

FLEXIBILITY ANALYSIS OF PIPE LINES OF BUNSEN SECTION OF IODINE-SULFUR THERMOCHEMICAL PROCESS

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ABSTRACT

Hydrogen is considered as one of the potential energy carriers in future sustainable energy economy. Hydrogen can be produced by several routes. Iodine-Sulfur (I-S) thermo-chemical cycle is widely considered as most promising one. Bunsen reaction is one of the key steps in Iodine Sulfur (I-S) thermo-chemical cycle. Bhabha Atomic Research Centre is involved in the development of I-S process. The pipe lines used in the I-S process are not of conventional type but these are of jacketed type, hence the analysis become more complicated. Since the various pipe lines carry hazardous fluids at high temperature & pressure, ensuring its integrity is very important. This paper deals with flexibility analysis of pipelines of Bunsen Section Project. The required flexibility has to be built in the pipe line. A few pipelines such as H₂SO₄ Feed line, H₂SO₄Product line, Iodine line, N₂ line, HI_x Product line, Scrubber line etc, where problems were observed in the codal qualification, additional flexibility were introduced to reduce the stresses. The problems identified & the solutions arrived at based on the analysis are elaborated with the help of a few case studies in this paper. These analytical experiences will be helpful for qualifying higher temperature (upto 1000 °C) sulfuric acid section piping later.

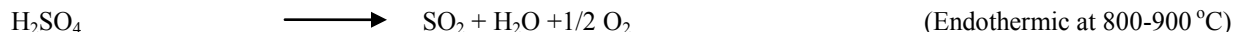
INTRODUCTION

Hydrogen is considered as one of the potential energy carriers in future sustainable energy economy. Hydrogen can be produced by several routes. Iodine-Sulfur (I-S) thermo-chemical cycle is widely considered as most promising one. Bunsen reaction is one of the key reaction steps in Iodine & Sulfur thermo-chemical cycle to produce H₂ for which following three chemical reaction steps are involved:

Bunsen Reaction



Decomposition of H₂SO₄



Decomposition of HI



Out of the above three reactions, first reaction is called Bunsen Reaction. To begin with, the work on the development of metallic system to carry out Bunsen reaction is in progress at Bhabha Atomic Research Centre. The system consists of many pipelines connecting vessels & equipment. This paper deals with the flexibility analysis of the piping systems of the Bunsen Section Project.

SYSTEM DESCRIPTION

Bunsen Section Project deals with a part of thermo-chemical iodine sulfur process. In this section SO₂, I₂ & H₂O are reacted to generate H₂SO₄ & HI. This is a closed loop process in which H₂O & heat are the inputs, H₂ is the product & O₂ is the by-product. The pipe lines used in this project are of jacketed type. Since the inner pipe contain hazardous fluids, so the integrity of various pipe lines at operating conditions is very important. The required

flexibility has to be built in the pipeline such that stresses do not exceed allowable limit in any section of piping making it unsafe [1].

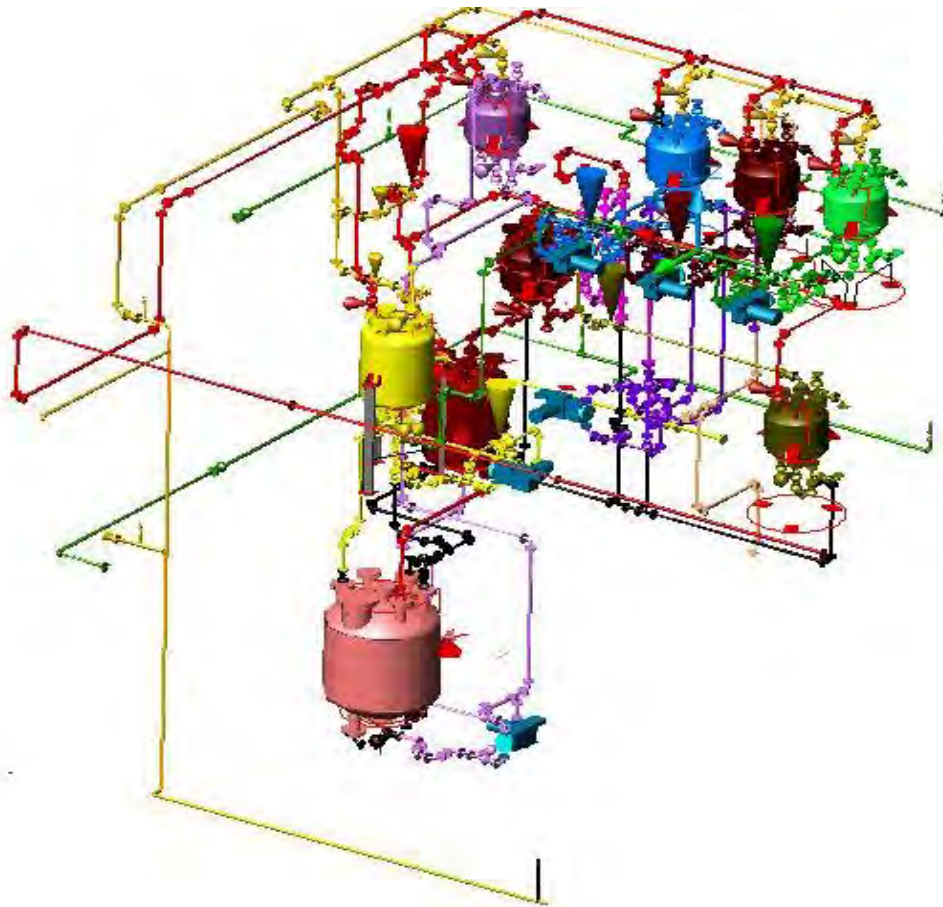


Fig. 1: Bunsen Section Project Pipe lines

CODAL QUALIFICATION

The design code for Bunsen Section pipe line is Power Piping Code ASME B31.1. Codal qualifications of all the pipe lines have been carried out as per codal provisions in the following manner [2]:

Stress Due To Sustained Loads

The effects of pressure, weight & other sustained mechanical loads shall meet the following requirement.

$$S_L = [\{(PD_o)/4t_n\} + (0.75i M_A/Z)] \leq 1.0 S_h \quad (1)$$

Where

P = Design pressure

D_o = Outside pipe dia.

M_A = Resultant moment loading due to wt. & other sustained loads

Z = Section Modulus

i = Stress intensification factor (the product 0.75i shall never be taken as less than 1.0)

S_L = Sum of the longitudinal stresses due to pressure, wt, & other sustained loads.

S_h = Allowable Stress of the piping material at operating temp.

Thermal Expansion Stress Range

The effects of thermal expansion range shall meet the following requirement.

$$S_E = \{i M_C/Z\} \leq \{S_A + f (S_h - S_L)\} \quad (2).$$

Where

$$S_A = f (1.25S_C + 0.25 S_h) \quad (3)$$

M_C = Range of Resultant moments due to thermal Expansion

Z = Section Modulus

i = Stress intensification factor (the product $0.75i$ shall never be taken as less than 1.0)

f = Stress range reduction factor for cycling conditions for total number N of full temp cycle

S_L = Sum of the longitudinal stresses due to pressure, wt, & other sustained loads.

S_h = Allowable Stress of the piping material at operating temp.

S_C = Allowable Stress of the piping material at room temp

If the Eq. (1) & Eq. (2) are satisfied then the layout will be flexible enough to take care of stresses due to sustained loads & thermal expansion loads.

FEM MODELING OF PIPING LOOPS

The systems have been divided into twelve piping loops depending on the anchor locations. FEM model has been prepared for all the piping loops using elements of pipe, elbow & tee. The jacketed piping has been modeled in such a way as to ensure that the movement of end points for both outer & inner pipe during thermal expansion should be same at connection points to the rigid elements. The connection points of piping to the vessel are considered as anchor points in the modeling. The inner pipes are of size 33.4 mm OD and 3.38 mm thick (size: 25 NB Sch 40). The outer pipes are of size 60.3 mm OD and 3.91 mm thick (size: 50 NB Sch 40). The outer pipelines are insulated with glass wool having thickness 40 mm. The material of construction of the pipeline is SA-106 Gr B (Carbon steel).

All the layouts have been analyzed for the design conditions. The results have been checked as per the requirements of ASME Power Piping Code B31.1. The stresses due to pressure, temperature, weight & other sustained loads are compared with the code allowable limits. It was found that for a few layouts, stresses were exceeding the allowable limits at a few locations for thermal loading. The problems were solved with the addition of extra flexibility. With these modifications the stresses could be brought well within code allowable limits. A few case studies have been presented below in this paper where stresses were exceeding the allowable limits and it could be brought within limits through layout modifications.

CASE STUDIES**H₂SO₄ Feed Line****Loop Description**

One end of the H₂SO₄ feed line is connected to H₂SO₄ feed tank and other end is connected to DM water line as shown in the Fig.2.

Table 1: Design Conditions of H₂SO₄ feed line

Inner Pipe Line		Outer Pipe Line	
Design Temp	120 oC	Design Temp	150 oC
Design Pressure	8 bar	Design Pressure	4 bar
Fluid used	H ₂ SO ₄	Fluid used	Thermic fluid

Preliminary Analysis and Results

In the initial analysis of the H₂SO₄ feed loop, the stresses were found to be more than the allowable as shown in the Fig.2.

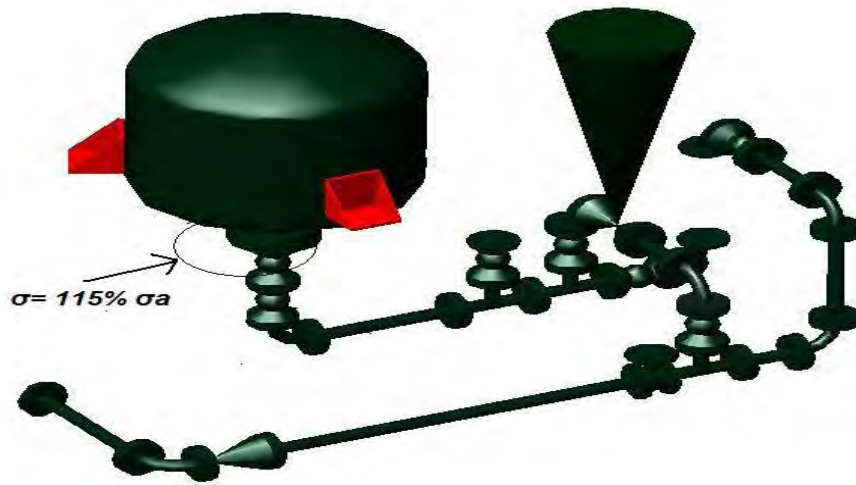


Fig. 2: H₂SO₄ Feed Line (Initial 3-D Layout)

Results With Modification

It was observed from the initial piping layout that at one location, thermal stress was higher than the allowable limit. Hence, the different piping length & looping were tried to add more flexibility to the existing piping layout. Many possibilities were explored to bring down the thermal stresses during operating condition. Fig.3 shows the inclusion of a loop as the final suggested change to bring the stress well within the allowable limit.

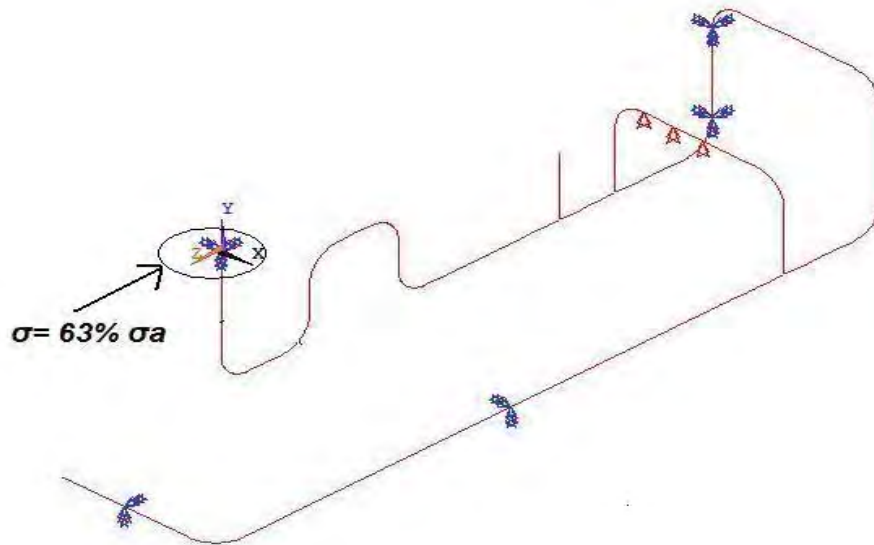


Fig. 3: FEM Models of H₂SO₄ Feed Line (Modified Final Layout)

Table 2: FEM Results of H₂SO₄ feed line

S.No.	Name of the pipeline layout	Actual stress before modification (% of allowable stress)	Actual stress after modification (% of allowable stress)
1	H ₂ SO ₄ Feed Line	115%	63%

HI_x Distillation Line

Loop Description

One end of the HI_x Distillation Line is connected to HI_x Distillation tank and other end is connected to waste liquid tank as shown in the Fig.4.

Table 3: Design Conditions of HI Distillation line

Inner Pipe Line		Outer Pipe Line	
Design Temp	120 oC	Design Temp	150 oC
Design Pressure	8 bar	Design Pressure	4 bar
Fluid used	HI	Fluid used	Thermic fluid

Preliminary Analysis and Results

In the initial analysis of the HI_x Distillation loop, the stresses were found to be more than the allowable as shown in the Fig. 4.



Fig. 4: HI_x Distillation Line (Initial 3-D Layout)

Results with Modification

It was observed from the initial piping layout that at one location, thermal stress was higher than the allowable limit. Hence, the different piping length & looping were tried to add more flexibility to the existing piping layout. Many possibilities were explored to bring down the thermal stresses during operating condition. Fig.5 shows the inclusion of a loop as the final suggested change to bring the stress well within the allowable limit.

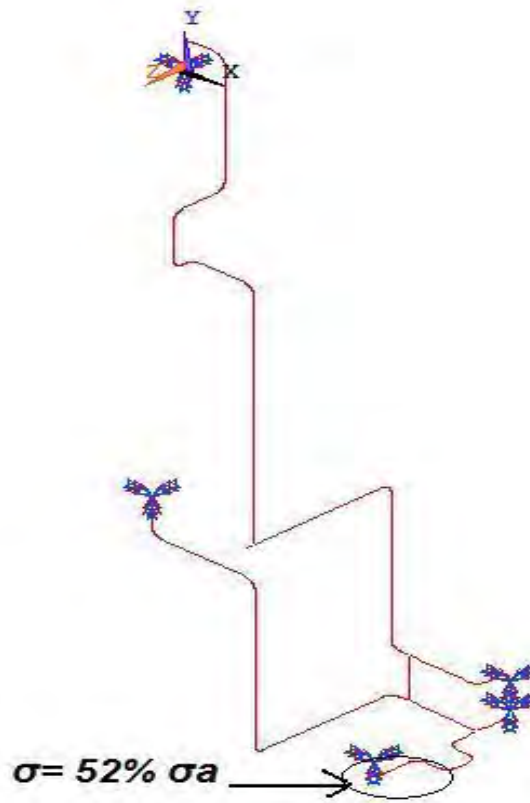


Fig. 5: HI_x Distillation Line (Modified Layout)

Table 4: FEM Results of HI Distillation line

S.No.	Name of the pipeline layout	Actual stress before modification (% of allowable stress)	Actual stress after modification (% of allowable stress)
1	HI Distillation Line	111%	52%

Iodine Line

Loop Description

One end of the Iodine Line is connected to Iodine tank and other end is connected to Chlorine tank as shown in the Fig.6.

Table 5: Design Conditions of Iodine line

Inner Pipe Line		Outer Pipe Line	
Design Temp	120 oC	Design Temp	150 oC
Design Pressure	8 bar	Design Pressure	4 bar
Fluid used	Iodine	Fluid used	Thermic fluid

Preliminary Analysis and Results

Analysis carried out on the initial layout showed that the stresses due to sustained loads were well within the allowable limit (i.e. Eq. (1) is satisfied). The stresses for thermal loading conditions were found exceeding the codal limits by 9% in the region shown in Fig.6 (i.e. Eq. (2) is not satisfied).

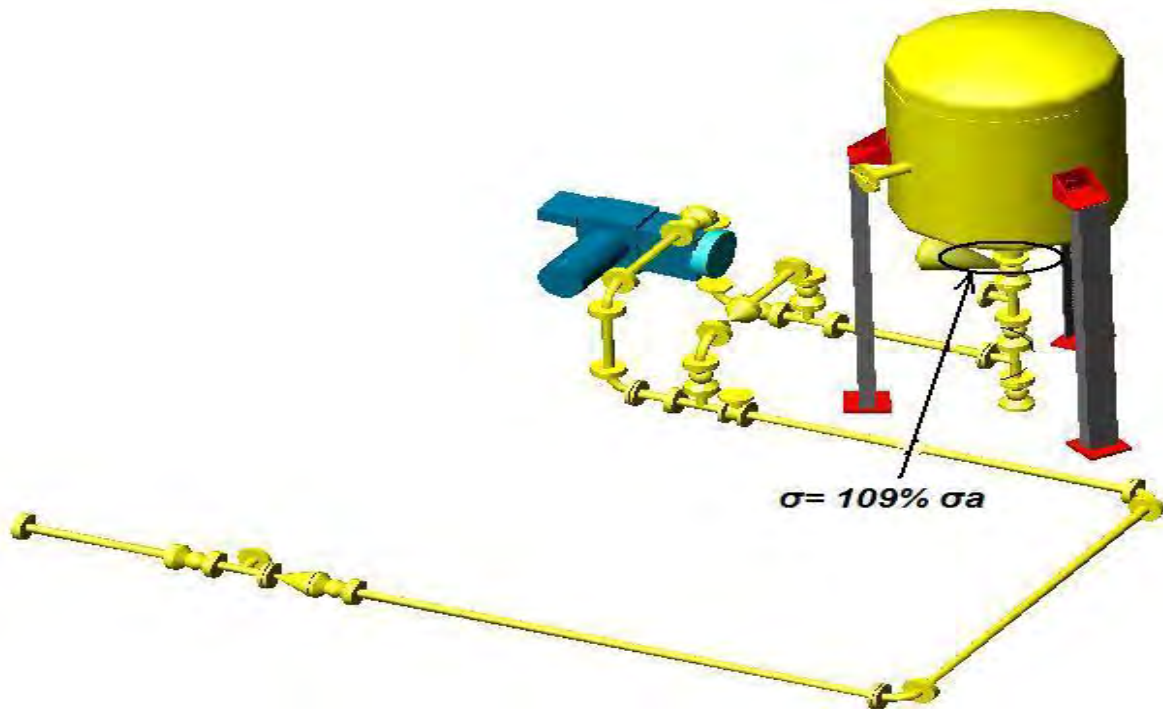


Fig. 6: Iodine Line (Initial 3-D Layout)

Results with Modification

It was observed from the initial piping layout that at one location, thermal stress was higher than the allowable limit. Hence, the different piping length & looping were tried to add more flexibility to the existing piping layout. Many possibilities were explored to bring down the thermal stresses during operating condition. Fig.7 shows the inclusion of a loop as the final suggested change to bring the stress well within the allowable limit.

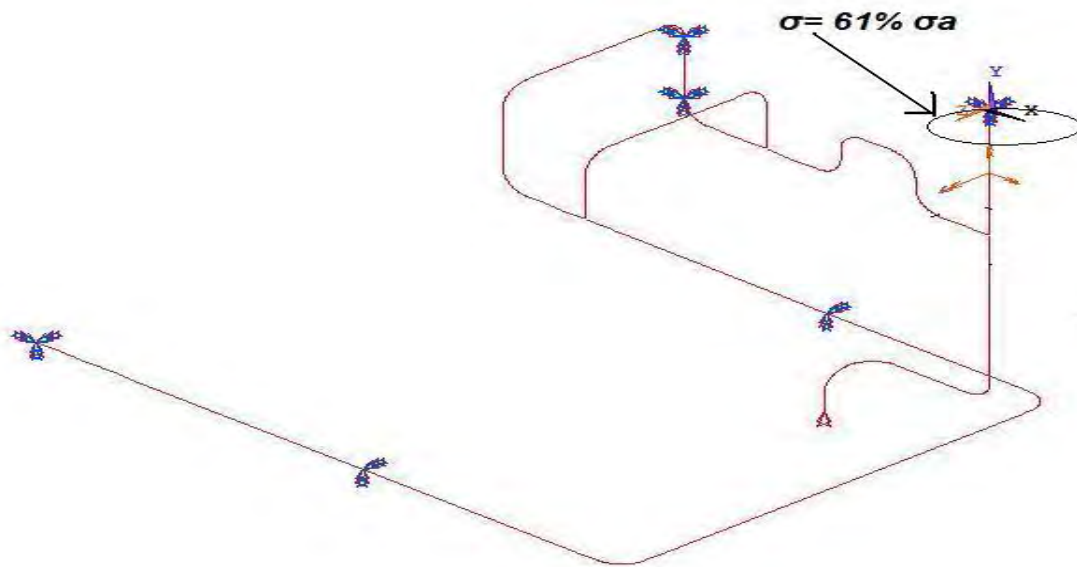


Fig. 7: Iodine Line (Modified Layout)

Table 6: Results of Iodine line

S.No.	Name of the pipeline layout	Actual stress before modification (% of allowable stress)	Actual stress after modification (% of allowable stress)
1	Iodine Line	109%	61%

CONCLUSIONS

The pipelines of Bunsen Section project are analyzed for design conditions. Flexibility analysis has been carried out for all the pipelines. In some of the layouts, stresses were found to be more than the allowable limits. Hence flexibility has been increased by changing the length of pipe & by including loops. Supporting arrangements have been finalized for various pipelines. The analysis carried out with the modified layout along with suggested supports showed that the stresses for sustained as well as thermal loadings are well within the codal limits for all the layouts.

REFERENCES

- [1] **Piping** Design & Flexibility Analysis by Kellogg
- [2] **ASME** Power Piping Code B31.1