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HEAT TRANSFER ANALYSIS OF LNG TRANSFER LINE

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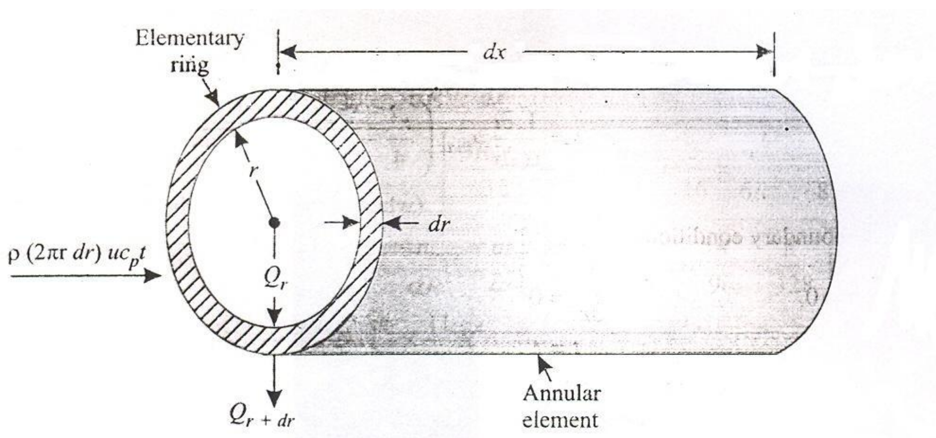
Abstract: *Our objective of heat transfer analysis is to find out the amount of heat to be transferred. In our cryogenic transfer line our effort is to find out the ways to prevent the heat to be transferred from high temperature to low temperature fluid. We use insulation to prevent the heat transfer. The choice of insulation for a particular application is usually a compromise in which factors such as economy, convenience, weight, ruggedness, volume and other properties are considered along with the effectiveness of insulation. Once the insulation is selected, heat transfer rate is to be calculated and optimization of the insulation is to be done*

I. INTRODUCTION

One of the main challenges during the time of transportation of LNG from offshore to the storage terminal and during other means of transportation is to minimise the heat in-leak. In this paper we will calculate the heat in-leak or Heat transfer during the transportation of LNG.

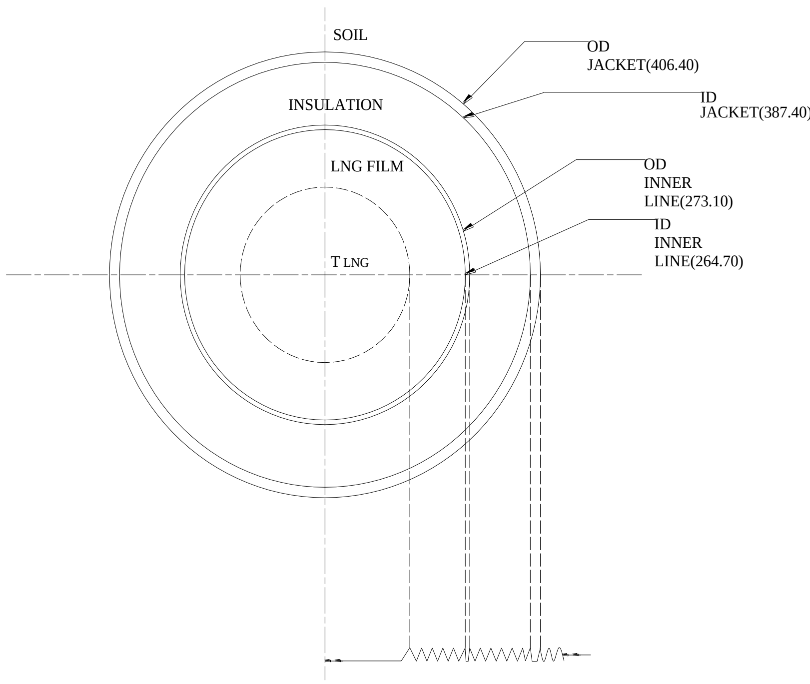
II. PROCEDURE FOR HEAT IN-LEAK CALCULATION

Heat transfer through transfer line is a case of heat transfer through composite cylinder. Figure shows the heat transfer in composite cylinder.



Heat Transfer through Composite Cylinder

LNG transfer line is also a composite cylinder system made of layers of different materials as shown in figure.



Thermal Resistances of the LNG Transfer Line

$R_1 = R_{LNG}$
$R_2 = R_{PIPE}$
$R_3 = R_{INSULATION}$
$R_4 = R_{JACKET}$
$R_5 = R_{SOIL}$

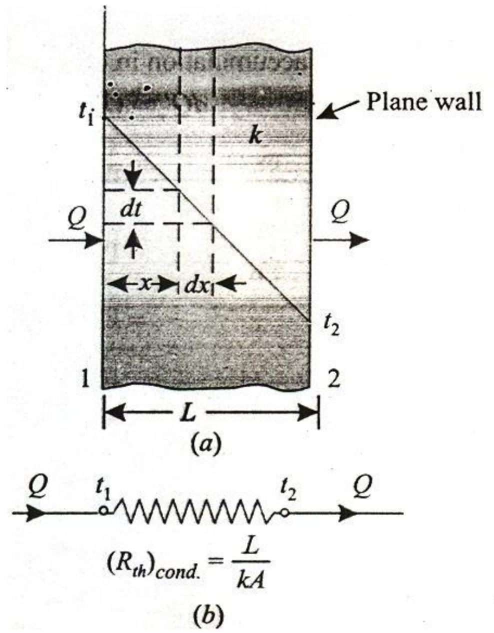
Heat transfer through a cylinder is given by

$$Q = \frac{T_o - T_i}{\frac{1}{2\pi k L} \ln\left(\frac{r_o}{r_i}\right)} \quad \text{.....(1.1)}$$

Where,

To = Temperature of the outer surface
T_i = Temperature of the inner surface
K = Thermal conductivity of the cylinder material
L = Length of the cylinder
r_o = Outer radius of the cylinder
r_i = Inner radius of the cylinder
This is the heat transfer through a single hollow cylinder, but we have many cylinders. So, here is the case of heat transfer through composite cylinders. The denominator $\frac{1}{2\pi k L} \ln\left(\frac{r_o}{r_i}\right)$ in equation (1.1) represents the resistance to the heat transfer.

Complicated conductive system can often be treated with analysis by introducing the concept of thermal resistance.



Heat Transfer through a Plan Wall or Slab

For a wall or slab type configuration, as shown in figure 6.3, thermal resistance R can be written as,

$$R = \frac{L}{kA} \qquad \text{....(1.2)}$$

Where,
A = area of heat transfer
L = length of section in the direction of heat flow
K = thermal Conductivity

For cylinder, as shown in figure

$$R = \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi k L} \qquad \text{......(1.3)}$$

Total thermal resistance to heat transfer of a composite cylinder is given by:

$$R = \sum_{i=1}^{n} R_i$$

In our system,

$$\Sigma R = R_1 + R_2 + R_3 + R_4 + R_5$$

Here,

$$\mathbf{\Sigma R = R_{LNG} + R_{pipe} + R_{insu} + R_{jacket} + R_{soil}} \qquad \text{......} \qquad (1.4)$$

The method of computing each resistance in a composite cylindrical system of LNG transfer line is discussed in detail in the following sections.

i. RESISTANCE TO HEAT TRANSFER BY LNG

$$R_{LNG} = \frac{1}{\pi\, d_{ip}\, L\, h_{LNG}} \qquad \text{.....(1.5)}$$

Where,

h_{LNG} = Convective heat transfer co-efficient of LNG.
d_{ip} = inner diameter of pipe
L = length of pipe

ii. RESISTANCE TO HEAT TRANSFER BY INNER PIPE

Pipe line is a case of hollow cylinder heat transfer, so resistance of pipe

$$R_{pipe} = \frac{\ln\left(d_{op}/d_{ip}\right)}{2 \times \pi \times k_{pipe} \times L} \qquad \text{......(1.6)}$$

Where,

Kpipe = Thermal conductivity of pipe material
dip = inner diameter of pipe
L = length of inner pipe
dop = outer diameter of pipe

iii. RESISTANCE TO HEAT TRANSFER BY INSULATION

Resistance of insulation to heat transfer is also a hollow cylinder case, so resistance,

$$R_{insu} = \frac{\ln\left(d_{ij}/d_{op}\right)}{2 \times \pi \times k_{insu} \times L} \qquad \text{......(1.7)}$$

Where,

K insu = Thermal conductivity of Insulation
dij = inside diameter of jacket
L = length of inner pipe
dop = outer diameter of pipe

iv. RESISTANCE TO HEAT TRANSFER BY JACKET.

Jacket is also like a hollow cylinder, so its resistance to heat transfer is also given by,

$$R_{jacket} = \frac{\ln\left(d_{oj}/d_{ij}\right)}{2 \times \pi \times k_{jacket} \times L} \qquad \text{......(1.8)}$$

Where,

K jacket = Thermal conductivity of jacket
dij = inside diameter of jacket line
L = length of inner line
doj = outside diameter of jacket pipe.

v. RESISTANCE TO HEAT TRANSFER BY SOIL.

The resistance to heat transfer by soil may be written as

$$R_{soil} = \frac{\cosh^{-1}\left(z/r_{oi} \right)}{2 \times \pi \times k_{soil} \times L} \qquad \ldots(1.9)$$

Where,

Ksoil = Thermal conductivity of soil
roi = outer radius of insulated pipe
Z = centre line depth below ground surface

Let,

$$\cosh^{-1}\left(z/r_{oi} \right) = x \qquad \ldots\ldots.(1.10)$$

$$\therefore \frac{z}{r_{oi}} = \cosh x$$

$$\therefore \frac{z}{r_{oi}} = \frac{1}{2}\left(e^{x} + e^{-x}\right)$$

$$\therefore 2\left(\frac{z}{r_{oi}}\right) = \left(e^{x} + e^{-x}\right)$$

$$\therefore 2\left(\frac{z}{r_{oi}}\right)e^{x} = e^{2x} + 1$$

$$\therefore e^{2x} - 2\left(\frac{z}{r_{oi}}\right)e^{x} + 1 = 0$$

This is a quadratic equation in e^{x}.

So, a =1, $b = -2\left(\frac{z}{r_{oi}}\right)$ C =1

Solving this equation, the roots of the equation are:

$$e^x = \frac{-\left[-2\left(\frac{z}{r_{oi}}\right)\right] \pm \sqrt{4\left(\frac{z^2}{r_{oi}^2}\right) - 4 \text{ x } (1) \text{ x } (1)}}{2 \text{ x } 1}$$

$$\therefore e^x = \left(\frac{z}{r_{oi}}\right) \pm \sqrt{\left(\frac{z^2}{r_{oi}^2} - 1\right)}$$

Taking +ve root only,

$$\therefore e^x = \left(\frac{z}{r_{oi}}\right) + \sqrt{\left(\frac{z^2}{r_{oi}^2} - 1\right)}$$

$$\therefore x = \ln\left[\frac{z}{r_{oi}} + \left(\frac{z^2}{r_{oi}^2} - 1\right)^{1/2}\right] \qquad \text{......(1.11)}$$

But, $\mathbf{x} = \cosh^{-1}(z/r_{oi})$ (Assumption-Equation 1.10)

So $\cosh^{-1}(z/r_{oi}) = \ln\left[\frac{z}{r_{oi}} + \left(\frac{z^2}{r_{oi}^2} - 1\right)^{1/2}\right]$

Putting values of $\cosh^{-1}\left(\frac{z}{r_{oi}}\right)$ in equation (6.17),

We have,

$$R_{soil} = \frac{1}{2\pi\, k_{soil}\, L} \ln\left[\frac{z}{r_{oi}} + \left(\frac{z^2}{r_{oi}^2} - 1\right)^{1/2}\right] \qquad \text{....(1.12)}$$

From equation (1.4),

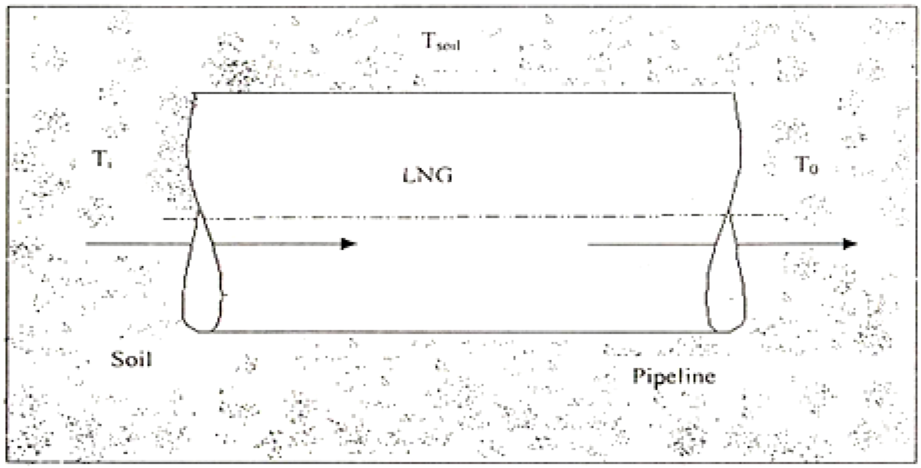
Total resistance to heat transfer,

$\mathbf{\Sigma\, R = R_{LNG} + R_{pipe} + R_{insu} + R_{jacket} + R_{soil}}$

But, resistance to heat transfer by the inner line surface, the wall thickness, and the jacket surface are negligibly small compared to the resistance of the insulation and the soil. But, still we find the value of each resistance to see the result.

Therefore, the total resistances to heat transfer,

$$\Sigma R = R_{insu} + R_{soil} \quad \text{…….. (1.13)}$$



LNG Transfer line buried under the Soil

Putting values of R_{insu} and R_{soil} from above equation, we have,

$$\Sigma R = \frac{\ln\left(d_{ij}/d_{op}\right)}{2\times\pi\times k_{insu}\times L} + \frac{1}{2\pi\, k_{soil}\, L}\ln\left[\frac{z}{r_{oi}} + \left(\frac{z^2}{r_{oi}^{\,2}} - 1\right)^{1/2}\right] \quad \text{… (1.14)}$$

The LNG transfer line is buried under the soil as shown in figure. The soil temperature is about atmospheric temperature and pipeline is at LNG temperature, so the heat exchange between soil and the pipeline takes place as in the heat exchanger. Figure shows the temperature variation of LNG pipeline and soil versus length or area. The temperature profile can be considered the same as in the condenser with a sensible loop.

III. CONCLUSION

Heat transfer rate of the entire LNG pipe buried in soil system is given by,

$$Q = \frac{\theta_m}{\Sigma R} \quad \text{……(1.15)}$$

It gives the amount of heat in-leak. To remove this heat, we have to provide cooling station at regular intervals.

Where,

$$\theta_m = \frac{\left[\left(T_{atm} - T_{c2}\right) - \left(T_{atm} - T_{c1}\right)\right]}{\ln\left(\frac{T_{atm} - T_{c2}}{T_{atm} - T_{c1}}\right)} \quad \text{…….(1.16)}$$

Where, Tc_1 and Tc_2 = Temp. of entering and existing cold fluid and Tatm= Atm. Temp.

Th_1 and Th_2= Temp. of entering and existing hot fluid

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REFERENCES

[1] Dissertation Report prepared by the Author.
[2] Heat and mass transfer by R. K. Rajput
[3] Randall F. Barron, Cryogenic System
[4] Flynn Cryogenic process Engineering
[5] R. S. Khurmi and Gupta J.K; Machine Design
[6] Coulter, D. M., Design consideration for LNG pipe line, Advances in cryogenic engineering, vol-15.