products along with materials like natural gas used in manufacturing.

- Refineries and similar facilities also utilize it to move chemical compounds.
- In power plants, to connect various equipments.

C. Codes and standards

The integrity of a piping system depends on the considerations and principles used in design, construction and maintenance of the system. Piping systems are made of components as pipes, flanges, supports, gaskets, bolts, valves, strainers, flexible and expansion joints. The components can be made in a variety of materials, in different types and sizes and may be manufactured to common national standards or according a manufacturers proprietary item. For scientific design of Piping Systems, selection of proper material of construction and to detail out the material specification, knowledge of Codes and Standards is essential. Standardization can, and does, reduce cost, inconvenience, and confusion that result from unnecessary and undesirable difference is systems, components and procedures. Professional societies, committees and trade organization publish industry standards. A code is basically a standard that has been generally accepted by the government. The objective of each code is to ensure public and industrial safety in a particular activity or equipment. Codes or often developed good engineering practices and published as Recommended Practices. Codes and standards apart from being regulations might be considered as design aids since they provide guidance from experts. Each country has its own codes and standards. On global basis, American national Standards are undoubtedly the most widely used and compliance with those requirements are accepted world over. In India, other than American standards, British standards and Indian standards are also used for design and selection of equipment and piping systems.

ASME B 31.3 code provide requirements for design, erection, materials, inspection, fabrication, testing for process piping in petroleum refineries, chemical plants, pharmaceutical plants, textile plants, paper plants, Semiconductor Plants, Cryogenic.

II. PROBLEM DESCRIPTION OF THE PROJECT

A good amount of research is done on piping, problems or failure in piping, steam piping. Process piping is a form of pipe work used to transport materials used in industrial processes and manufacturing. The piping systems are designed by using some reference data like P&ID. So here arised an idea about the project to take reference initial data like P&ID and line list and to design a piping system to meet process requirements and analyse the system for stresses.

So the required reference data was taken from Seven Lines, Pune and the steam pipeline was routed and analysed as per their demand. The steam in the piping is transported to the dryers (drums)in the dryer section of the paper machine plant through steam outlets. The pipeline was routed over pipe rack.

A. Problem definition of the project

The aim of proposed project is to design a process piping system and to prepare piping layout and isometrics by using data like P&ID, line list of the system by following international codes and standards. And also checking sustainability of that piping system in design service condition by using finite element analysis.

B. Methodology for the project

- Piping literature and some concepts in piping engineering were studied.
- By using input data like P&ID, plot plan and line list, pipeline was routed.
- Pipe material and components like flanges and valve were designed and checked for acceptance as per code.
- The system was stress analyzed using CAESAR II and results were obtained.

III. PIPING DRAWINGS

The piping drawings are very useful data for a site engineer while erection of the system. Input drawings like P and ID, plot plan are required to prepare isometrics and GA drawings of the piping system. These drawings are prepared in AUTOCAD software. Various drawings which are important in the piping engineering are discussed below. [1]

A. Piping And instrumentation diagram (P&ID)

A Piping and Instrument Drawing (P&ID) includes more details than a PFD. A P& ID as defined by institute of Instrumentation and Control, Australia, A diagram which shows interconnection of process equipments and instrumentation used to control the process. It consists of:

i) All equipments
ii) All connected piping
iii) Piping components maybe there
iv) Valves along with their types
v) Instruments

B. Plot plan

Plot is the master plan locating each unit/facility within the battery limit for a process industry. A battery limit is a defined boundary between two areas of responsibility, which may be physical (e.g. a flange on a pipe); or represented by a map coordinate. Plot plan shows all the equipments and supporting facilities like pipe rack, buildings etc. Usually this arrangement is shown in plain view. It also consists of future facilities required for.

C. General arrangement drawing (GA Drawing)

General Arrangement drawings for piping systems and equipments are developed by piping designers. These drawings indicate the locations of main equipments in the plant. The main piping items, valves, and fittings are also indicated in the General Arrangement or GA drawings. Most often the piping is indicated using a top-view. Sometimes a side view of the pipe rack is also presented on the GA drawing. General arrangement drawings are also developed for individual equipments. These drawings present the main dimensions of that equipment using 2D views, top-view, side-view and sometimes front-view. [5]

D. Isometrics

In complex piping system, especially within the unit/plant building where orthographic views do not illustrate the details of design, pictorial view isometric presentation is drawn for clarity. Unlike orthographic, piping isometrics allow the pipe to be drawn in a manner by which the length, width and depth are shown in a single view. Isometrics are usually drawn from information found on a plan and elevation views. The symbols that represent fittings, valves and flanges are modified to adapt to the isometric grid. The Iso, as isometric are commonly referred, is oriented on the grid relative to the north arrow found on plan drawings. Because Isometrics are not drawn to scale, dimensions are required to specify exact lengths of piping runs. Pipe lengths are determined through calculations using coordinates and elevations. [6]

❖ *Guidelines for developing piping layouts*

- Process requirements indicated in P & ID should be meet.
- The lines should be routed in orderly manners. Line should be grouped in bunch & run together where ever possible for the ease of supporting.

- Only the standard pipe, fitting, special parts mentioned in pipe specification should be used for routing. Anything outside the specification is not permitted.
- Overhead piping should have clear headroom for many ways, & movements of cranes, truck where applicable.
- Piping on the grade level should be minimized as it blocks the free movement.
- The piping component that requires frequent maintenance should be easily accessible from grade or platform &should have adequate clear working space.
- Each line should be designated with complete line no as in line list.
- All piping components & special items should be represented by its tag no.
- Line is generally represented by centre line elevation. Lines on rack or sleeper are represented by BOP/TOS (Base of pipe/ Top of surface)
- Every line should have flow direction.

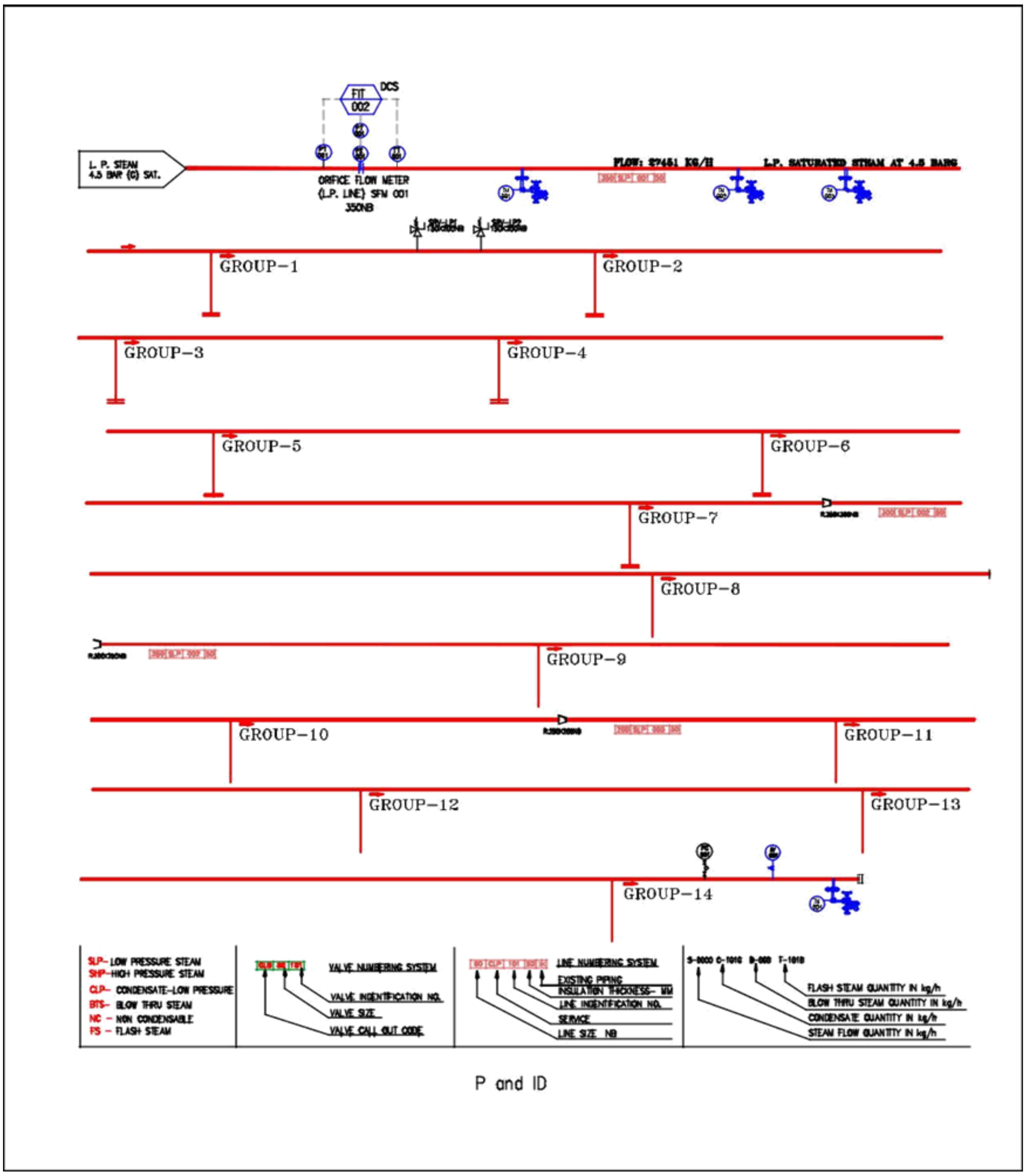
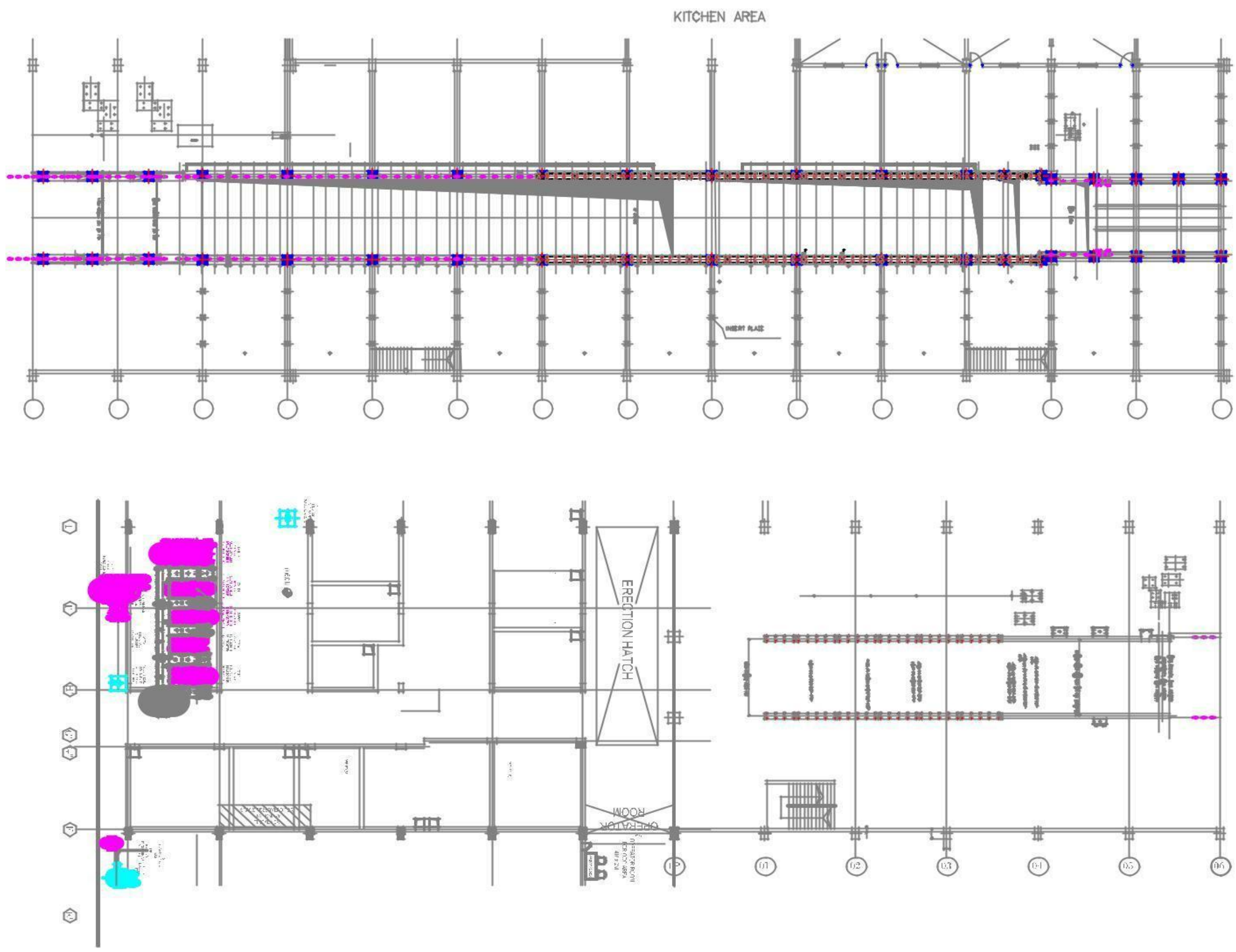


Fig. 1 P&ID



Plot plan

Fig.2 Plot Plan

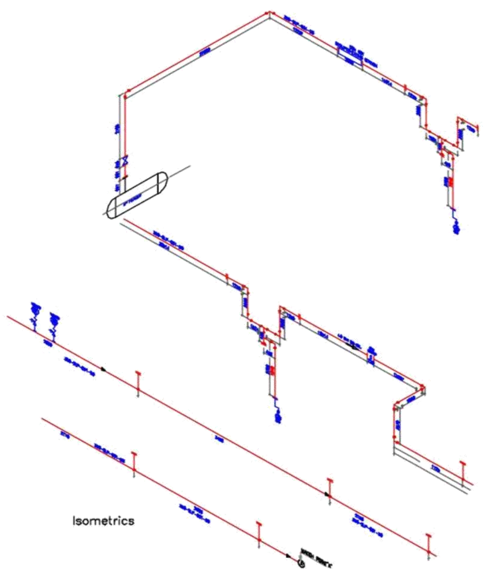


Fig.3 Isometrics

Fig.4 GA Drawing

III. DESIGN

Starting the design of the piping system with selection of pipe

A. Selection of Pipe

Starting the design of the piping system with selection of pipe. Working service fluid, pressure, temperature are the main factors considered while selecting the material for pipe. Material properties should be known so as to select appropriate material of construction for the pipe material for corresponding factors like temperature, pressure and working fluid of the system. Secondly, economy factor should be considered, unnecessary costly materials should also be avoided. In this case service fluid steam with temperature 392˚ F is transported through piping system at a pressure 4.5 bar.

1) Pipe material:

ASTM A 106 B is selected as it is a case of high temperature. It is seamless carbon steel pipe for high temperature service. [7] Conversion of carbide to graphite may occur after prolonged exposure at high temperatures above 800 F. So our selected material is safe at 392 F in our case. [8]

2) Pipe schedule:

It relates to the thickness on the wall of pipe. As the schedule number of particular pipe size increases wall becomes thicker. Though schedule number for different sized pipe is same it will have different wall thickness**.** Based on the NPS and schedule of a pipe, the pipe outside diameter (OD) and wall thickness can be obtained from reference tables which are based on ASME standards B36.***10****M* and B36.19M.

3) Pipe schedule selection:

Given:

Pipe material: ASTM A106 B Seamless pipe Pipe OD=14 inches Internal

Pressure=50.55 psi Temperature=392 F.

Corrosion allowance (A) is taken as 0.125”

Here, basic allowable stress of pipe material from Table A-1 of B 31.3:
S= 20 ksi …. (Page 142 of code)
Quality factor for longitudinal weld joint from Table A-1B of B 31.3:
E=1 …. …. (Page 191 of code)
Co-efficient of material based on temperature
From Table 304.1.1 of B 31.3: Y=0.4 …. (Page 18 of code)
Now, we have equation for pressure design thickness t from Para 304.1.2 of B 31.3:

$$= \frac{\quad}{2} *(+)$$

$$= 50.55 * \frac{14}{2} * (20000 * 1 + 50.55 * 0.4)$$

$$= 0.01767$$

$$= + = 0.01767 + 0.125 = 0.1426$$

$$= \frac{\quad}{0.875} = \frac{0.14267}{0.875} = 0.1630''$$

For this wall thickness, selecting Sch 10 for 14" pipe. …. (Page 96 of standards) ….[20]

B. Selection of flange

Flanges are used to make temporary joints so that it can be removed for maintenance. Flanges joints consists of three independent but related components, those are a pair flanges, gasket, set of bolts and nuts. The selection and dimension specification is taken from ASME B 16.5.

- *Ratings of flanges and its selection:*

A flanged joint is composed of three separate and independent, although interrelated components: the flanges, the gasket and the bolting. Proper controls must be exercised in the selection and application for all these elements to attain a joint which has acceptable leak tightness. Ratings in this standard apply to flanged joints which conform to the limitations on bolting and gasket. Ratings are maximum allowable working gage pressures at the given temperature for applicable material and rating. For intermediate temperatures, linear interpolation is permitted. [10]

In this case, Table 2 of ASME B 16.5: For class 150: Pressure at 300 F=230 psi Pressure at 400 F= 200 psi. We observe that, for 100 F rises in temperature there is 30 psi drop in pressure. So by interpolation we get pressure 202.4 psi at 392 F.
That means code allowable pressure is 202.4 psig for class 150 at 392 F is greater than our working pressure 50.55 psig …. [10]
So selecting class 150 with same material and size as pipe. Selecting weld neck flanges with butt welding for this high pressure steam piping of size 14".

C. Selection of Valve

Valves are very important part of piping system, as they provide facility to regulate the quantity of fluid passing through the pipe.

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F=230 psi Pressure at 400 F= 200 psi

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➢ *Selection of valves:*

- Gate valve is selected as isolation (ON-OFF) valve. Fluid hammer is minimum as it operates slowly also it has less pressure drop.
- It opens by lifting a round or rectangular gate/wedge out of the path of the fluid.
- 14" gate valve of class 150 with flanged connection is selected.
-

IV. STRESS ANALYSIS

Stress Analysis is a subject, which is more talked about and less understood. The Objective of pipe stress analysis is to ensure safety against failure of the Piping System by verifying the structural integrity against the loading conditions, both internal and external stresses expected to occur during the lifetime of the system in the plant. [1] A piping system will undergo dimensional changes with any change in temperature. If it is constrained from free expansion or contraction, it will be displaced from it unrestrained position causing strain and stresses. [11]

A. Objective

- The scope of this document is to calculate the static stresses, displacements, forces and moments acting (internally & externally) on the piping system interaction under various conditions/cases (e.g. sustained, expansion and operating) due to the combined effect of internal pressure, system temperature, bending and external loads etc.

- For each system, detailed stress calculations using Caesar II version 5.10.03 have been carried out and a report has been prepared.

B. Methodology

- Pipeline routing is done by using line list, P& ID, Plot plan etc.

- A detailed analysis using stress analysis software has been done for this line. Stress isometrics have been prepared using Isogen on the basis of the piping routing layouts.

- For the loads, system weight, internal pressure and temperature expansion have been considered. [12]

C. Assumptions and considerations

- All valve and flange weight are considered from Caesar library.
- The analysis is carried out as below:

1. The system is analyzed for design and operating temperature and pressure conditions.

2. The Design input parameters are considered as per Line List.

3. The standard guide gap is 3 mm.

4. The friction coefficient at restraints is 0.3 for Steel to Steel.

D. Codes and standards

The following codes and standards form the basis of the Stress Analysis:

- ASME B 31.3 for Process Piping
- ASME B16.5 for Pipe Flanged and flanged fittings
- ASME B 36.10 for Welded and Seamless Wrought Steel Pipe.

E. Load cases

The following load cases have been considered for the analysis: ○ (OPE) W+T1+P1

○ (SUS) W+P1

○ (EXP) L4=L2-L3

- Where,
- WW = Weight of pipe with water.
- W = Weight of pipe and contents
- P1 = Design Pressure
- T1 = Design temperature

F. Given case

Pipe material: ASTM A106 B Seamless pipe Pipe OD=14 inches at start Internal Pressure= 4.5 bar for steam as working fluid

Temperature= 392 F.

Corrosion allowance is taken as 0.125” [13] the given piping system is shown in isometrics form below in the stress isometrics.

G. Results

The result of the analysis of the piping system is discussed in detail below. Some of the results related to stress are tabulated below..

H. Isometrics

The isometric model of the piping system which was taken as input for stress analysis is shown below. [14] This is only starting one fourth part of the system. The whole system can be shown in similar way.

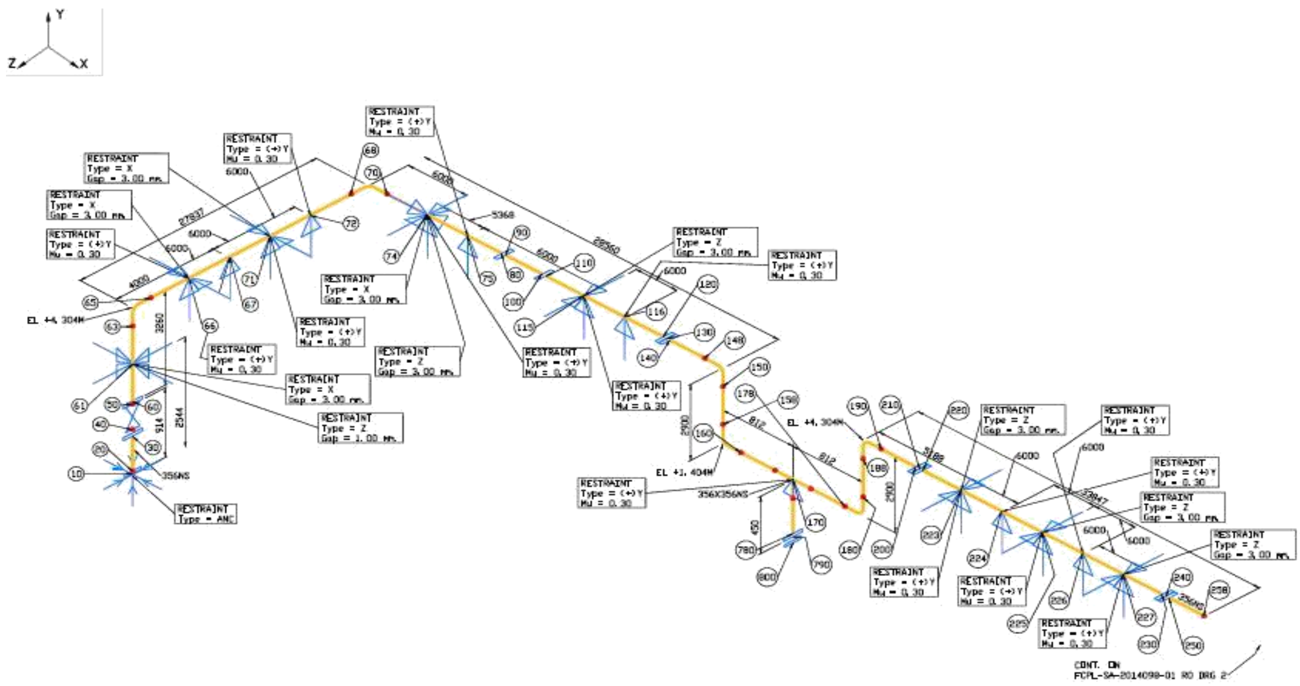

Fig.5 Stress isometrics of designed piping system

The piping system shown in yellow line is a single continuous line but for better view it is shown in four parts. Whole piping isometric model is differentiated into number of elements. Element may be a piece of pipe, flange, valve or some other fitting. Elements are separated with nodes which are shown in red dots in the isometrics. Each node has given some number to it which is encircled in the given isometric drawings. The model has been terminated at supports, supports like guides, stops, rests are provided wherever needed during analysis. These supports are shown as blue arrows in the stress isometrics. While entering the data into the Input Spreadsheet of the Piping module of CAESAR II, each element is taken at a time with corresponding node numbers and details like size and length in X, Y, Z direction of that element, type of material, wall thickness, and corrosion allowance, type of restraint, insulation thickness, temperature and pressure is entered.

I. Input listing

The size, type and length of each element between the two nodes are given in detail in the results of the analysis report. The element maybe a part of pipe, a flange, a valve, reducer or any other fitting or instrument. Few input listings can be discussed as below.

A pipe element of material A 106 B having diameter of 355.6 mm diameter is there between nodes 10 and 20. It is 130.175 mm long with wall thickness 11.125 mm and having insulation of 50 mm. Its rigid weight is 538.23 N. Between nodes 20 to 30 there is pipe element having length 239.65 mm.

A flange with rigid weight 538.23 N and dimension 130.175 mm in the direction of run of pipe is present between node numbers 30 and 40. After that there is a valve between node numbers 40 and 50 having length 414 mm. Then a flange with rigid weight 538.23 N and dimension 130.175 mm in the direction of run of pipe on next side if valve between nodes 50 and 60.

A long reducing elbow element is present between the nodes 61 to 65. It is a 90° angle elbow. The element between node numbers 400 to 410 is a welding TEE. It is 1725 mm long. Reducers are also used here to connect pipe of different sizes. Between node numbers 630 and 640 reducer is used to connect 12 inch and 10 inch pipes. It has 203mm length

J. Stress summary

Highest Stresses Mini Statement
Various Load Cases
LOAD CASE DEFINITION KEY
CASE 2 (SUS) W+P1
CASE 3 (EXP) L3=L1-L2
Piping Code: B31.3 = B31.3 -2006, May 31, 2007

CODE STRESS CHECK PASSED: LOADCASE 2 (SUS) W+P1

Highest Stresses: (KPa)
Code Stress Ratio (%): 29.5 @Node 420
Code Stress: 40620.4 Allowable: 137895.1
Axial Stress: 5307.7 @Node 510
Bending Stress: 36010.9 @Node 420
Torsion Stress: 1948.2 @Node 389
Hoop Stress: 9514.8 @Node 600

CODE STRESS CHECK PASSED: LOADCASE 3 (EXP) L3=L1-L2

Highest Stresses: (KPa)
CodeStress Ratio (%): 45.9 @Node 160
Code Stress: 153527.2 Allowable: 334474.7
Axial Stress: 3806.4 @Node 75
Bending Stress: 153526.5 @Node 160
Torsion Stress: 15674.2 @Node 389
Hoop Stress: 0.0 @Node 20
[4]

V. CONCLUSION

Isometrics and General arrangement drawings are prepared to meet the process requirements as per the line list and P&ID.

The routed line was stress analyzed to check its sustainability. Pipe supports were provided to the pipes for carrying their weight (pipe weight+ insulation weight+ fluid weight) to avoid vibrations, shock movements for flexibility of the line. Supporting elements were directed towards preventing piping stresses in excess of those permitted in the code, leakage at joints, excessive thrust and movements on connected equipment, excessive stresses in the supporting elements etc. Anchors, Line stops, Guides, Rests were used as for support of the line.

From the results of the stress analysis we can also conclude that, the primary and secondary stresses were within the code allowable limits.

Also the loads on restraints / supports were within the practical limits. There were no abnormal values of loads observed in terms of corresponding pipe sizes.

It’s important to intensify the technical and administrative measures and understanding material strength relationship between treated substances and the equipment. [15]

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