INTRODUCTION

This section of the Mechanical Insulation Design Guide, adapted from the technical note by the National Mechanical Insulation Committee (NMIC) and duly converted to SI units from FPS system, is a collection of information and data that are useful to designers and end-users of mechanical insulation systems. The section contains some simple calculators that allow the calculation of heat flow and surface temperatures. The same can be used to create more sophisticated computer programs for performing these calculations.

ESTIMATING HEAT LOSS / HEAT GAIN

Steady-state, one dimensional heat flow through insulation systems is governed by Fourier's law:

Equation 1: $\mathbf{q = - k \cdot A \cdot dT/dx}$

Where:

q = rate of heat flow, W/hr
A = cross sectional area normal to heat flow, m^2
k = thermal conductivity of the insulation material, W/m K
dT/dx = temperature gradient, K/m

For flat geometry of finite thickness, the equation reduces to:

Equation 2: $\mathbf{q = k \cdot A \cdot (T_1 – T_2)/X}$

Where:

X = thickness of the insulation, m.

For cylindrical geometry, the equation becomes:

Equation 3: $\mathbf{q = k \cdot A_2 \cdot (T_1 – T_2)/(r_2 \cdot \ln (r_2/r_1))}$

Where:

r_2 = outer radius, m
r_1 = inner radius, m
A_2= area of outer surface, m^2

The term $r_2 \ln (r_2/r_1)$ is sometimes called the "equivalent thickness" of the insulation layer. Equivalent thickness is that thickness of insulation, which, if installed on a flat surface, would yield a heat flux equal to that at the outer surface of the cylindrical geometry.

Heat transfer from surfaces is a combination of convection and radiation. Usually, it is assumed that these modes are additive, and therefore a combined surface coefficient can be used to estimate the heat flow to/from a surface:

Equation 4: $\mathbf{h_s = h_c + h_r}$

Where:

h_s = combined surface coefficient, W/m^2 °K
h_c = convection coefficient, W/m^2 °K
h_r = radiation coefficient, W/m^2 °K

Assuming the radiant environment is equal to the temperature of the ambient air, the heat loss/gain at a surface can be calculated as:

Equation 5: $\mathbf{q = h_s \cdot A \cdot (T_{surf} - T_{amb})}$

The radiation coefficient is usually estimated as:

Equation 6: $\mathbf{h_r = \varepsilon \cdot \sigma \cdot (T_{surf}^4 - T_{amb}^4)/(T_{surf} - T_{amb})}$

Where:

ε = emissivity of the surface
σ = Stephen-Boltzmann constant (=5.67 × 10^{-8} W/m^2 K^4)
T_x = Absolute Temperature, °K

The emissivity (or emittance) of the surface is defined as the ratio of radiation emitted by the surface to the radiation emitted by a black body at the same temperature. Emissivity is a function of the material, its surface condition, and its temperature. A table giving the approximate emissivity of commonly used materials is given in Table 1.

Table 1. Emissivity Data of Commonly Used Materials

Material	**Emissivity (~25 °C)**
All Service Jacket	0.9
Aluminium paint	0.5
Aluminium, anodized	0.8
Aluminium, commercial sheet	0.1
Aluminium, embossed	0.2
Aluminium, oxidized	0.1-0.2
Aluminium, polished	0.04
Aluminium-zinc coated steel	0.06
Canvas	0.7-0.9
Coloured mastic	0.9
Copper, highly polished	0.03

Material	**Emissivity (~25 °C)**
Copper, oxidized	0.8
Elastomeric or Polyisobutylene	0.9
Galvanized steel, dipped or dull	0.3
Galvanized steel, new, bright	0.1
Iron or steel	0.8
Painted metal	0.8
Plastic pipe or jacket (PVC, PVDC, or PET)	0.9
Roofing felt and black mastic	0.9
Rubber	0.9
Silicon impregnated fiberglass fabric	0.9
Stainless steel, new, cleaned	0.2

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Convection is energy transport by the combined action of heat conduction, energy storage, and mixing action. It is classified as either forced convection (when the mixing motion is induced by some external agency) or natural convection (when the mixing action takes place as a result of density differences caused by temperature gradients). Convection coefficients (h_c) may be estimated for a number of simple geometries utilizing correlations of data from experimental studies. These studies utilize appropriate dimensionless parameters to correlate results. These correlations are summarized in the ASTM Standard Practice C 680 and in Chapter 3 of the 2005 ASHRAE Handbook—Fundamentals.

CONTROLLING SURFACE TEMPERATURES

A common calculation associated with mechanical insulation systems involves determining the thickness of insulation required to control the surface temperature to a certain value given the operating temperature of the process and the ambient temperature. This thickness of insulation is also referred to as “critical thickness of insulation”.

For example, it may be desired to calculate the thickness of tank insulation required to keep the outside surface temperature at or below 60 C when the fluid in the tank is 250 C and the ambient temperature is 25 C.

At steady state, the heat flow through the insulation to the outside surface equals the heat flow from the surface to the ambient air. In equation form:

Equation 7: $q_{ins} = q_{surf}$

Or

Equation 8: $(k/X)\cdot A\cdot(T_{hot}–T_{surf}) = h\cdot A\cdot(T_{surf}–T_{amb})$

Rearranging, this equation yields:

Equation 9: **$X = (k/h)\cdot[(T_{hot}–T_{surf})/(T_{surf}–T_{amb})]$**

Since the ratio of temperature differences is known, the required thickness can be calculated by multiplying by the ratio of the insulation material conductivity to the surface coefficient.

In the example above, assume the surface coefficient can be estimated as 1.0 W/m^2 °K, and the conductivity of the insulation to be used is 0.025 W/m^2 K. The required thickness can then be estimated as:

$X = (0.25/1.0)\ [(250-60)/(60-25) = 0.109$ m.

This estimated thickness would be rounded up to the next available size, probably 125-150 mm.

For radial heat flow, the thickness calculated would represent the equivalent thickness; the actual thickness (r_2-r_1) would be less (see equation (8) above).

This simple procedure can be used as a first-order estimate. In reality, the surface coefficient is not constant, but varies as a function of surface temperature, air velocity, orientation, and surface emissivity.