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(Review Article)

Thermal shock: A flange leakage cause

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Abstract

Flange leakage due to thermal shock is a critical issue in piping systems. This paper presents a comprehensive case study on the impact of thermal shock on flange leakage in piping systems. It explores the phenomenon where a sudden increase in operating temperature can compromise the integrity of flanged joints, leading to leakage. The study delves into the thermal response of flanges and how it can precipitate a loss of bolt loading, resulting in a decrease in gasket seating pressure. Through detailed analysis, the paper discusses the steady-state operation of flanges, temperature variations within piping systems, and the events of thermal transients. It further evaluates the effects of forced displacement on bolt stress and the subsequent impact on flange stability.

Keywords: Flange Integrity; Bolt Loading; Gasket Seating Pressure; Bolt Stress; Flange Stability; Quality Assurance

1. Introduction

How sudden increase in temperature can result in leakage at flange joints, i.e., how a thermal transient at a flange joint can lead to loss of bolt loading and hence loss of gasket seating pressure. As per *Nirmal Surendran Menon [1], Pipeline operating at high temperature moves upwards/downwards (depending on the pipe configuration) due to thermal expansion, any rigid support provided on such a line tends to lift pipe up/down and hence remain inactive during operating conditions,* so in order to further understand how temperature increase can lead to flange leakage, this paper throws some light into the thermal response of a flange, how the thermal response of a flange can cause loss of bolt loading and the alleviation measures.

2. Steady State Operation of Flange

During steady state operation, a flange has a constant temperature field which depends on the operating Temperature: $T_{ope,}$ the influx of the heat, and loss of heat to its surroundings (Fig.2a)

(An operation is considered to be at a steady state with respect to an operation variable if that variable does not change with time)

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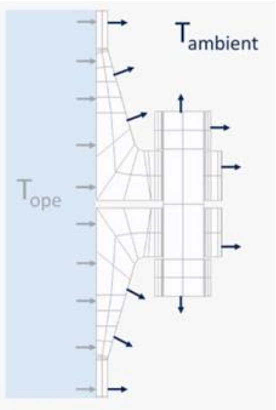

Figure 2a Steady State Operation of Flange – Constant Temperature

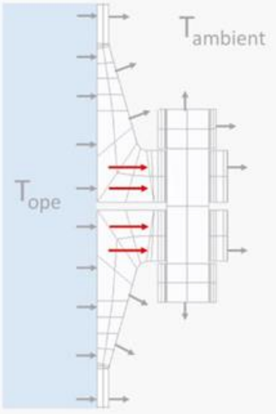

Figure 2b Heating of Bolts by convection

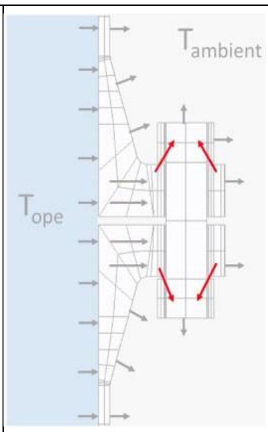

Figure 2c Heating of Bolts by conduction

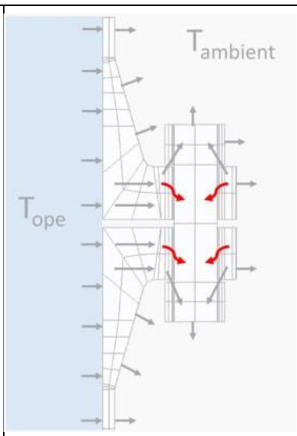

Figure 2d Heating of Bolts by radiation

Now that the heat conductivity in metal is relatively high, the temperature on an average will be constant throughout the material (Fig.2a) which includes the flange bolts which gets heated up by heat conduction (Fig.2b) through the nuts (Fig.2c) and radiation directly to the bolts (Fig.2d).

3. Temperature in Piping System

When the operating temperature (T_{ope}) in the pipe system increases, additional heat is transferred into the metal. See Fig.3a and Fig.3b

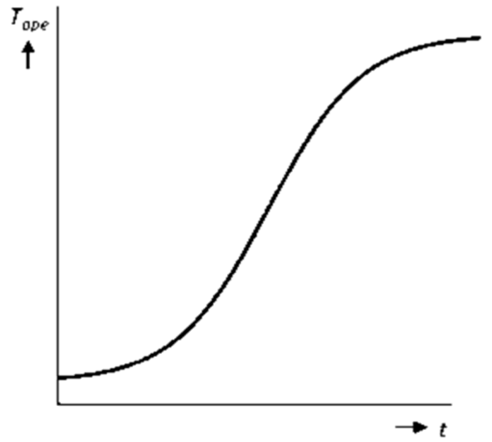

Figure 3a T_{ope} vs Time (t)

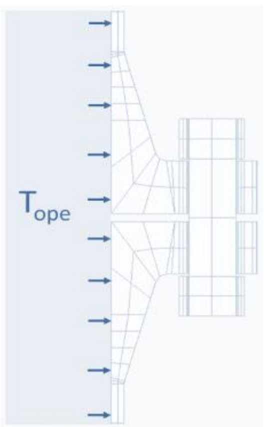

Figure 3b T_{ope} on Pipe Flange

If a quick increase in temperature is considered, it can be seen that some time is needed to warm up the flange and to create a new equilibrium temperature, during which time a thermal gradient travels through the metal which is considered a ***thermal transient event (Thermal Transient Event - A thermal transient event is a thermal response that occurs when an object's temperature changes over time, such as when it heats up or cools down) - T (x, t)***.

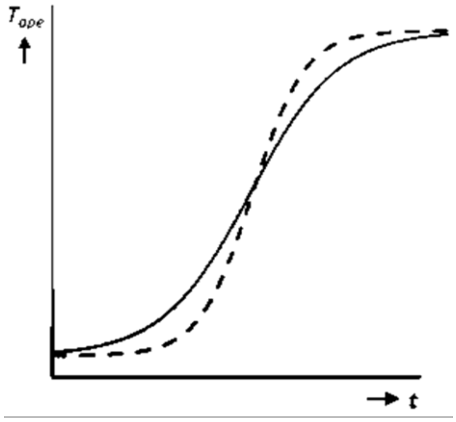	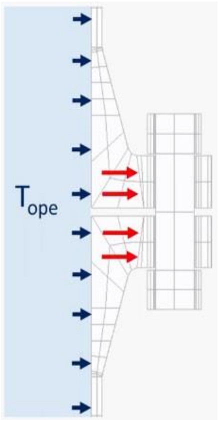
Figure 3c Thermal Transient Event – T_{ope} vs Time (t)	**Figure 3d** Thermal Transient Event effect on Flange

4. Thermal Transient Event

Transient thermal analysis is the evaluation of how a system responds to fixed and varying boundary conditions over time. In order to investigate the thermal transient event in a pipe flange, a piping apparatus is setup for the analysis where in the temperature in the system will rise from 86°F (30°C) to 572°F (300°C) in 3 seconds. The temperatures will be monitored at the center of the flange (Fig.4a) and center of the bolt (Fig.4b)

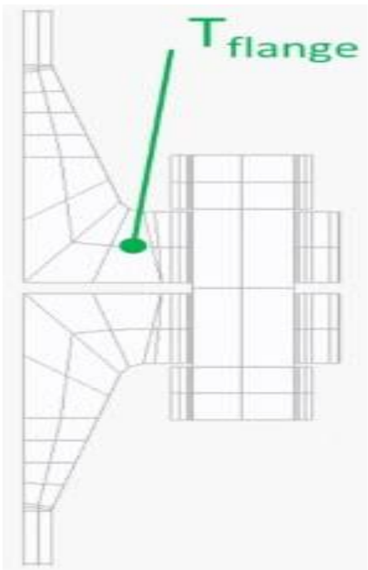	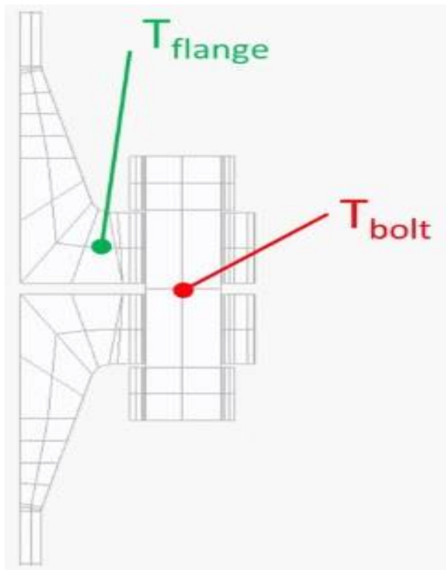
Figure 4a Temperature Increase – Centre of Flange	**Figure 4b** Temperature Increase – Centre of Bolt

After running the thermal transient analysis, it has been revealed that the temperature on the flange rises in direct proportion as the pipe operating temperature.

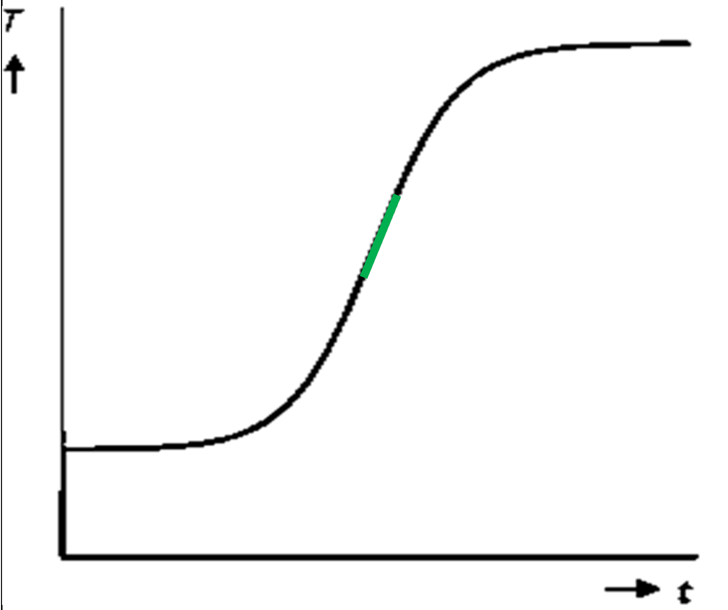	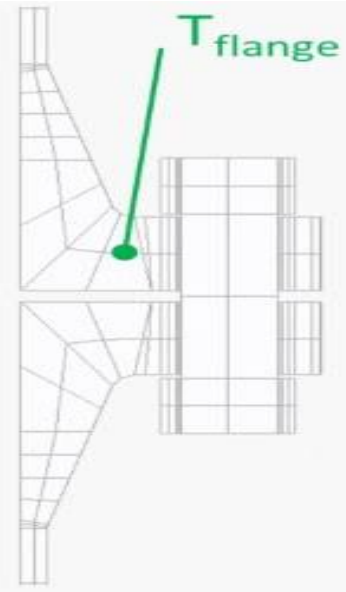
Figure 4c Rise of Temperate on Flange – Thermal Transient Analysis	**Figure 4d** Rise of Temperate on Flange – Random Location

The increase in bolt temperature is also in direct proportion as the pipe operating temperature but with a slight lag/delay as shown in Fig.4e.

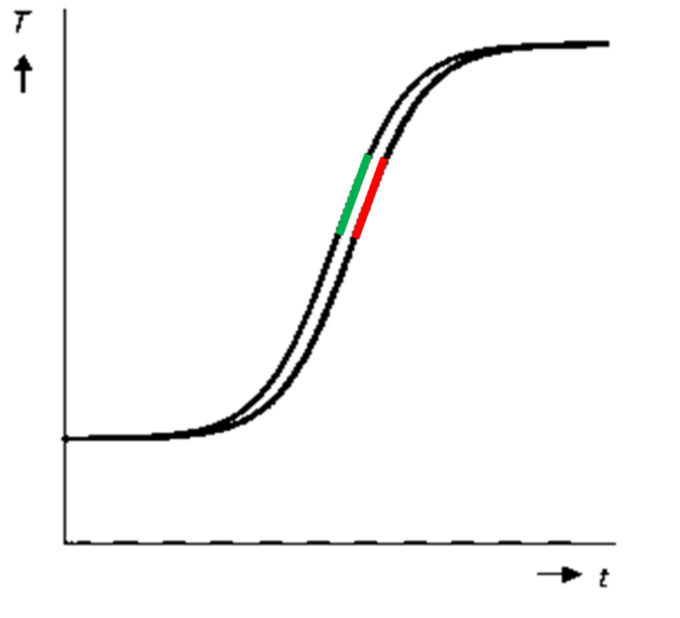	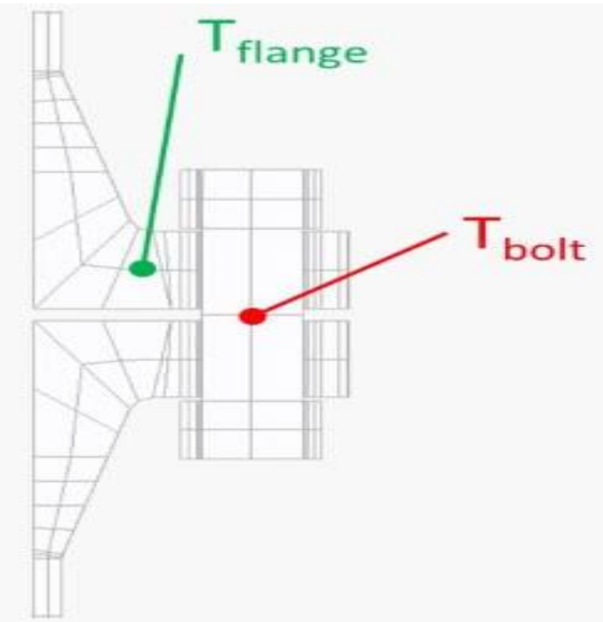
Figure 4e Bolt Temperature Increase vs Flange Temperature Increase	**Figure 4f** Random spots of Bolt Temperature and Flange Temperature

The bolt temperatures lags behind that of the flange temperature as it takes some time for the heat to be transferred into the bolt as a result of which a temperature difference arises between the flange and the bolt which is then reduced again as the bolt catches up and reaches its final temperature.

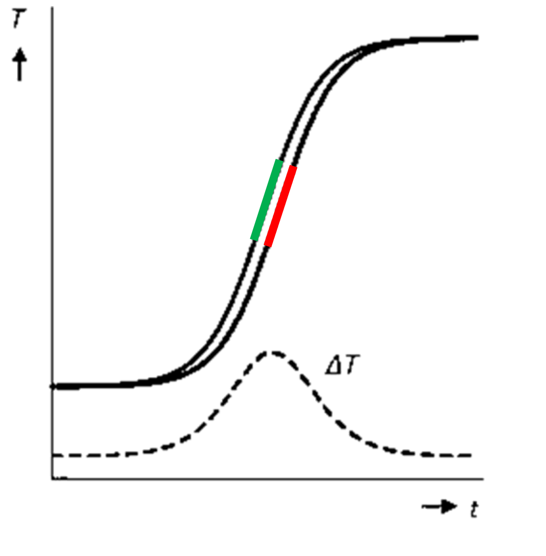

Figure 4g Thermal Expansion Difference between Flange and Bolt over time

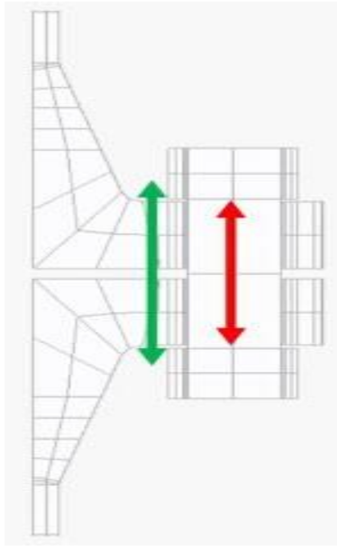

Figure 4h Increase in Flange Thickness

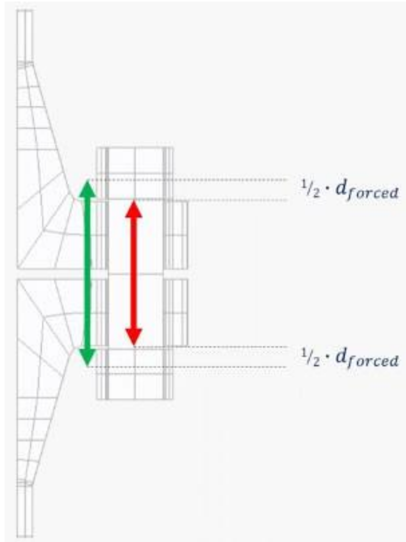

Figure 4i Forced Displacement – Flange vs Bolt

This temperature difference is crucial as it also causes a difference in thermal expansion between the flange and the bolt (Fig.4g). Looking at the actual direction, the thickness of the flange will increase due to thermal expansion (Fig.4h), but the temperature of the bolt lags behind the flange temperature and hence as a result, the flange will force a displacement onto the bolt which is equal to the difference in the thermal expansion (Fig.4i). This forced displacement is temporary and will be reduced when the temperature of the bolt catches up with that of the flange (Fig.4j & Fig.4k). *Per Menon (2021, p. 47) [2], by providing an expansion joints in a piping system, thermal expansion or terminal movement are absorbed where the use of expansion loop is undesirable or impossible.*

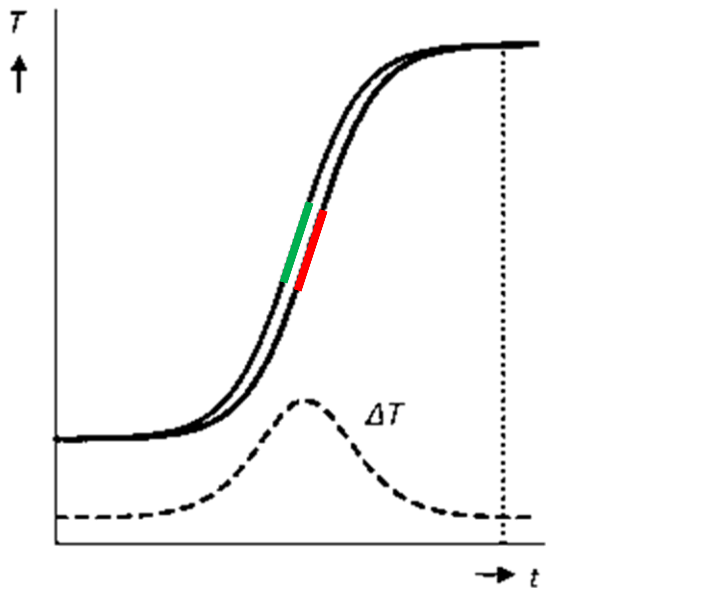

Figure 4j Thermal Equilibrium of Flange and Bolt over time

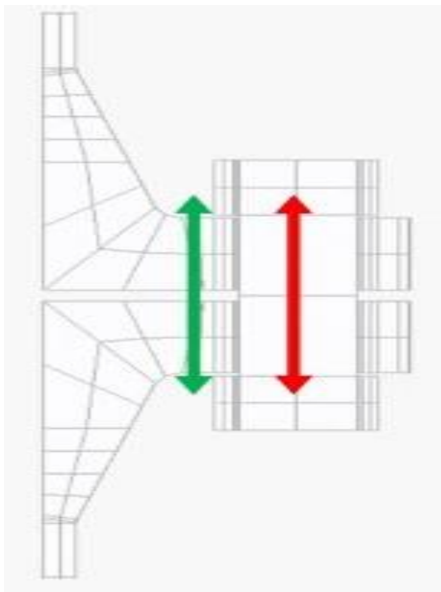

Figure 4k Thermal Equilibrium of Flange and Bolt

4.1. Forced Displacement – Evaluation of Bolt Stress

The material stress in the bolt which is tensile will be positioned somewhere in the elastic region during typical steady state operation as this gives the best control over the tightening of the joint.

Figure 5 Bolt Stress–strain curve showing typical yield behaviour

5. Impact of Forced Displacement

Depending on the piping system configuration, the forced displacement might cause the bolt stress to enter the plastic region causing some amount of plastic deformation. When the temperature of the bolt catches up with the temperature of the flange, the difference in thermal expansion reduces and it is then this amount of plastic deformation which forms a problem as the bolt is now permanently stretched (Fig.5a & Fig.5b).

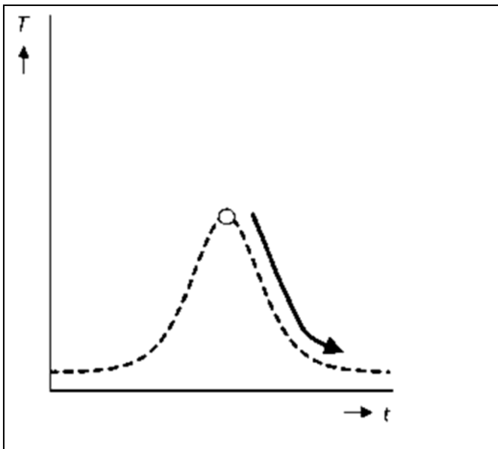

Figure 5a Temperature profile over time

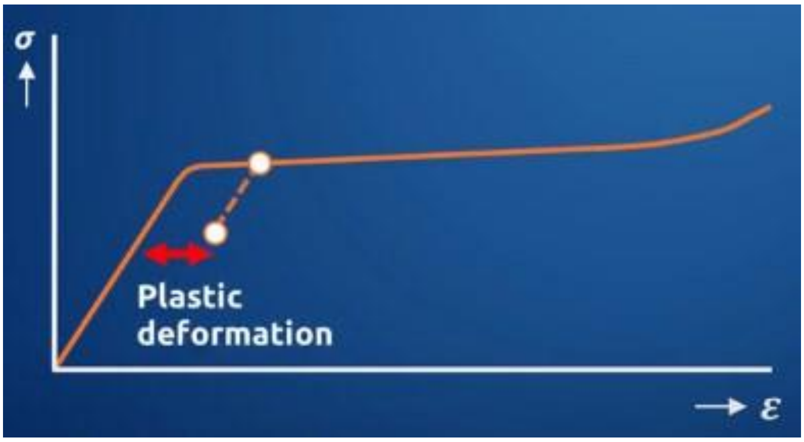

Figure 5b Bolt Plastic Deformation

This causes the seating stress in the bolt to be reduced and hence the seating pressure on the gasket as well (Fig.5c, Fig.5d & Fig.5e). *Menon (2021, p. 35) [2], notes that, Many SWG (*Spiral Wound Gasket) *for critical application induce inner guide ring as well which gives the Gasket better resistance to thermal shock and in case of vacuum service, prevent the filler material being sucked in*.

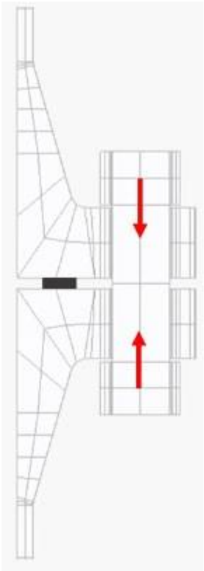	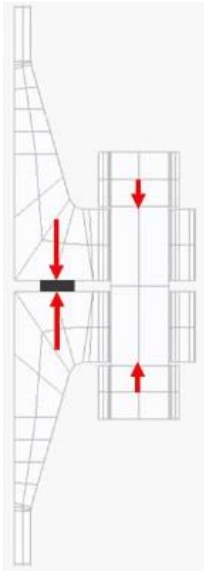	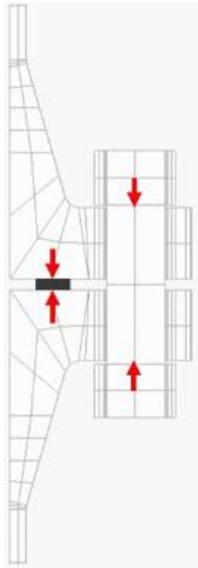	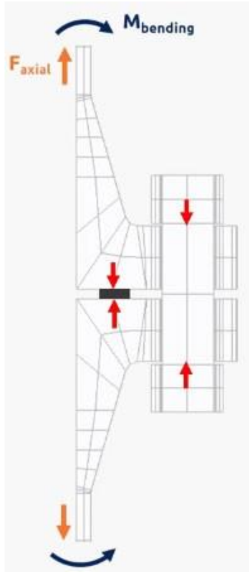
Figure 5c Seating Stress on Bolt	**Figure 5d** Gasket Seating pressure decreasing over decreasing Bolt seating Stress	**Figure 5e** Gasket Seating pressure decreasing over decreasing Bolt seating Stress	**Figure 5f** Axial Load and Bending Moment effect on Flange

As a result, the flange joint is compressed less tightly and might leak when the piping system is subjected to high bending moments or axial loads (Fig.5f).

6. Discussion

A swift rise in operating temperature in a piping system causes a temperature difference between the flange and the bolt as the heat travels into the joint and that the difference in the thermal expansion causes a forced displacement on to the bolt thereby potentially deforming it ***"plastically".***

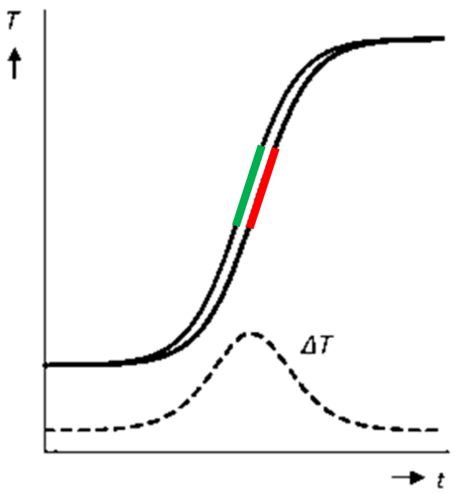	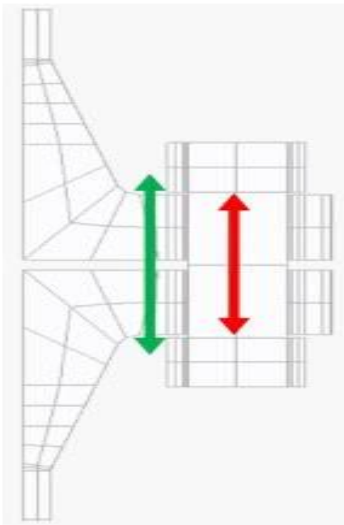	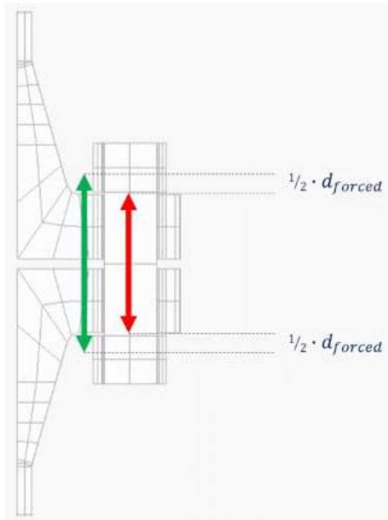
Figure 6a Thermal Expansion Difference between Flange and Bolt over time	**Figure 6b** Increase in Flange Thickness	**Figure 6c** Forced Displacement – Flange vs Bolt

In this experimentation, the radiation heating between the flange and the bolt has not been included. The heat transfer co-efficient has been chosen to provide a clear illustration of the phenomena. The numbers will vary based on the specific parameters of the piping system configuration including the type of flow medium, the material and whether or not the insulation is applied to the piping system including the flange. Also details like, heat conduction between the flange and the nuts can be relevant as these impacts how much the bolt temperature will lag behind the temperature of the flange.

6.1. Mitigation

ASME B31.3, Paragraph 323.4.2 [3], specifies about the use of cast iron other than ductile iron permitted for specified conditions only when safeguarded against excessive heat and thermal shock and mechanical shock and abuse. This paper has clearly thrown light on how flange joint responds to a sudden increase in operating temperature and how this can affect the bolt load, the following throws light on some of the mitigation measures:

6.1.1. Avoid sudden increase in operating temperature

Having a slow and gradual increase in temperature will cause the thermal gradient in the joints to be much lower and thereby minimizing the risk of plastically stretching the bolts.

6.1.2. Reducing thermal gradients

Taking measures to reduce thermal gradients will be beneficial such as by insulating the piping system including the flanges, avoiding corrosion between the flange and bolt nuts (which allows good thermal conduction).

6.1.3. Use of spacers

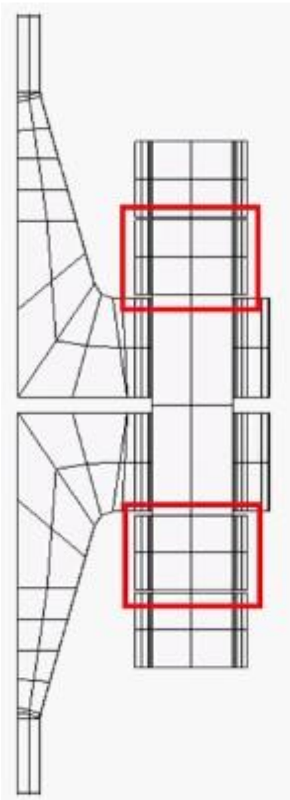

Figure 7a Spacers between Flange

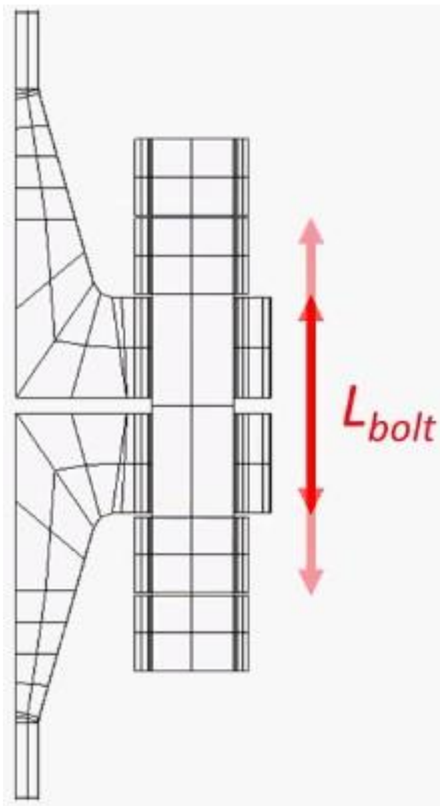

Figure 7b Increase in bolt length due to spacers

The overall length of the bolts used in the flange can be increased by using spacers. It must be remembered that the problem was caused by a forced displacement from the flange to the bolt, hence this displacement is fixed based on the temperatures, but the elongation is determined by the fixed displacement by the material length that will absorb the displacements.

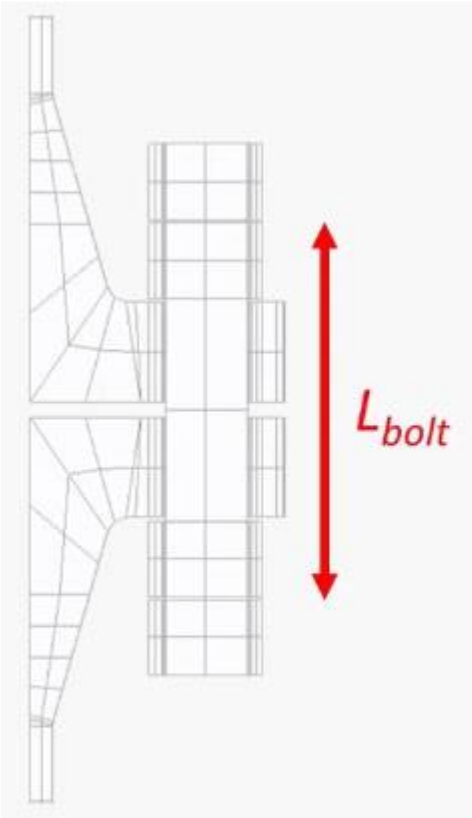

Figure 7c Elongation Determination - $\varepsilon_{forced} = d_{forced}/L_{bolt}$

For longer bolts, the elongation will be lower, which reduces the risk of plastic deformation. All piping systems may not be prone to this phenomenon, but a maintenance engineer or process engineer who works with the systems in which sudden temperature rise are unavoidable, this paper will help to understand such systems.

7. Conclusion

This case study has rummaged up the thermal response of flanges and lead to bolt loading loss scenario and concludes with a summary of findings and proposes mitigation strategies to prevent leakage, including the avoidance of rapid temperature increases, reduction of thermal gradients, and the strategic use of spacers. These measures aim to enhance the reliability and safety of piping systems in industrial applications.

References

[1] Nirmal Surendran Menon, "Pipe Support Design Considerations for Hydrocarbon Facilities", International Journal of Science and Research (IJSR), Volume 8 Issue 2, February 2019, pp. 406-409, https://www.ijsr.net/getabstract.php?paperid=ART20195078

[2] Menon, N. S. (2021). *Process Piping Components Quick Reference Flash Cards*.

[3] B31.3 - Process Piping - (2022) ASME. Available at: https://www.asme.org/codes-standards/find-codes-standards/b31-3-process-piping