Insulation Audit and the Economic Thickness of Insulation

An Online Continuing Education Course for Engineers

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Insulation Audit and the Economic Thickness of Insulation

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Overview

One of the primary purposes of insulation is to conserve energy and increase plant profitability by reducing operating expenses. In existing plants, the planned and conscientious maintenance of insulated steam, chilled water, and other process distribution pipelines is required to minimize financial and thermal losses. This seems like a statement of the obvious, and it is. However, the maintenance and upgrade of thermal insulation is generally regarded as a low priority or on a "do it later" basis. What eventually transpires is that pipeline insulation maintenance issues tend to accumulate until major repairs are required, and more importantly, until extensive financial losses have been incurred.

Part 1 of the course, Overview of Insulation Materials, focuses on the type, properties, application, and installation guidelines of the insulation material and finishes. Insulation is used to perform one or more of the following functions:

- Reduce heat loss or heat gain to achieve energy conservation.
- Protect the environment through the reduction of CO_2, NO_x, and greenhouse gases.
- Control surface temperatures for personnel and equipment protection.
- Control the temperature of commercial and industrial processes.
- Prevent or reduce condensation on surfaces.
- Increase the operating efficiency of heating/ventilation/cooling, plumbing, steam, process, and power systems.
- Prevent or reduce damage to equipment from exposure to fire or corrosive atmospheres.
- Reduce noise from mechanical systems.

Other than the application of insulation, the selection aspects of the insulation material are also very important. The following design and installation considerations must be noted:

- Type of insulation: rigid, flexible, ease of handling, installation, and adjustment.
- How easy it is to modify, repair, and alter.
- Skilled and unskilled labor requirements.
- Safety and environment considerations.
- Weight and density of insulation material.
- Ease of removal and replacement.
- Type of vapor retarder and insulation finishes.
- Thermal performance.

This part of the course focuses on the assessment of thermal heat losses, and includes examples of the savings that can be realized by using the systematic approach of the insulation audit, economics, and acceptable thickness of insulation.

In heat transfer, we study energy in motion, which can occur through a mass by conduction, from a solid to a moving liquid by convection, or from one body to another through space by radiation. Heat transfer always takes place from a warmer environment to a colder one. Heat transfer for conduction and for convection is directly proportional to the driving temperature differential, $T_1 – T_2$. Heat transfer by radiation is proportional to the fourth power of the temperature difference, $T_1^4 – T_2^4$. Small changes in temperature can create relatively large changes in radiation heat transfer. Quantitative heat transfer is proportional to the heat transfer surface area.

Identifying the rate of thermal energy (heat) loss from an inadequate or un-insulated surface is the starting point for understanding the incentive for installing thermal insulation. Let us look at some basic thermodynamic equations that govern the heat transfer principles.

Heat Gain/Loss from Flat Surfaces

The heat loss (in Btu/hr) under a steady-state energy balance through a homogeneous material is based on the Fourier equation, Q = k * A * dt/dx. In practice, the equation is modified to include the film resistance at its surfaces.

$$\mathbf{Q = A\,U\,(T_1 - T_2)}$$

For a flat surface covered with insulation,

$$U = 1 / R = \frac{1}{L/k}$$

$$\mathbf{Q = A\,(T_1 - T_2) / (L/k)}$$

- Q = heat transfer from the outer surface of insulation in Btu/hr
- T_1 = hot face temperature, °F
- T_2 = cold face temperature, °F
- T_a = surrounding air temperature, °F
- U = overall coefficient of heat transfer per degree of temperature difference between the two fluids that are separated by the barrier
- L = thickness of insulation
- k = thermal conductivity of insulation, Btu/h ft ^{0}F
- $\frac{L}{K}$ ="R" and is called the thermal resistance of insulation

For a unit area, the heat transfer in Btu/ft^2 hr is:

$$Q = \frac{T_1 - T_2}{\frac{L}{k}}$$

$$Q = (T_2 - T_a) f$$

$$Q = \frac{(T_1 - T_a)}{\frac{L}{k} + \frac{1}{f}}$$

The surface temperature may be calculated from the following equation:

$$T_2 = \frac{Q}{f} + T_a$$

Where:

- f is the surface coefficient, Btu in/ft^2 hr °F

The lower the thermal conductivity or the k value, the higher the R value and the greater the insulating power.

The thermal conductivity of insulation changes as the difference in temperature between the hot surface and the ambient temperature changes. *The thermal conductivity value of a material is taken at the mean temperature* $(T_1 + T_2)/2$ °F, and it varies *with mean temperature, material density, and moisture absorption.*

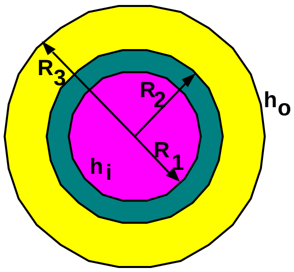
Heat Gain / Loss from Cylindrical Surfaces like Pipes

Unlike flat surfaces, the inner and outer surface areas for pipes are different. Therefore, the heat transfer equation is different. The pipe wall surface will gain heat directly by conduction from the fluid flowing through it. The heat is then dissipated to the atmosphere, or it flows at a restricted rate through the insulation if the pipe is insulated. The exact rate of heat loss is very complicated to calculate on a theoretical basis alone, since it is affected by:

- Color, texture, and shape of the casing
- Vertical or horizontal orientation of the casing
- Air movement or wind speed over the casing
- Exposure to thermal radiation; e.g., sunlight, temperature parameters, etc.

Because of the number of complicating factors, generalizations must be utilized. The theoretical methods for calculating the heat transfer for pipe or any other cylindrical objects like tanks is based upon the equivalent thickness of insulation and the area of the outer surface of insulation.

The most basic model for insulation on a pipe is as follows:



R_1 and R_2 are the inside and outside radius of the pipe.

R_2 and R_3 are the inside and outside radius of the insulation.

The equivalent length of insulation is given by the following equation:

$$\text{Equivalent length} = R_3 \log_e(R_3 / R_2)$$

Considering other factors such as the pipe thickness, the overall thermal conductivity (U) value is defined by:

$$U = \frac{1}{\dfrac{R_3}{R_1 h_i} + \dfrac{R_3 \log_e(R_2/R_1)}{k_{pipe}} + \dfrac{R_3 \log_e(R_3/R_2)}{k_{insulation}} + \dfrac{1}{h_o}}$$

Where:

- h_i is the heat transfer coefficient inside the pipe (air /liquid film conductance inside) in Btu/ft^2 hr °F
- h_o is the air film conductance on the outer surface in Btu/ft^2 hr °F
- k_{pipe} is the thermal conductivity of the pipe material
- $k_{insulation}$ is the thermal conductivity of the insulation

The heat loss is defined by equation:

$$Q = A \times U \times (T_{inside\ pipe} - T_{ambient})$$

Or the heat loss per unit of area is given by:

$$Q = \frac{T_{inside\ pipe} - T_{ambient}}{\frac{R_3}{R_1 h_i} + \frac{R_3 \log_e (R_2 / R_1)}{k_{pipe}} + \frac{R_3 \log_e (R_3 / R_2)}{k_{insulation}} + \frac{1}{h_o}}$$

When dealing with insulation, engineers are typi[…] linear heat loss or heat loss per unit length.

$$\frac{Q}{L} = \frac{2\pi \ldots}{\frac{R_3}{R_1 h_i} + \ldots}$$

The surface temperatu[…]

$$T_{surface} = \left(\frac{Q}{f} \times \frac{R\ldots}{R\ldots}\right.$$

f is the surface coefficie[…]

For simplicity, the tempe[…]

In actual practice, the log[…]ference is taken. The heat transfer is defined by:

$$Q = 2 \pi R_3 L\ U\ \Delta T_{LM}$$

Where:

$$\Delta T_{LM} = \frac{(T_2 - T_{amb}) - (T_1 - T_{amb})}{LN\left(\frac{T_2 - T_{amb}}{T_1 - T_{amb}}\right)}$$

Depending on the complexity of the system, it may be necessary to make more than one calculation to arrive at mean temperatures and the losses in different parts of the system.