Designing Factors

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For hot (above-ambient) applications, thermal insulation reduces heat loss. On cold (below-ambient) applications, the insulation generally serves to minimize heat gain.

Thermal insulation provides many uses in industrial (such as power and petrochemical) and commercial applications. In this article, we will only discuss industrial applications. In simple terms, thermal insulation reduces heat flow from one surface to another.

In some cases, the application design purpose may seem unrelated to heat loss or heat gain. However, the net result is that heat transfer is reduced. Examples of this are insulation for personnel protection and condensation control (sweating). For personnel protection, enough insulation is provided to keep the surface below a given temperature. For condensation control, enough insulation is provided to keep the surface temperature above the dew point. In both cases, insulation is used to control the surface temperature for a desired effect other than thermal conservation. The effect, however, is that in both cases heat transfer is reduced to maintain the surface temperature at a given design criteria.

Correctly designing and specifying an insulation system is much more involved than just selecting a particular material. An insulation system can include any combination of insulation materials used with mastics, adhesives, sealants, coatings, membranes, barriers, and/or other accessory products to produce an efficient assembly to reduce heat flow. Frequently, the design of insulation systems can either determine or direct the ultimate performance of the process. Improperly designed insulation systems are subject to damage and degradation. Degradation will compromise the material's performance characteristics, and in many cases the entire process for which the insulation system was designed.

There are many different types of insulation materials available. Each has its own set of properties and performance characteristics. For each insulation material, a proper application procedure and corresponding accessory material(s) or "system" application is available. The single most important thing to remember is the word "system." This refers not only to the insulation materials, but also to the application and finish.

When asked to supply an insulation specification for a power plant or process plant, several questions must first be considered. Some examples are:

- What are the temperature limits of the items to be insulated?
- Where is the plant geographical location and what are the environmental conditions?
- What fluids are being insulated?
- Why is insulation required?
- What type of insulation material should be used?
- What type of finish is necessary?

Temperature Limits for Insulated Items

This starts the entire design and material selection. For a power plant, temperatures range from above 32˚F to about 1,200˚F. At an ethylene plant, the range is between minus 250˚F and 1,200˚F. Two very different types of design considerations are required, although the materials and application for the 32˚F range and 1,200˚F range could be the same. This also necessitates expansion and contraction joints.

The design of hot service insulation expansion joints and insulation supports are quite important. In steam system design at 1,000˚F the piping would expand .095 inches per foot of pipe, and the insulation (calcium silicate or perlite) would contract .024 inches per foot. A total of 5.95 inches of expansion must be accounted for if the pipe length was 50 feet. The pipe expansion must still be accounted for, even though some materials will not contract (such as mineral wools). It is also important to control where the expansion will occur. On vertical piping and equipment, this is done with the use of insulation/expansion supports. Without these, all the expansion will occur at the top.

Contraction joints are just as important to cold insulation design as expansion joints are to hot insulation. If the system has an operating temperature of minus 100˚F, the stainless steel pipe will contract 0.0176 inch per foot and the insulation, depending on the material, will contract 0.01 inch per foot for cellular glass insulation to 0.102 inch per foot for polyisocyanurate insulation.

Geographic and Environmental Factors

Geographic design considerations depend on plant location. Facilities located in hot and humid climates will have different parameters than those located in a dry, cooler climate. The National Weather Bureau; the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.; U.S. meteorological services cited data; or similar service provides local weather data that can be used in determining the minimum, maximum, and average daily temperatures, wind, humidity, and rainfall.

A review of the following parameters should give the necessary design data:

- Wind
- Snowfall
- Extreme temperatures
- Relative humidity
- Rainfall
- Water table
- Seismic readings.

It is important to know if a plant is located near an industrial complex, where potentially corrosive chemicals are present, or near coastal areas, which can affect the insulation selection, weatherproofing materials, and application procedures. Insulated equipment located near a cooling tower or ash-handling equipment will be exposed to a more corrosive environment than will other plant equipment.

Wind conditions (both positive and negative [backside negative pressure]) must be considered in insulation design. In hot service, the weatherproofing could be supported by angle irons attached to the vessel or vessel support system. The insulation material could be rigid enough to support the positive pressure of the weatherproofing, but the attachments must be strong enough to resist the negative pressure on the backside. Corrugated metal is usually preferred on vessel sidewalls held in place with stainless steel bands on 18-inch centers and screws in the vertical overlapping seams.

Types of Fluids Being Insulated

Insulation design for pipe and equipment that handles hazardous chemicals, such as flammable or toxic materials, requires special consideration.

Insulation materials that can absorb fluids (such as hot oils/heat transfer fluids) and cause that fluid's flash point to be reduced should not be used in such service. Non-absorbent type insulation materials should be used in these services. These insulation materials may also be required for toxic services, where trapping of a toxic substance in the insulation can pose health hazards.

Reasons for Insulation

Why is insulation required? Because it's necessary! The real question is: Will it be necessary to limit heat loss for personnel protection, to reduce heat gain, to limit surface condensation, or to provide process control? Or will it be used for product stabilization, freeze protection, noise control, and fire protection? Each of these may require different thickness, materials, finish, and extent of insulation.

Limit Heat Loss or Heat Conservation

Insulation by itself will not maintain or hold temperatures within a system. Insulation can only provide a means to limit, conserve, control, reduce, or minimize the rate of heat flow through a system, but it cannot stop the process. Insulation is merely a heat flow reducer, not a barrier to heat flow.

It might be that condensate and blowdown lines to drains or holding tanks may require insulation to limit heat loss. However, heat losses through valves and flanges are not critical to the system; therefore they are not insulated (although personnel protection may be required).

Personnel Protection

When designing insulation systems for personnel protection, only enough insulation should be used to reduce the surface temperature to an acceptable limit to prevent individuals from being burned. Traditionally, the insulation surface's upper temperature for personnel protection is 140˚F. To date, no mandates or statutes govern the upper limit for personnel protection. Refer to ASTM C1055 *Standard Guide for Heated System Surfaces Conditions That Produce Contact Burn Injuries* (1) for guidance in selecting acceptable temperature limits.

Insulation for personnel protection is generally applied only in those areas accessible to persons during normal plant operation and maintenance, and applied to a high of 7 feet above or 3 feet from platforms or work areas. In some system designs where there is no justification for insulation, and the insulation could actually be detrimental to the process. Fabrication guards may be employed to provide personnel protection.

When insulation is used for personnel protection, it is very important to flash the ends to prevent water or moisture from getting behind the insulation, and to prevent insulation deterioration and surface corrosion. Note that most mastics and sealants could have temperature limits lower than the operating or design temperature of the surface for personnel protection.

In situations where solar loads are high, highly reflective metal jacketing materials reflect much of the radiant heat, thereby creating surfaces that could be too hot to touch. Dull, textured, or painted surfaces tend to absorb more of the radiant heat, creating a surface condition cooler to the touch. Gray-coated metal jacketing can reduce insulation thickness for personnel protection by as much as 2 inches. As a general rule, the closer the materials emittance is to 1, the cooler the surface temperature will be.

Wind conditions also influence the selection of insulation for personnel protection. For example, in open areas in coastal regions, a prevailing wind is usually present, which can be considered in the insulation design. In this situation, less insulation would be required than in an enclosed space sheltered from the wind.

Reducing Heat Gain on Cold Surfaces

In below-ambient applications, the main objective for providing insulation is to reduce heat gain and prevent moisture migration or water intake into the system. This type of moisture migration will have a dramatic effect on insulation performance. Cold systems are more subject to degradation from the environment than are hot systems, because of the direction of the vapor driving force. On hot insulation systems, the water vapor's driving force is away from the hot surface; and although the ingress of water into the insulation can adversely affect performance, it is generally considered to be temporary. Conversely, on cold systems, the water vapor's driving force is inward toward the colder surface.

The ingress of water into the insulation will gradually increase with time. The moisture will slowly deteriorate and eventually destroy the system. For this reason, it is extremely important that the total insulation system design be detailed and well-planned, using vapor barrier mastics, vapor barrier stops, and low-permeability joint sealants.

Usually, the cost of removing British thermal units (Btu) (heat gain) by refrigeration is greater than that of producing process Btu (heat loss) by heat generating equipment. Therefore, the heat gain in cold processes must be kept to a minimum. The rule of thumb is to provide sufficient insulation to maintain heat gain of 8 to10 Btu per hour per square foot (hr/ft^2) to the cold process. The design's ambient temperature and wind conditions must be utilized when calculating the insulation thickness.

In cold insulation system design, vapor barriers and vapor stops are extremely important. Vapor stops, which seal the insulation to the pipe or equipment, should be installed at all insulation protrusions and terminations. These vapor stops will prevent any failure of the insulation system from traveling along the entire system.

Limiting or Controlling Surface Condensation

Insulation systems can be designed to limit or retard condensation, but in most cases they cannot be designed to prevent condensation. In humid regions it's unfeasible to consider designing an insulation system to prevent condensation 100% of the time. In these areas, the required thickness of even the most efficient insulation would be unrealistic from both a financial and practical standpoint.

Insulation thickness is determined using ambient conditions and relative humidity, along with the process operating temperature and surface emittance. The insulation system should be designed to keep the surface temperature above the dew point of the ambient air. This will keep condensation from forming on the outer surface of the insulation, avoiding safety hazards and preventing dripping condensate on buildings or electrical equipment. It is essential to agree on how often condensation is acceptable.

In hot and humid outdoor environments and during rain, it is virtually impossible to prevent condensation 100% of the time. If the insulation thickness is designed to allow for a heat gain of 8 to 10 Btu per hr/ft^2, this will be sufficient to prevent condensation the majority of the time.

Providing Process Control

Process control is a critical design parameter in many industrial applications, particularly for steam and critical process piping and equipment. Providing a stable temperature flow and heat loss throughout a process system is, in many cases, more important than any other system design.

When designing for process control, other information is also necessary, such as determining what heat loss or temperature must be controlled. What pipe length and equipment size? How is the piping and equipment supported? Are they on insulated shoes, vessel skirts, legs, or other components? Also, any protrusions should be accounted for in the heat loss.

Freeze Protection

Freeze protection can be maintained by fluid flowing insulation or by insulation with some form of additional heat input. Insulation alone cannot maintain a temperature. It will delay the time required for a fluid to reach a design temperature, but it cannot (or will not) stop it.

In the Gulf Coast region, generally most stagnant water lines in sizes 6 inches and smaller should be heat-traced and insulated. Only lines between 8 feet and 12 feet need insulation.

Freeze protection could also refer to prevention of product solidification. In product solidification, additional heat input is usually required to replace the heat loss through the insulation. For example, heavy fuel oil might have to be maintained at 250˚F and will require additional heat input to replace the heat loss through the insulation.

Noise Control

Environmental acoustic issues can be addressed by thermal insulation system design. However, serious noise problems should be treated as a separate and independent study.

Sound attenuation is a natural by-product of the insulation design. Because of their sound absorption characteristics, some insulation and accessory products provide greater sound attenuation than others. Mineral fiber products are among the best thermal insulation materials for sound attenuation.

The jacketing material used to cover the insulation can play an important role in sound attenuation. A fabric-reinforced mastic finish over insulation has better sound absorption properties than metal jacketing. Metal jacketing may also be purchased with a loaded mass to reduce noise.

Fire Protection

As a general rule, insulation materials are better suited as insulation than as a fire protection product. However, the American Petroleum Institute (API) acknowledges conditions under which some insulation materials may provide "credit" in the design and sizing of pressure relief valves. *API Recommended Practice 521* (2) states insulation system requirements. Included is a requirement that the finished insulation system will not be dislodged when subjected to the fire/water stream used for fire fighting, either by hand lines or monitor nozzles. Most insulation systems used in fire protection are metal with stainless steel jackets and bands, which meet these criteria.

Physical and Mechanical Conditions

Physical and mechanical conditions also play an important part in insulation system design. Indoor applications generally do not require the complexity of outdoor designs. Similarly, below-ambient applications are more complex than hot applications. The physical abuse and mechanical conditions that an insulation system is subject to are also important to consider during design.

Rigid insulation is resistant to deformation when subjected to foot traffic. Compressible insulation does not offer the same resistance to such loads. Areas that experience loads or repetitive personnel access/use will require a firmer system than inaccessible areas. Piping used as ladders/ walkways and riggings hung from pipes and horizontal surfaces subject to vibration/loads are examples where rigid insulation is required. Compressible insulation is required for filling voids and closing gaps in insulation, which allows expansion, contraction, or movement of rigid insulation.

Mechanical abuse should be considered case by case. Insulated items located in high traffic areas should have a structure such as a platform or similar protection, to avoid having personnel stepping directly on insulation.

Insulation Materials

There are many types of insulation materials available for industrial application, though there are too many to discuss in detail here. A few of the most common industrial insulations and types will be described. These are:

- Calcium silicate
- Cellular glass
- Fibrous materials (fiberglass and mineral wool)
- Perlite
- Polyisocyanurate foam.

The *Insulation Material Specification Guide* (3) from the National Insulation Association's (NIA) National Insulation Training Program, which may be obtained by contacting NIA at *www.insulation.org*, gives a quick comparison of ASTM values for these and other insulation materials.

When comparing material properties, keep in mind that ASTM test methods are usually performed under laboratory conditions and may not accurately represent field conditions. These depend on process temperatures, environment, and operating conditions.

Calcium Silicate

Calcium silicate insulation is a rigid, dense material used for above ambient to 1,200˚F applications. This has been the industry standard for high-temperature applications. It has good compressive strength and is non-combustible.

Cellular Glass

Cellular glass insulation is also a rigid, dense material normally used in the temperature range from minus 450˚F to 400˚F. Its closed-cell structure makes it preferable for low-temperature applications, and for use on services where fluid absorption into the insulation could be a problem.

Fibrous Materials (Fiberglass and Mineral Wool)

Fiberglass and mineral wool are actually two separate types of insulation. However, many of their applications and physical properties are the same. These products are generally not used where mechanical or physical abuse could occur. Although they may be used in high temperatures, some of their physical and acoustical properties may be lessened.

Perlite

Perlite insulation is generally used in the same type of applications as calcium silicate insulation. However, it is somewhat lighter in density and lower in compressive strength then calcium silicate. It is treated with a water inhibitor, which prevents the material from absorbing atmospheric moisture during storage and installation.

Polyisocyanurate Foam

Polyisocyanurate foam insulation is used in temperature ranges from minus 200˚F to 300˚F. It has very good thermal properties and is 90% closed cell. In cold service application, it requires multiple layers because of its contraction characteristics.

Accessory Materials

The insulation's accessory materials used are as important as the insulation material itself. If the wrong accessory material is selected, the system will not provide the required performance.

Typical accessory materials include acrylic latex mastic, aluminum jacketing, stainless steel jacketing, stainless steel bands and screws, hypalon mastic, and electrometric joint sealers.

Metal jacketing is preferred to mastic for most outdoor applications because of its durability.

Colored jacketing should be used for cold service and personnel protection insulation to reduce surface emittance from 0.01 for new aluminum to 0.8 for colored aluminum, which will reduce insulation thicknesses.

References

1. ASTM International, ASTM C1055, *"Standard Guide for Heated System Surfaces Conditions That Produce Contact Burn Injuries,"* 2003. For referenced ASTM standards, visit the ASTM Web site, *www.astm.org*, or contact ASTM Customer Service at *service@astm.org*. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM Web site.
2. American Petroleum Institute, *API Recommended Practice 521—Guide for Pressure Relieving and De-Pressuring Systems*. 4th Edition. March 1997, *www.api-ep.api.org.*
3. National Insulation Association's (NIA) *Insulation Material Specification Guide, www.insulation.org.*