Stress Analysis of Process Piping using Caesar II

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Abstract—*Process piping system are governed by international & codes standards to transport the fluid, steam or air in industries & in many industries plant. The design code ASME 31.3 process piping is the used in this paper which is applied in petroleum refineries, oil and gas industries, chemical plants, textile plant, paper plant, semi-conductor plant and in many industries. Stresses in pipe or in piping system are generated due to load like expansion and contraction due to thermal load seismic load wind load sustained load reaction load etc. The objective of this paper is to Analysis thermal flexibility of expansion loop by CAESAR II software. So that various stress value, displacement, force and expansion are analyzed at each node to make the design at safe operating condition.*

Keywords—Piping systems; CAESAR II; ASME B 31.3; Expansion loop.

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1. INTRODUCTION

CAESAR II:Computer Aided Engineering Stress Analysis & Routing is a complete pipe stress analysis software that allows quick and accurate analysis of piping system subjected to weight, pressure, thermal, seismic and static and dynamic loads. It can analyses piping system of any size and complexity.

Stress Analysis: 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. A hot piping system will expand or elongate. A cold piping system will contract or shrink. Both these create stress problems. Stress analysis determines the forces exerted in the pipe, anchor points, restraints in piping system, stress included in pipe must be checked against the allowable limits as per the respective codes and standards. For a given a piping system the type of analysis to be carried out depends upon the size of the pipe, temperature and connected equipment.

Codes and Standards:In order to satisfy the safety requirements ,local regulations, design constraints of clients, piping systems have to be designed and built according to determine codes and standards.

Piping codes:

- ASME B 31.1 - Power Piping
- ASME B 31.2 - Fuel gas Piping
- ASME B31.3 - Process Piping
- ASME B31.4 - Liquid Piping
- ASME B31.5 - Refrigeration Piping
- ASME B 31.8 - Gas Distribution and Transportation
- ASME B 31.11- Slurry Piping

ASME B31.3 process piping covers almost all the requirements to design, erection testing of piping system. The stress analysis requirement detailed in this code. And also establishes the allowable stresses, the design, the fabrication, the erection the tests, the fatigue resistance and the operation for non-nuclear piping systems. For the paper we are particularly interested in the facilities covered by the code 31.3.

2. THERMAL EXPANSION

All pipe and vessels expand and contract in direct proportion to a temperature change .This can be due to temperature of the flowing media or from surrounding ambient temperature. Wind chill and solar gain are also factors that should be considered.

$$X = L(T_1 - T_2)C_{exp}$$

Where,
X -Expansion or Contraction (m)
L- Length of the pipe or vessel (m)
T_1 - Starting temperature (°F)
T_2 - Final temperature (°F)

TABLE 1 *Co-efficient of thermal expansion for common pipe material.*

MATERIAL	CO-EFFICIENT
Copper	16.4×10^{-6}
Carbon steel	12.2×10^{-6}
Stainless steel(austenitic)	16.3×10^{-6}
Stainless steel (ferritic)	10.9×10^{-6}
Cast iron	11.0×10^{-6}

Expansion rate of common material at various temperature are follows as:

Table 2 *Temperature change rate of thermal expansion for common pipe materials (mm/m).*

°C	COPPER	CARBON STEEL	STAINLESS STEEL
10	0.16	0.12	0.16
30	0.49	0.37	0.49

50	0.82	0.69	0.82
70	1.15	0.85	1.14
100	1.64	1.22	1.63
150	2.46	1.83	2.45
200	3.28	2.44	3.26
250	-	3.05	4.08
300	-	3.66	4.89

3. EXPANSION LOOP

Expansion loops are used to release the stresseswhich produced due to thermal gradients. All pipes will be installed at ambient temperature. Pipes carrying hot fluids such as water or steam operate at higher temperatures. It follows that they expand, especially in length, with an increasefrom ambient to working temperatures. This will create stress uponcertainareas within the distribution system, such as pipe joints, which, in the extreme, could fracture. Therefore the piping system must be sufficiently flexible to accommodate the movements of the components as they expand .The expansion loop is one of method of accommodating expansion. These loop are placed with in a line, and are designed to accommodate the expansion, without the total length of the line changing.
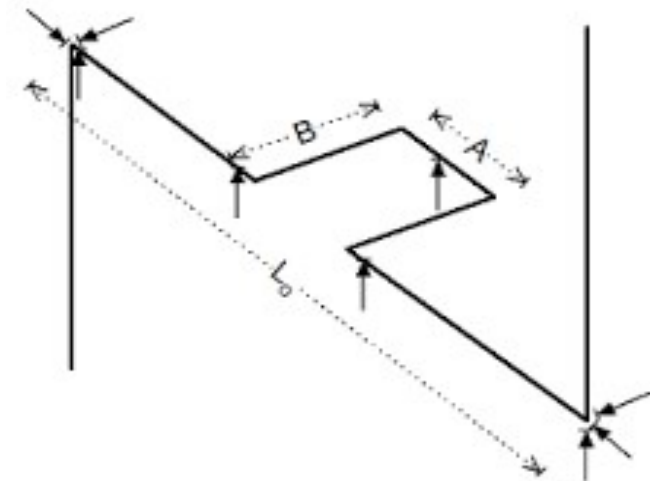

Fig 1: Expansion loop

4. PIPE STRESS PRIORITY PIPING

A.Selection criteria listed below
The following selection criteria apply:
1) All lines at design temperature above 180℃.
2) 4'' NPS and larger at design temperature above 130℃.
3) 16'' NPS and larger at design temperature above 105℃.
4) All lines with design temperature below -30℃ and wherethe largest possible T>190℃.
5) Lines 4'' and larger with design temperature below -30℃ and where the largest possible T> 140℃.
6) Lines 16'' and larger with design temperature below - 30℃ where the largest possible T >115°C.

B.Flexibility Analysis: Flexibility analysis is done on the piping system to study its behavior when its temperature changes from ambient to operating, so as to arrive at the most economical layout with adequate safety.

The following are the considerations that decide the minimum acceptable flexibility on a piping configuration.
1) The maximum allowable stress range in system
2) The limiting values of forces and moments that the piping system is permitted to impose on the equipment to which it is connected.
3) The displacement within the piping system.
4) The maximum allowable load on the supporting structure.

According to the ASME B 31.3 Code the stress to which a piping system is subjected may be separate in three main classes, for which the codes establish limits;
1) The stresses caused by sustained loads
2) The stresses caused by occasional loads
3) The stresses caused by thermal

Sustained loads: These loads are expected to be present throughout the plant operation e.g. pressure and weight.

Occasional loads: These loads are present at infrequent intervals during plant operation e.g. earth quake, wind, etc.

Expansion loads: These are the loads due to displacement of piping .e.g. thermal expansion seismic anchor movement and building settlement.

5. PROCEDURE FOR STRESS ANALYSIS

The procedure for stress analysis are as follows,
1)Identify the possible loads that occur in piping systems during the life of the plants (self-weight, wind, seismic etc.)
2) Relate each of these load to the stress developed
3) Get the cumulative effect of the possible load in the system
4) As per allowable load at connection and find the stress and compensate the effect of place supports and loop if required.
5) As per the allowable limit find the deformation and place the supports as per requirement.
6) After the system is designed, to ensure that the stresses are the safe within the limit.

6. EXPERIMENTAL RESULT USING CAESAR II

A. Inputs for Linear pipe stress analysis

Pipe diameter: 14.961 in
Operating Pressure: 43.5123 lb./sq.in.
Design Pressure: 79.7726 lb./sq.in
Operating Temperature: 329°F
Design temperature: 383°F
Material: A106 B
Output for Linear pipe stress analysis

CODE COMPLIANCE EVALUATION FAILED

Highest Stresses: (lb./sq.in.)

Ratio (%): 220.5 at Node 90
LOADCASE: 7 (EXP) L7=L3-L5

Code Stress: 102824.9

Allowable Stress: 46631.8

Axial Stress: 102824.9 at Node 80
LOADCASE: 7 (EXP) L7=L3-L5
Bending Stress: 6857.2 at Node 40
LOADCASE: 4 (SUS) W+P1
Torsion Stress: 0.0 at Node 20
LOADCASE: 1 (HYD) WW+HP
Hoop Stress: 1607.5 at Node 30
LOADCASE: 5 (SUS) W+P2
Max Stress Intensity: 177913.3 at Node 90
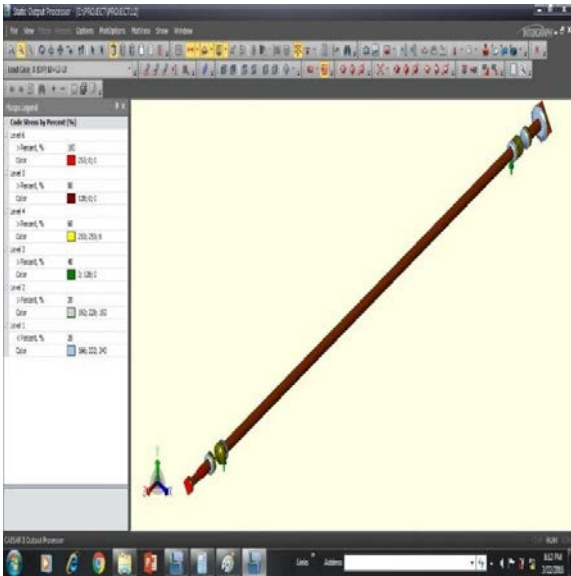LOADCASE: 3 (OPE) W+T2+P2
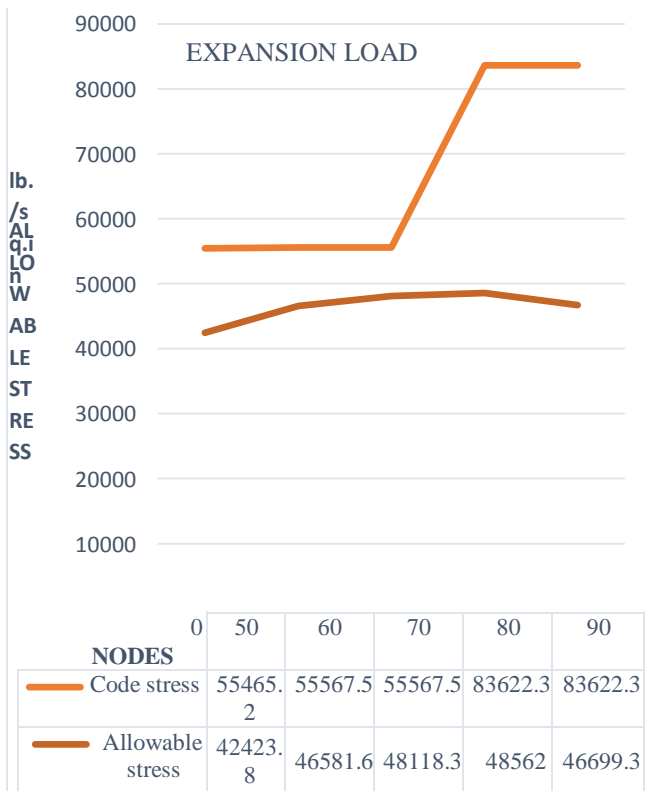

Fig 2: Analysis of linear pipe

B. Inputs for Expansion Loop
Pipe diameter: 14.961 in
Wall thickness: 4.409 in
Operating Pressure: 43.5123 lb./sq.in.
Design Pressure: 79.7726 lb./sq.in
Operating Temperature: 329
Design temperature: 383
Material: A106 B Carbon steel
Output for Expansion loop
CODE COMPLIANCE EVALUATION PASSED
Highest Stresses: (lb./sq.in.)
Ratio (%): 63.0 at Node 46
LOADCASE: 7 (EXP) L7=L3-L5
Code Stress: 29500.8
Allowable Stress: 46822.9
Axial Stress: 24742.9 at Node 30
LOADCASE: 7 (EXP) L7=L3-L5
Bending Stress: 14847.6 at Node 450
LOADCASE: 3 (OPE) W+T2+P2
Torsion Stress: 2419.4 at Node 80
LOADCASE: 4 (SUS) W+P1
Hoop Stress: 1607.5 at Node 30
LOADCASE: 5 (SUS) W+P2
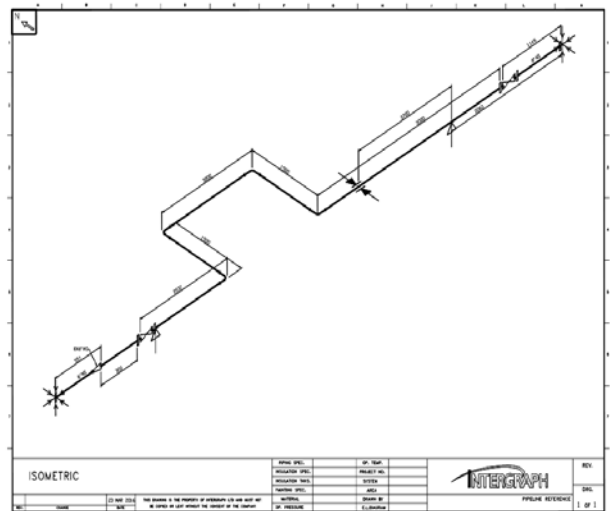Max Stress Intensity: 46614. 9 at Node 46
LOADCASE: 3 (OPE) W+T2+P2

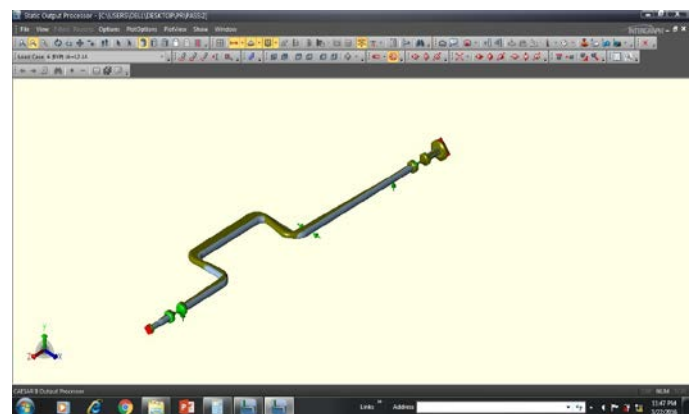

Fig 4: Stress Isometric drawing

EXPANSION LOAD

NODES	0	50	60	70	80	90
Code stress		55465.2	55567.5	55567.5	83622.3	83622.3
Allowable stress		42423.8	46581.6	48118.3	48562	46699.3

Fig 3: Allowable stress Vs Code stress for linear pipe

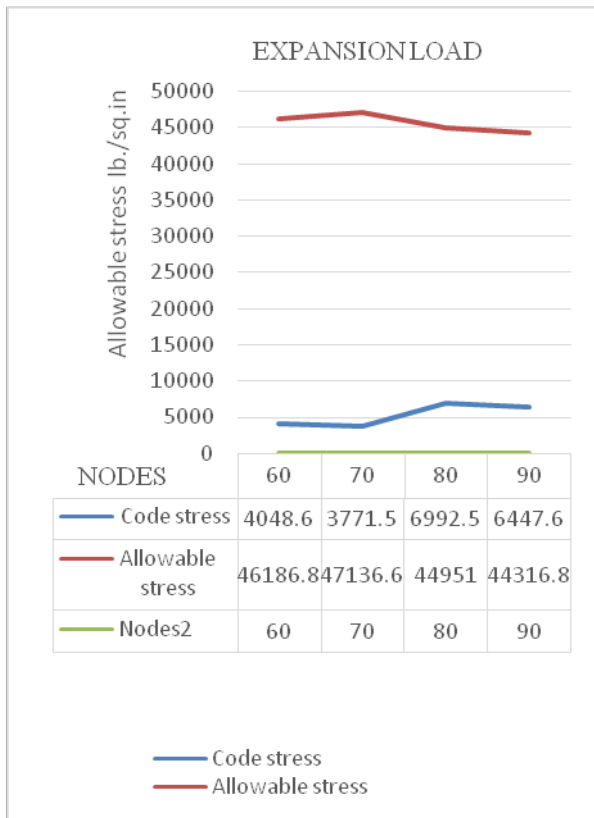*Fig 5: Analysis of Expansion loop*

Fig 6: Allowable stress vs Codes stress for Expansion loop

7. CONCLUSION

The objective of the work is to summarize thermal expansion of a linear pipe and increasing thermal flexibility using expansion loop, to prevent from overloading and overstressing the piping components and connected equipment. It is experimentally concluded that pipe loops are very effective way to increase system'sflexibility.

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