Engineering Standard

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Thermal Expansion Relief in Piping

Document Responsibility: Piping Standards Committee

Saudi Aramco DeskTop Standards

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1 Scope

This standard defines the minimum mandatory requirements for the relief of thermal expansion of liquids in piping as a result of temperature rise when the liquid is blocked in. This standard does not apply to thermal expansion of liquids in piping caused by fire.

2 Conflicts and Deviations

2.1 Any conflicts between this standard and other applicable Saudi Aramco Engineering Standards (SAESs), Materials System Specifications (SAMSSs), Standard Drawings (SASDs), or industry standards, codes, and forms shall be resolved in writing by the Company or Buyer Representative through the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

2.2 Direct all requests to deviate from this standard in writing to the Company or Buyer Representative, who shall follow internal company procedure SAEP-302 and forward such requests to the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

3 References

The selection of material and equipment, and the design, construction, maintenance, and repair of equipment and facilities covered by this standard shall comply with the latest edition of the references listed below, unless otherwise noted.

3.1 Saudi Aramco References

Saudi Aramco Engineering Procedure

SAEP-302	*Instructions for Obtaining a Waiver of a Mandatory Saudi Aramco Engineering Requirement*

Saudi Aramco Engineering Standard

SAES-A-112	*Meteorological and Seismic Design Criteria*
SAES-J-600	*Pressure Relief Devices*

Saudi Aramco Standard Drawing

AA-036873	*Pipeline Vents Assembly and Details*

3.2 Industry Codes and Standards

American Petroleum Institute

API MPM CH11.1	*Manual of Petroleum Measurement Standards: Physical Properties Data – Section 1: Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products and Lubricating Oils*
API MPM CH11.2.2	*Manual of Petroleum Measurement Standards: Compressibility factors for Hydrocarbons (0.350-0.637 Relative Density and -50°F to 140°F Metering Temperatures)*

4 Definitions

Thermal Expansion: The tendency of matter to change in volume in response to change in temperature.

Coefficient of Thermal Expansion: A description of how the size of an object changes with a change in temperature. It specifically measures the fractional change in size per degree change in temperature at a constant pressure.

Bulk Modulus Elasticity: A material property characterizing the compressibility of fluid (how easy a unit of the fluid volume can be changed when changing the pressure working up unit).

5 Relief Requirements

5.1 A relief valve shall be provided on each section of a pipeline in liquid service which can be fully blocked in and subsequently can be subject to a temperature rise such that the resulting pressure will exceed the maximum allowable operating pressure. This condition shall be evaluated in each of the situations listed in paragraph 5.3 and a relief valve shall be installed unless a detailed analysis, based on conservative assumptions as stated below, is made and recorded to demonstrate that the piping will not be overstressed.

5.2 Unless a more rigorous analysis is made, thermal expansion calculations shall be based on conservative assumptions including the following:

5.2.1 The pipe section shall be assumed to be blocked in under the following conditions:

a) while at the ambient temperature or at the normal operating temperature whichever is lower;

b) while at highest expected pressure.

5.2.2 Solar radiation of 950 W/m² (300 Btu/hr.ft²) shall be assumed during 10 hours on the projected area of the exposed pipe surface.

5.2.3 Any temperature rise of buried or insulated pipelines which normally operate at or above ambient temperature may be disregarded.
The temperature of refrigerated liquids in buried or insulated lines shall be assumed to rise to the ambient after being blocked in at normal operating temperature.

5.2.4 The heat loss of the exposed pipe surface to ambient per unit length of the pipe shall be determined in accordance with equations (1) and (2):

By convection:

$$Qc = C_1 * D^{0.75} * (T1-Ta)^{1.25} \qquad \text{Watts(Btu/hr.ft)} \qquad (1)$$

By radiation:

$$Qr = C_2 * D * [(T1/100)^4 - (Ta/100)^4] \qquad \text{Watts(Btu/hr.ft)} \qquad (2)$$

where:

C_1 = 1.28 for Metric units and C_1 = 0.85 for English units

C_2 = 8.97 for Metric units and C_2 = 0.27 for English units

D = pipe outside diameter in meter or feet

T1 = pipe temperature, degrees Kelvin/Rankine

Ta = ambient temperature, degrees Kelvin/Rankine

5.2.5 The temperature of insulated lines with steam tracing or other external heat source shall be assumed to reach the temperature of the source.

5.2.6 The temperature of a liquid in piping connected to the cold side of a heat exchanger shall be assumed to reach the temperature of the hotter medium of the exchanger.

5.2.7 The following parameters that affect the pressure rise in a pipe due to solar radiation shall be considered as minimum:

a. Thermal expansion of liquid.

b. Compressibility of liquid.

c. Pipe expansion due to pressure.

d. Thermal expansion of pipe.

Appendix A of this Standard provides procedures to determine the volume and pressure changes of a liquid due to thermal expansion.

5.2.8 No credit shall be taken for any leakage of valves which are intended to provide tight shut off, whether with special metal to metal seats or with soft seats or sealant.

5.3 Except as provided in paragraph 5.1 a relief valve shall be installed in the following cases:

5.3.1 On each section of a cross-country pipeline between main line block valves when the above ground length exceeds 10% of the total length of the section.

5.3.2 On each section of buried or insulated pipelines which carry a refrigerated liquid.

5.3.3 On the piping in a heat exchanger in which a liquid is heated between the block valves.

5.3.4 On each section of liquid lines with steam tracing, jacket or other external heat source.

6 Installation Requirements

6.1 The set pressure of a thermal relief valve shall not exceed 110% of the maximum allowable operating pressure for the maximum temperature during shut in, considering pipe hoop stress, combined stress, flange rating and any other weakest component in the system.

6.2 Relief valve selection shall be in accordance with SAES-J-600.

6.3 The location of the relief valve on sections of cross-country pipelines shall be selected to provide the largest margin above normal operating pressure considering pipeline elevations and the hydraulic profile unless the location is dictated by accessibility requirements. Relief valves which are not located within a fenced area shall be provided with a suitable cover to prevent tampering or damage in accordance with Standard Drawing AA-036873.

6.4 The outlet of thermal relief valves which release flammable or toxic vapor inside plant areas shall be piped to a closed piping system. Oil and other liquids may be piped to an entry point of the gravity sewer.

Revision Summary

16 March 2011	Major revision.
13 October 2012	Editorial revision.

Appendix A – Calculation Method for Thermal Relief

A.1 The following procedures may be used as guidelines to determine the volume change and pressure rise due to thermal expansion of liquids.

A.1.1 Thermal Expansion of Liquid

The volume change of a liquid due to thermal expansion is shown in Equation A-1.

$$\frac{dV}{V} = \alpha\,(T1 - T2) \qquad \text{A-1}$$

where:

dV = change in volume

V = volume

α = coefficient of thermal expansion of liquid, 1/°F

α = $450 * 10^{-6}$/°F for 35° API oil

α = $250 * 10^{-6}$/°F for water at 120°F

α = $(-64.268 + 17.0105T - 0.20369(T^2) + 0.0016048\,(T^3))*10^{-6}$, for water in 1/°C. T is in °C. Divide by 1.8 to convert it to 1/°F

T1 = final temperature of liquid, °F

T2 = initial temperature of liquid, °F

A.1.2 Compressibility of Liquid

The volume change of a liquid due to compressibility is shown in Equation A-2.

$$\frac{dV}{V} = \frac{-\,dP}{K} \qquad \text{A-2}$$

where:

dP = change in pressure, kPa (psi)

K = bulk modulus elasticity of liquid, kPa (psi)

K = $0.2 * 10^6$ psi for oil

K = $0.3 * 10^6$ psi for water

A.1.3 Volume Changes with Pressure Increase in Unrestrained Pipe

$$\frac{dV}{V} = \frac{dP\,D\,(2.5 - 2\nu)}{2\,Et} \qquad \text{A-3}$$

where:

dP = change in pressure, kPa (psi)

D = pipe outside diameter, m

t = pipe wall thickness, m

ν = Poisson's ratio

E = modulus of elasticity, kPa (psi)

For steel pipes, $\nu = 0.3$, so

$$\frac{dV}{V} = \frac{0.95\,dP\,D}{Et} \qquad \text{A-4}$$

A.1.4 Volume Change with Pressure Increase in Restrained Pipe

$$\frac{dV}{V} = \frac{2\,Sc\,(1 - \nu^2)}{E} \qquad \text{A-5}$$

where:

Sc = hoop stress, kPa (psi)

For steel pipes, $\nu = 0.3$, so

$$\frac{dV}{V} = \frac{0.91\,dP\,D}{Et} \qquad \text{A-6}$$

A.1.5 Volume Change with Temperature Increase in Unrestrained Pipe

$$\frac{dV}{V} = 3\beta\,(T1 - T2) \qquad \text{A-7}$$

where:

β = coefficient of expansion of pipe material, 1/°F

β = $6.5*10^{-6}$/°F for steel at 70°F

A.1.6 Volume Change with Temperature Increase in Restrained Pipe

$$\frac{dV}{V} = 2\beta(1+\nu)(T1 - T2) \quad \text{A-8}$$

For steel pipe, ν = 0.3, so

$$\frac{dV}{V} = 2.6\beta(T1 - T2) \quad \text{A-9}$$

A.1.7 Overall Change in Pressure

The change in pressure can be related to the change in temperature by equating the change in fluid volume to the change in pipe volume.

For an unrestrained steel line, use Equations A-1, A-2, A-4 and A-7.

$$\frac{dV}{V} = \alpha(T1 - T2) - \frac{dP}{K} = \frac{0.95\,dP\,D}{Et} + 3\beta(T1 - T2)$$

$$\left(\frac{0.95\,D}{Et} + \frac{1}{K}\right) * dP = (\alpha - 3\beta)(T1 - T2)$$

$$dP = \frac{(\alpha - 3\beta)\,E\,(T1 - T2)}{\frac{0.95\,D}{t} + \frac{E}{K}} \quad \text{kPa (psi)} \quad \text{A-10}$$

Equation A-10 can be simplified for water and for oil by substituting typical values as follows:

α = 138.9 * 10^{-6}/°F for water

α = 450 * 10^{-6}/°F for oil

β = 6.5 * 10^{-6}/°F for steel

E = 30 * 10^{6} psi for steel

K = 0.3 * 10^{6} psi for water

K = 0.2 * 10^{6} psi for oil

$$dP = \frac{90350\,(T1 - T2)}{\frac{D}{t} + 105} \quad \text{kPa for water, T1 and T2 °C}$$

$$dP = \frac{7280\,(T1 - T2)}{\frac{D}{t} + 105} \quad \text{psi for water, T1 and T2 °F}$$

$$dP = \frac{168800\,(T1 - T2)}{\frac{D}{t} + 158} \quad \text{kPa for oil, T1 and T2 °C}$$

$$dP = \frac{13600\,(T1 - T2)}{\frac{D}{t} + 158} \quad \text{psi for oil, T1 and T2 °F}$$

For a restrained steel line, use Equations A-1, A-2, A-6, and A-9.

$$\frac{dV}{V} = \alpha\,(T1 - T2) - \frac{dP}{K} = \frac{0.91\,dp\,D}{Et} + 2.6\beta\,(T1 - T2)$$

$$\left(\frac{0.91\,D}{Et} + \frac{1}{K}\right) dP = (\alpha - 2.6\beta)(T1 - T2)$$

$$dP = \frac{(\alpha - 2.6\beta)\,E\,(T1 - T2)}{\frac{0.91D}{t} + \frac{E}{K}} \quad \text{kPa (psi)} \qquad \text{A-11}$$

Equation A-11 can be simplified for water and for oil by substituting the typical values above:

$$dP = \frac{95400\,(T1 - T2)}{\frac{D}{t} + 110} \quad \text{kPa for water, T1 and T2 °C}$$

$$dP = \frac{7685\,(T1 - T2)}{\frac{D}{t} + 110} \quad \text{psi for water, T1 and T2 °F}$$

$$dP = \frac{177500\,(T1 - T2)}{\frac{D}{t} + 165} \quad \text{kPa for oil, T1 and T2 °C}$$

$$dP = \frac{14300\,(T1 - T2)}{\frac{D}{t} + 165} \quad \text{psi for oil, T1 and T2 °F}$$

A.1.8 Pipe with Buried Sections

The equations above assume that the whole pipe is aboveground, exposed to the sun. Many lines will have aboveground sections and buried sections. In such cases only the aboveground section of pipe and fluid is heated by the sun and will expand due to pressure and temperature increases. The buried section of pipe and fluid will not be heated, but will expand due to the pressure rise.

Thus, the equations for liquid expansion and pipe expansion due to a pressure change stay the same. For a restrained line:

$$\frac{dV}{V} = \frac{-\,dP}{K} \qquad \text{A-2}$$

$$\frac{dV}{V} = \frac{0.91\ dP\ D}{Et} \qquad \text{A-6}$$

Now consider the change in volume of the pipe due to heating of the aboveground section of a restrained line. Subscript “a” refers to the aboveground section, and subscript “b” refers to the buried section.

Initial Diameters $D = D_a = D_b$

Initial and Final Aboveground Length L_a

Initial and Final Buried Length L_b

Initial and Final Total Length $L = L_a + L_b$

Final Diameters $D_b = D$

$$D_af = D_a + \beta D_a (1 + \nu)(T1 - T2)$$

$$D_af = D\{1 + \beta (1 + \nu)(T1 - T2)\}$$

Initial Volume $Vi = (\pi/4)(D^2) L = (\pi/4)(D^2)(L_a + L_b)$

Final Volume can be determined as follows:

$$Vf = (\pi/4)(D^2) L_b + (\pi/4)(D^2)\{1 + \beta (1 + \nu)(T1 - T2)\}^2 (L_a)$$

$$Vf = (\pi/4)(D^2) L_b + (\pi/4)(D^2) L_a * \{1+2\beta (1 + \nu)(T1 - T2) + \beta^2 (1 + \nu)^2 (T1 - T2)^2\}$$

The last term is small compared to the others, so

$$Vf = (\pi/4)(D^2)(L_a + L_b) + (\pi/4)(D^2) L_a (2\beta)(1 + \nu)(T1 - T2)$$

$$Vf = Vi + (\pi/2)\,(D^2)\,L_a\,\beta\,(1 + \nu)\,(T1 - T2)$$

$$Dv = Vf - Vi = (pi/2)\,(D^2)\,L_a\,\beta\,(1 + \nu)\,(T1 - T2)$$

$$\frac{dV}{V} = \frac{\frac{\pi}{2} * (D^2)\, La\, \beta\, (1+\nu)\,(T1 - T2)}{\frac{\pi}{4} * (D^2)\,(La + Lb)}$$

$$\frac{dV}{V} = \frac{La}{(La + Lb)} * 2\beta\ (1+\nu)\,(T1 - T2)$$

Let $f = \dfrac{La}{(La + Lb)}$ = fraction of line aboveground

$$\frac{dV}{V} = 2 * f * \beta\,(1+\nu)\,(T1 - T2)$$

For a steel line with $\nu = 0.3$,

$$\frac{dV}{V} = 2.6 * f * \beta\,(T1 - T2) \qquad \text{A-12}$$

Similarly, the volume change of the liquid due to a temperature change will be the following:

$$\frac{dV}{V} = f * \alpha\,(T1 - T2) \qquad \text{A-13}$$

To solve for the pressure rise, equate liquid volume changes to pipe volume changes.

$$\frac{dV}{V} = f * \alpha\,(T1 - T2) - \frac{dP}{K} = \frac{0.91\, dP\, D}{Et} + 2.6 * f * \beta\,(T1 - T2)$$

$$\left(\frac{0.91D}{Et} + \frac{1}{K}\right) dP = f\ (\alpha - 2.6\beta)\,(T1 - T2)$$

$$dP = \frac{f\ (\alpha - 2.6\beta)\ E\ (T1 - T2)}{\frac{0.91D}{t} + \frac{E}{K}} \qquad \text{A-14}$$

Comparing Equation A-14 to Equation A-11 shows that the pressure rise for the pipe with buried sections is just the fraction of line aboveground times the pressure rise for an aboveground line.

A.1.9 Maximum Temperature for an Exposed Pipe

For an exposed pipe, the heat input per unit length due to solar radiation is 950 W/m² (300 BTU/hr ft²) times the pipe outside diameter:

where

$$Qs = C_3 * D \text{ W/m (BTU/hr ft)} \qquad \text{A-15}$$

C_3 = 950 W/m² for Metric units

C_3 = 300 BTU/hr ft² for English units

D = pipe outside diameter, m

The solar heat input will just balance the convection and radiation heat loss at the maximum temperature. The heat loss can be calculated using Equations 1 and 2 in paragraph 5.2.4 for an assumed maximum temperature T1 until the heat losses equal the heat input:

$$C_3 * D = C_1 (D^{0.75}) (T1 - Ta)^{1.25} + C_2 * D \{(T1/100)^4 - (Ta/100)^4\} \qquad \text{A-16}$$

Then, the change in pressure can be calculated for the change in temperature using equations such as Equation A-10, A-11 or A-14.

Depending on the size of the pipe, it may take a while to reach the maximum temperature. An iterative process is needed to predict the temperature change every hour.

Evaluate the heat capacity of the pipe and the contents as follows:

$$C = (C_p M)_{pipe} + (C_p M)_{contents} \qquad \text{A-17}$$

where

C = heat capacity per unit length, J/°C m (BTU/°F ft)

C_p = specific heat, J/kg °C (BTU/lb °F)

M = mass per unit length, kg/m

Set the initial conditions of ambient temperature Ta, pipe temperature T2, and pressure P at time 0 hours. Then, assume a temperature change dT for the first hour. The average temperature for the first hour is T = T2 + (dT/2). Now calculate the heat input and losses:

$$Qs = C_3 * D \qquad \text{A-18}$$

$$Qc = C_1 (D^{0.75}) (T - Ta)^{1.25} \qquad \text{A-19}$$

$$Qr = C_2 * D \{(T/100)^4 - (Ta/100)^4\} \qquad \text{A-20}$$

(C1 and C2 are defined in paragraph 5.2.4, C_3 in Equation A-15)

Calculate dT as follows:

$$dT = (Qs\text{-}Qc\text{-}Qr) / C \text{ (3600 sec), in °C,} \qquad \text{A-21}$$
for metric units

or

$$dT = (Qs\text{-}Qc\text{-}Qr) / C \text{ (1 hr), in °F,} \qquad \text{A-22}$$
for English units

If the calculated value of dT is not close to the assumed value, keep trying until the two are close. Then, the final temperature at the end of the hour is T1 = T2 + dT and the pressure rise can be calculated for the temperature rise dT. The same procedure can be continued as long as desired to determine the temperature and the pressure versus time.

A.2 Temperature rises quickly for small pipes and slowly for large pipes. Thus, for small pipes the maximum temperature is usually reached within 10 hours, but for large pipes the temperature may not approach the maximum in 10 hours. Therefore, a large pipe may not need thermal relief valves if the temperature and pressure do not reach the maximum values within the 10 hours of solar radiation assumed for one day.