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Revision Memo

12/01 Tables 4 and 10 have been updated.



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SCOPE

This section gives an abbreviated summary of the heat transfer equations, which describe the heat leakage, which the use of insulation is intended to control, plus information on various types of insulation systems. There are a number of factors, which must be taken into account in establishing the suitability of an insulation system for a particular application. This section describes the considerations involved in selecting insulation and jacketing materials, and presents properties for many commonly-used insulations.

As a result of the new U.S. Department of Labor Standards for employee exposure to asbestos, EMRE's policy is asbestos insulation should not be specified for any project. However, since most existing facilities have used asbestos insulation in the past asbestos has been included in the list of common insulation materials indicated above, to provide data needed for checking existing facilities.

REFERENCES

GLOBAL PRACTICES

- GP 14-1-1 Hot Service Thermal Insulation, Design
- GP 14-1-2 Hot Service Thermal Insulation, Materials and Application
- GP 14-2-1 Cold Service Thermal Insulation, Design
- GP 14-2-2 Cold Service Thermal Insulation, Materials and Application

OTHER LITERATURE

1. ASTM Standards, Part 14, *Thermal Insulation; Acoustical Materials; Fire Tests; Building Constructions*, 1970.
2. Malloy, J. F., *Thermal Insulation*, Van Nostrand Reinhold Company, New York, 1969.

BACKGROUND

Heat transfer may be compared by analogy with the flow of electricity against an electrical resistance, R_{electric} . The flow of heat, q , against a thermal resistance, R_{thermal} , as a result of a temperature difference, $T_1 - T_2$, is analogous to the flow of electric current, I_e , as a result of an electrical potential difference, $E_1 - E_2$. From Ohm's law of electricity:

$$R_{\text{electric}} = \frac{E_1 - E_2}{I_e} \quad \text{Eq. (1)}$$

By analogy, a heat transfer resistance may be defined as:

$$R_{\text{thermal}} = \frac{T_1 - T_2}{q} \quad \text{Eq. (2)}$$

The thermal resistance in **Eq. (2)** is compared to the equations for conduction, convection and radiation given below:

Conduction equation:

$$\text{Flat plate: } q = \frac{k A}{t} (T_1 - T_2) \quad (\text{Customary}) \quad \text{Eq. (3a)}$$

$$q = \frac{10^3 k A}{t} (T_1 - T_2) \quad (\text{Metric}) \quad \text{Eq. (3a)M}$$

$$\text{Cylinder: } q = \frac{2\pi L k (T_1 - T_2)}{\ln(r_2 / r_1)} \quad \text{Eq. (3b)}$$

$$\text{Convection equation: } q = h A (T_1 - T_2) \quad \text{Eq. (4)}$$

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BACKGROUND (Cont)

Radiation equation: $q = \sigma A \left[(T_1 + 460)^4 - (T_2 + 460)^4 \right] = h_r A (T_1 - T_2)$ (Customary) Eq. (5)

$$q = \sigma A \left[(T_1 + 273)^4 - (T_2 + 273)^4 \right] = h_r A (T_1 - T_2)$$
 (Metric) Eq. (5)M

Comparison of **Eq. (2)** with **Eqs. (3), (4), and (5)** yields:

Conduction:

Flat plate: $R = \frac{t}{A k}$ (Customary) Eq. (6a)

$$R = \frac{t}{10^3 A k}$$
 (Metric) Eq. (6a)M

Cylinder: $R = \frac{\ln(r_2 / r_1)}{2\pi L k}$ Eq. (6b)

Convection: $R = \frac{1}{A h}$ Eq. (7)

Radiation: $R = \frac{1}{A h_r}$ Eq. (8)

In the above equations, A = area, h = heat transfer coefficient, k = thermal conductivity, r = radius, t = thickness and σ = constant for radiant heat transfer. See also **NOMENCLATURE**.

In the foregoing, the various modes of heat transfer have been considered separately. However, in practice, heat is transferred by all the modes in series or in parallel. For example, the heat transferred through a solid body is by conduction, while the heat transferred by the body in contact with a fluid is by convection. The total rate of heat transfer through a body is then related to the temperature difference and all the thermal resistances involved.

Normally, a body is constructed of one or more materials in successive layers. **Figure 1** shows a composite flat slab made of Materials a and b in contact with two fluids at temperatures T_i and T_o . The conduction equation for each portion of this body is:

$$T_i - T_1 = q R_i \text{ (hot fluid)}$$

$$T_i - T_2 = q R_a \text{ (metal a)}$$

$$T_2 - T_3 = q R_b \text{ (metal b)}$$

$$T_3 - T_o = q R_c \text{ (cold fluid)}$$

adding these four equations gives:

$$T_i - T_o = q (R_i + R_a + R_b + R_c)$$
 Eq. (9)

Eq. (9) shows that the overall heat transfer resistance is the sum of the individual resistances.

BACKGROUND (Cont)

For the composite flat wall shown in **Figure 1**, the heat loss is given by **Eq. (10)**:

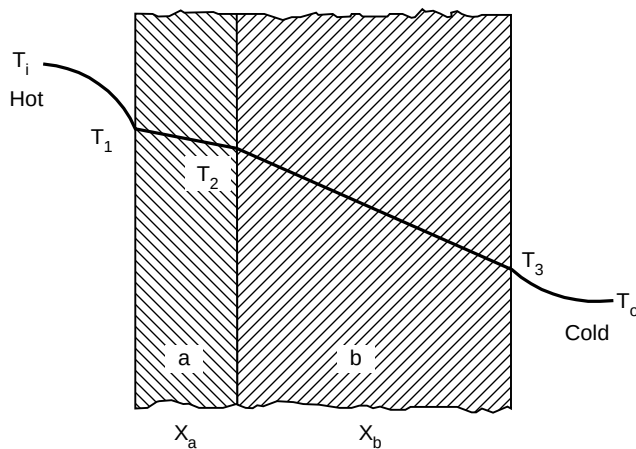
$$q = \frac{T_i - T_o}{\frac{1}{A h_j} + \frac{x_a}{A k_{ma}} + \frac{x_b}{A k_{mb}} + \frac{1}{A h_o}} \quad \text{(Customary) Eq. (10)}$$

$$q = \frac{T_i - T_o}{\frac{1}{A h_j} + \frac{x_a}{10^3 A k_{ma}} + \frac{x_b}{10^3 A k_{mb}} + \frac{1}{A h_o}} \quad \text{or} \quad q = \frac{10^3 (T_i - T_o)}{\frac{10^3}{A h_j} + \frac{x_a}{A k_{ma}} + \frac{x_b}{A k_{mb}} + \frac{10^3}{A h_o}} \quad \text{(Metric) Eq. (10)M}$$

For the cylindrical composite (see **Figure 2**), the same reasoning leads to:

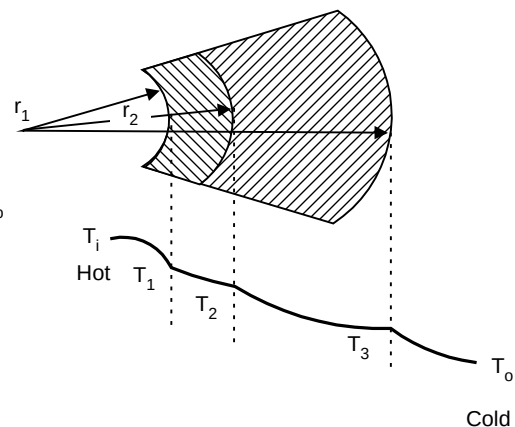
$$q = \frac{T_i - T_o}{\frac{1}{2\pi L r_1 h_i} + \frac{\ln(r_2/r_1)}{2\pi L k_{ma}} + \frac{\ln(r_3/r_2)}{2\pi L k_{mb}} + \frac{1}{2\pi L r_3 h_o}} \quad \text{Eq. (11)}$$

FIGURE 1
HEAT TRANSFER THROUGH LAYERS
FOR THE COMPOSITE FLATWALL



DP16A1&2

FIGURE 2
HEAT TRANSFER THROUGH LAYERS
FOR THE CYLINDRICAL COMPOSITE



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INSULATION TYPES AND APPLICATIONS

REQUIREMENTS OF AN INSULATING MATERIAL

Mechanical Requirements - Most insulating materials are not intended for structural applications and should not be used in this manner. However, there are cases where moderate loadings can occur, which should be accounted for in the selection of an insulation. For example, some locations, such as horizontal lines and the tops of large pieces of equipment, are subject to foot traffic. Insulation for this use should have sufficient compressive strength, about 25 to 50 psi (175 to 350 kPa) depending upon the type and frequency of traffic, to withstand the loading involved.

Thermal Requirements

1. **Temperature Limits** - An insulating material should never be used above its maximum rated service temperature. At the same time, over-conservative designs lead to waste, since higher-temperature insulations are more expensive and often have higher thermal conductivities than do the lower-temperature insulations. Therefore, the maximum temperature limit of an insulation should be matched as closely as possible with the expected conditions. Although it is sometimes overlooked, the maximum temperature limit is also important in cold service, since cleaning and purging operations must be taken into account. A particular cold insulation should be used only if it can withstand the maximum temperature encountered during cleaning.
2. **Thermal Diffusivity** - Where insulation is to be used as fire protection, a material that transfers temperature slowly is desirable. Resistance to temperature change is measured by thermal diffusivity, which is the ratio of thermal conductivity to the product of density and specific heat capacity, $k/c_p\rho$ (Customary) $10^3 k/c_p\rho$ (Metric), in ft^2/hr or mm^2/s . The lower the diffusivity, the higher the resistance.

Chemical Requirements - An insulation material should not react with the contents of the equipment to be insulated. Otherwise, leakage could cause extensive damage. Urethane foam, for example, is destroyed by certain solvents. Where toxic substances are involved, insulations with low absorptivity are desirable. If leakage occurs, a highly absorptive material can soak up large quantities of poisonous material, thus creating additional danger.

Moisture Considerations - In cold service, insulation has a tendency to absorb and condense water vapor if the cold face of the insulation is cooler than the atmospheric dew point. This situation occurs because the partial pressure of the water vapor in the air is greater than the saturation pressure of water at the cold face temperature. Thus, a partial pressure difference is established and becomes the driving force for the transfer of water vapor into the insulation.

As the vapor passes through the insulation, it eventually freezes into ice, and, since the rate of heat transfer through iced insulation is 50 to 100 times as great as that of dry insulation, the effectiveness of the material is destroyed. Therefore, insulation for cold service must offer a substantial resistance to the transfer of water vapor. This requirement is included in **GP 14-2-2** as a maximum permeability for cold insulation. In practice, this restriction implies that closed cell insulations such as cellular glass and urethane foams must be used.

In hot service, moisture considerations are somewhat different. While the presence of water in the insulation is detrimental to performance, the driving force for vapor is outward. Thus, moisture present in high-temperature insulation will be vaporized and driven out of the material provided that the insulations have adequate permeability. Closed cell insulations are usually not desirable in this service, except at the base of such items as storage tanks, where the possibility of absorbing large quantities of water from the ground exists.

Fire Protection - Where insulation serves as fire protection, it should be non-combustible. In addition, the insulation should have low absorptivity, so as not to act as a wick in the event of material leakage.

INSULATION MATERIALS AND INSULATION PROPERTIES

In the descriptions and tables which follow, the characteristics of commonly used insulating materials are presented. Where indicated, the properties listed are based upon ASTM standard specifications. Otherwise, the information has been drawn from vendors' literature and from *Reference 2*. For quick reference, a summary of the conductivities and temperature ranges of several important insulations is presented below, under TABLES OF INSULATION PROPERTIES. The thermal conductivities are listed in equation form in order to facilitate use with insulation computer programs.

Rigid and Semi-rigid Insulations - This category includes insulating material available in blocks, board, and pipe covering. Rigid insulation is used where strength is needed, where the insulation may be exposed to mechanical abuses, or where it must be partially self-supporting. Semi-rigid insulations are used for light mechanical abuses and for cases where curved surfaces make flexibility desirable.

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INSULATION TYPES AND APPLICATIONS (Cont)

1. **Amosite Asbestos** - Is composed principally of amosite asbestos fiber with a heat-resistant inorganic binder. Amosite asbestos is available only as pipe covering, for applications up to 1500°F (816°C). Refer to **Table 1** for properties. *This material is not to be specified for any project. See the warning at the beginning of this section.*
2. **Calcium Silicate** - Is composed principally of hydrous calcium silicate with reinforcing mineral fibers. It is available in temperature limits up to 1400°F (260°C), as rigid blocks or pipe covering. Calcium silicate is now the standard hot service insulation; however, other high-temperature insulations are similar in performance. Asbestos has been used as the binder in the past. However, vendors are switching to non-asbestos binders as a result of the new U.S. Department of Labor Standards. Refer to **Table 2** for properties.
3. **"Super" Calcium Silicate** - Is similar to the standard calcium silicate, but can be used for temperatures up to 1700 - 1850°F (927 - 1010°C). This increase in maximum temperature limit is offset by a higher thermal conductivity and a higher cost. See the comment on asbestos in the preceding paragraph. Refer to **Table 2** for properties.
4. **Diatomaceous Earth** - Is composed principally of diatomaceous earth (see loose fill insulations) with a heat-resistant inorganic binder and reinforcing mineral fiber. It is available in rigid block sheets, and pipe covering for temperatures up to 2000°F (1093°C). Refer to **Table 3** for properties.
5. **Glass, Cellular** - Cellular glass is composed of hermetically sealed glass cells, fused together. This material has almost perfect resistance to the migration of moisture vapor and is intended for use between -300 and 800°F (-184 and 427°C). It is available in rigid blocks, sheets, and pipe covering. Refer to **Table 4** for properties.
6. **Glass Fiber** - This material is composed of glass fibers and organic binders. It is available in a wide range of properties, as both rigid and semi-rigid insulation. Generally, fiberglass insulation can be used between -120 and 450°F (-84 and 232°C), although permeability limits in **GP 14-2-2** restrict its use in cold services. Special binders are also available for high-temperature use [up to 1000°F (538°C)]. Refer to **Table 5** for properties.
7. **Mineral Fibers** - Are composed of fibers processed from mineral substances, such as rock or slag, and inorganic binders. It is available as rigid and semi-rigid blocks for temperatures up to 1800°F (982°C). Refer to **Table 6** for properties.
8. **Perlite, Expanded** - This material is composed of expanded perlite (see loose fill insulations) with reinforcing mineral fibers and inorganic binders. It is commercially available for use at temperatures up to 1600°F (871°C). Refer to **Table 7** for properties.
9. **Urethane** - Is a rigid cellular foam plastic normally used in the range of -100 to 230°F (-73 to 110°C), although lower-temperature applications may also be considered. Urethane has the best insulating properties of any of the common rigid insulations and is available in rigid boards, sheets, and pipe covering. Refer to **Table 8** for properties.

Blanket and Felt Insulations - These are flexible insulations formed from woven fiber. They are available in a wide range of densities. These insulations are used where they can be supported by other member and for thermal and mechanical cushioning of rigid insulations.

1. **Asbestos** - For use up to 750°F (399°C). Refer to **Table 9** for properties. *This material is not to be specified for any project.*
2. **Glass, Fibrous** - This material is available with or without organic binders and facings for use up to 1200°F (649°C). Refer to **Table 10** for properties.
3. **Mineral fiber** blankets are available with or without binders. Refer to **Table 11** for properties.

Sprayed Insulations - Sprayed insulations come in the form of mixes which can be sprayed onto the surface of the equipment to be insulated. The mixture hardens or foams into rigid insulation. These insulations can be advantageous for use on large surfaces.

1. **Asbestos Fibers, Amosite, and Inorganic Binders** - The insulation comes as a sprayable cement mix. Water is added by the spray gun. Refer to **Table 12** for properties. *Asbestos material is not to be specified for any project.*
2. **Mineral Wool Granules, Asbestos, and Inorganic Binders** - This sprayable mix is formulated to be used as fire protection and high-temperature insulation (up to 1800°F or 982°C). Refer to **Table 13** for properties. *Do not specify a mixture with asbestos for any project.*
3. **Urethane** comes as a two-part liquid mixture. The liquids are combined in the spray gun and expand approximately 30-fold to form rigid insulation. Refer to **Table 14** for properties.

Loose Fill Insulation - Loose fill insulation consists of particulate material in granular, fibrous or powdery form. It is installed dry between retaining surfaces or as a covering layer.