Insulation For Mechanical Systems

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Most engineers and architects are familiar with using insulation to reduce heating and cooling loads and control noise in building envelopes. Insulations used for pipes, ducts, tanks, and equipment are not as familiar to them. The installed cost of these materials is usually a small part of the total cost of a project. As a result, mechanical insulation* is often overlooked or improperly specified in commercial and industrial construction projects.

In recognition of this, a new chapter has been added to the *2005 ASHRAE Handbook—Fundamentals* to specifically address mechanical insulation. The new chapter, Chapter 26, consolidates and reorganizes much of the information contained in earlier versions of the Handbook into a single location. In addition, a significant amount of new information has been included to assist designers in specifying these insulation systems.

The chapter was developed by ASHRAE Technical Committee (TC) 1.8, Mechanical Systems Insulation. TC 1.8 is a relatively new committee concerned with the application and performance of thermal and acoustical insulation systems used on pipes, tanks, equipment and ducts.

Chapter Overview

Chapter 26 is organized into four major sections: Design Considerations, Materials and Systems, Installation, and Design Data.

*The term mechanical insulation has been used to describe these insulation products because they typically are specified by the mechanical engineers involved in building projects.

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The Design Considerations section is probably the most important section of the chapter and is intended to identify and provide some guidance on the design objectives involved when specifying mechanical insulation systems. The design objectives discussed in the chapter include:

- **Energy conservation:** minimizing unwanted heat loss/gain as well as preserving natural and financial resources;
- **Personnel protection:** controlling surface temperatures to avoid contact burns;
- **Condensation control:** avoiding condensation by keeping the surface temperature above the dew-point temperature of the surrounding air;
- **Process control:** minimizing temperature change in process fluids where close control is needed;
- **Freeze protection:** minimizing energy required for heat tracing systems and/or extending the time to freezing in the event of system failure;
- **Noise control:** reducing noise in mechanical systems; and
- **Fire safety:** protecting critical building elements and slowing the spread of fire in buildings.

The importance of this section stems from the fact that multiple design objectives usually exist. Failure to focus on these multiple objectives can lead to problems with the insulation system.

Chilled Water Piping Example

One example of a project with multiple objectives is specifying the proper insulation design for a chilled-water piping system. In a typical project, there are usually at least two distinct design considerations: energy conservation and condensation control. Both considerations must be addressed during the design phase.

Energy conservation is important, and the mechanical engineer responsible may refer to ANSI/ASHRAE/IESNA Standard 90.1-2004, *Energy Standard for Buildings Except Low-Rise Residential Buildings,* to select insulation thicknesses. Standard 90.1-2004 uses the "economic thickness" concept to specify insulation thicknesses for a variety of pipe sizes and applications. Using the values from the standard is a reasonable solution to the energy conservation objective. However, the engineer may not realize that Standard 90.1-2004 does not address the objective of condensation control. Depending on the location of the chilled-water piping, additional thickness may be required to eliminate or minimize moisture condensation on the exterior surface of the insulation. The thicknesses specified in Standard 90.1-2004 should be viewed as minimum thicknesses.

For cold systems, avoiding surface condensation requires keeping the temperature of the exposed surface above dew-point temperature of the surrounding air. Insulation can help by reducing the heat flow to the cold pipe and effectively raising the surface temperature. This approach is effective if the relative humidity of the surrounding air is below 90%. Above 90% RH, the thicknesses required to prevent surface condensation become impractical, and other approaches are required.

The calculations involved are relatively straightforward, and are summarized in the Design Data section of Chapter 26. They can be best understood by considering an energy balance at the insulation surface. At steady state, the heat flux from the ambient air to the insulation surface must equal the heat flux from the insulation surface to the cold pipe. In equation form:

$$q_{surf} = q_{ins} \tag{1}$$

where

q_{surf} = heat flux from the ambient air to the insulation surface

q_{ins} = heat flux from the insulation surface toward the cold pipe

The heat flux to the insulation surface can be written as:

$$q_{surf} = h \cdot (T_{amb} - T_{surf}) \tag{2}$$

where

h = overall surface heat transfer coefficient

Similarly, the heat flux from the insulation surface can be written as:

$$q_{ins} = (k/t) \cdot (T_{surf} - T_{cold}) \tag{3}$$

where

k = thermal conductivity of the insulation material

t = thickness of the insulation layer

So that:

$$h \cdot (T_{amb} - T_{surf}) = (k/t) \cdot (T_{surf} - T_{cold}) \tag{4}$$

Rearranging yields a simple equation for insulation thickness:

$$t = (k/h)\,(T_{surf} - T_{cold})/(T_{amb} - T_{surf}) \tag{5}$$

To prevent condensation, we want the surface temperature to be greater than the dew-point temperature of the surrounding air. In other words:

$$t > (k/h)(T_{dp} - T_{cold})/(T_{amb} - T_{dp}) \tag{6}$$

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where

T_{dp} = dew-point temperature of the ambient air

By examining Equation 6, we can see that avoiding surface condensation requires a designer to know the conductivity of the insulation, the surface heat transfer coefficient, and the conditions of the ambient air. By way of illustration, Equation 6 has been solved for some typical conditions and the results tabulated in *Table 1*, which shows insulation thickness as a function of relative humidity of 80°F (27°C) ambient air.

At high relative humidities, the thickness required to prevent surface condensation increases dramatically, and becomes impractical above about 90% RH. For conditions where the dew-point temperature approaches the dry-bulb temperature (i.e., 100% RH), the thickness required approaches infinity.

This simple procedure can be used as a first order estimate. In reality, number of factors complicate the calculation. First, for radial geometries, the thickness calculated by Equation 6 represents the effective thickness $\left(r_o \cdot ln(r_o/r_i)\right)$; the actual wall thickness of pipe insulation required $(r_o - r_i)$ will be slightly less. In addition, the surface heat transfer coefficient is not a constant, but varies as a function of surface temperature, air velocity, orientation, and surface emittance. Likewise, the conductivity of insulation varies with temperature. When performing these calculations, it is important to use the effective thermal conductivity of the insulation material, which can be approximated by evaluating the conductivity at the mean temperature across the insulation layer. It is also important to use the actual dimensions for pipe and tubing insulation. Standard dimensions of pipe and tubing insulations are included in Chapter 26.

Relative Humidity	Insulation Thickness Required
20%	—
30%	0.1 in.
40%	0.2 in.
50%	0.3 in.
60%	0.5 in.
70%	0.7 in.
80%	1.3 in.
90%	2.9 in.
95%	6.0 in.

Note: Calculated using Equation 6, assuming an ambient temperature of 80°F, a cold surface temperature of 40°F, surface conductance of 1.2 Btu/h·ft^2·°F and insulation with a thermal conductivity of 0.30 Btu·in/(h·ft^2 °F).

Table 1: Thickness to prevent surface condensation.

These complications are readily handled for a variety of boundary conditions using available computer programs, such as the North American Insulation Manufacturers Association 3E Plus® insulation thickness computer program, which is downloadable at no charge from www.pipeinsulation.org.

We have shown that Equation 6 can easily be used to develop a first order estimate of the thickness required to prevent surface condensation. A more difficult task is determining conditions of the ambient air surrounding the cold pipe.

If the pipe is located outdoors, weather data is readily available to guide the design. For these outdoor applications, there will generally be many hours per year where the air is saturated or nearly saturated. A review of typical hourly weather data for Houston indicates that more than 2,000 hours per year exist when the relative humidity is greater than 90%. Even Minneapolis experiences more than 600 hours per year over 90%RH.

For outdoor applications, no amount of insulation prevents surface condensation all the time, and these installations must include "weather barriers" to protect the insulation system from damage due to surface condensation, even if they are protected from wind-driven rain.

For indoor environments, the situation is not as straightforward. While the systems in most buildings are designed to control temperature within the comfort range, active humidity control is rare. Humidity levels will vary depending on the outdoor conditions, moisture release from occupants and activities within the building envelope, and the operation of the cooling system. At the design stage, it is difficult to know the humidity conditions to be expected at the various locations within the building. This is particularly true within pipe chases and mechanical rooms that are sometimes vented to the outdoor air. The designer obviously must be aware of the possibility of night/weekend setback. Extended periods of system shutdown also are possible, and have been a problem for schools, where restart of cooling systems often occurs in late summer or early fall. Because of these considerations, it is recommended to design for relative humidities of 75% to 80%, even for chilled-water piping in conditioned spaces.

Another important consideration for below ambient piping is the possibility of water vapor flow through the insulation to the cold pipe. If the operating temperature of the cold fluid is below the dew-point temperature of the ambient air, condensation will occur on the cold surface of the pipe, creating a vapor pressure gradient through the system. While the absolute magnitude of this pressure difference is small (typically less than 0.5 in. Hg [1.7 kPa]), in some installations it can act over a large area for many hours per year. The control of water vapor, therefore, is critical for piping and equipment operating at below ambient temperatures. These systems must either use a continuous and effective vapor retarder to minimize the amount of water-vapor ingress, or incorporate a means of removing any condensed water from the system. One means of removing water is the use of a hydrophilic wicking material to transport liquid water outside the system where it can be evaporated to the ambient air.

This chilled water example illustrates two distinct design objectives that must be addressed in most design projects. Some projects may have additional objectives. Noise control and fire safety often are involved. Hopefully, the new chapter will help focus designers on the many issues.

Conclusion

In closing, I highlight some of the information contained in Chapter 26 that is new to the ASHRAE Handbook.

- The section on noise control includes a discussion of concepts, terms and test methods specific to this subject. New data on the insertion losses for pipe insulation and jacketing materials is included in tabular form.
- A section on fire safety discusses the requirements of the various model building codes as they apply to mechanical insulations, as well as reviewing the test methods used to evaluate the fire safety performance of insulation products.
- Corrosion of metals under insulation is a significant issue that is often overlooked during design. Corrosion under insulation depends on many factors, including the environment and the operating temperature of the metal. A discussion of the issues and suggestions for minimizing corrosion are included.
- The Materials and Systems section includes information on the various insulation materials available and a short discussion of the physical properties of interest. A summary table is included that presents key property information and points readers to some of the many applicable ASTM Material Standards. This section also includes a discussion of weather barriers and their importance in protecting insulation systems installed outdoors. The function of vapor retarders and a summary of the various types of vapor-retarder systems are discussed in some detail.
- The Installation section provides information on current installation practice. A discussion of securing methods, hangers, and insulation finish is provided for each of the major application areas (pipes, tanks, equipment, and ducts). New information in this section includes tables of saddle lengths suitable for supporting insulated pipes. The discussion on duct insulation summarizes the considerations specific to that application, in addition to providing sample calculations for temperature rise or drop in duct systems.
- The Design Data section serves as a catch-all for data thought to be useful to designers. Significant new data in this section are tables of standard dimensions of pipe and tubing insulation, both for rigid insulations and for standard flexible insulations. The standard insulation sizes have been available previously in insulation-industry publications, but have not previously been published in the Handbook.

TC 1.8 is in the process of reviewing and updating Chapter 26. Readers are encouraged to review the new chapter and provide suggestions to the TC 1.8 Handbook Subcommittee at tc0108@ashrae.net.