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IEEE Recommended Practice for Precipitator and Baghouse Hopper Heating Systems

Sponsor
Energy Development and Power Generation Committee
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IEEE Power Engineering Society

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Abstract: Recommendations on hopper heating system performance and equipment requirements necessary to provide an economical and effective hopper heating system are presented. System characteristics are described, and heat transfer analysis is covered. Heating module design considerations are presented. Control, monitoring, and alarm systems are discussed. Insulation, installation, operation, and maintenance are addressed.
Keywords: Baghouse hoppers, fly ash removal from boiler flue gas, hopper heating systems, precipitators

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Foreword

(This Foreword is not a part of IEEE Std 1069-1991, IEEE Recommended Practice for Precipitator and Baghouse Hopper Heating Systems.)

Precipitators and baghouses are two equipment systems designed to remove particulate (i.e., fly ash) from coal- and oil-fired boiler flue gas streams. The fly ash is collected in hoppers and transferred out of the hoppers for disposal. The reliable operation of the precipitator or baghouse and the removal of fly ash from the collection hoppers is essential to the efficiency of overall plant operation.

If the hoppers are not heated prior to the introduction of fly ash, the fly ash can cool down and plug the hopper throat, which will cause severe maintenance problems. If the hopper temperatures are not maintained above the flue gas acid dewpoint temperature, the fly ash could adsorb moisture and then agglomerate and plug the hopper throat, which could cause additional maintenance problems.

If these hopper plugging problems are not cleared, the fly ash could build up in the hoppers to the level where the performance and efficiency of the precipitator or baghouse is affected. Boiler de-ratings and even shutdowns may be required until the hopper plugging problems are resolved. Effectively designed hopper heating systems can minimize or completely eliminate the maintenance required to ensure proper fly ash removal from hoppers.

IEEE Std 1069-1991 presents recommendations on hopper heating system performance requirements and covers the following topics: heater design; control, monitoring, and alarm systems; installation and hopper insulation techniques; and system maintenance.

This recommended practice is consistent with industry practice and identifies the major areas that should be addressed when designing a hopper heating system. It is not the intent of this recommended practice to survey every style of heater that is available. Because the modular type of heater has been used in the majority of successful operating systems, this recommended practice addresses the design features required for modular heating systems.

The appendix includes a specification guideline for hopper heating systems. Since operating companies have differing design, control, and alarm requirements, the specification guideline should be adapted for each individual situation.

This document was prepared by the Station Design Subcommittee Working Group of the Energy Development and Power Generation Committee of the IEEE Power Engineering Society.

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IEEE Recommended Practice for Precipitator and Baghouse Hopper Heating Systems

1. Scope

Precipitators and baghouses are two systems designed to remove fly ash from boiler flue gas. Air pollution control regulations require that these precipitators and baghouses operate efficiently and reliably. Malfunctions or equipment failures could lead to boiler de-rating or complete shutdown, which increase the operation and maintenance expenses for the operating company.

Problems related to fly ash collection in the hoppers, such as fly ash agglomeration and fly ash solidification, can lead to precipitator and baghouse shutdowns. The proper design and installation of hopper heating systems can significantly reduce the maintenance problems associated with fly ash plugging in hoppers.

2. Purpose

This recommended practice is intended to define the system performance and equipment requirements to provide an economical and effective hopper heating system.

3. System Characteristics

For the purposes of this recommended practice, the hopper will be defined as “the structure below either the precipitator casing or baghouse flue gas inlet.”. The hopper ash collection area does not ordinarily have flue gas passage within it and is intended to temporarily collect fly ash for removal and disposal (see Fig 1).

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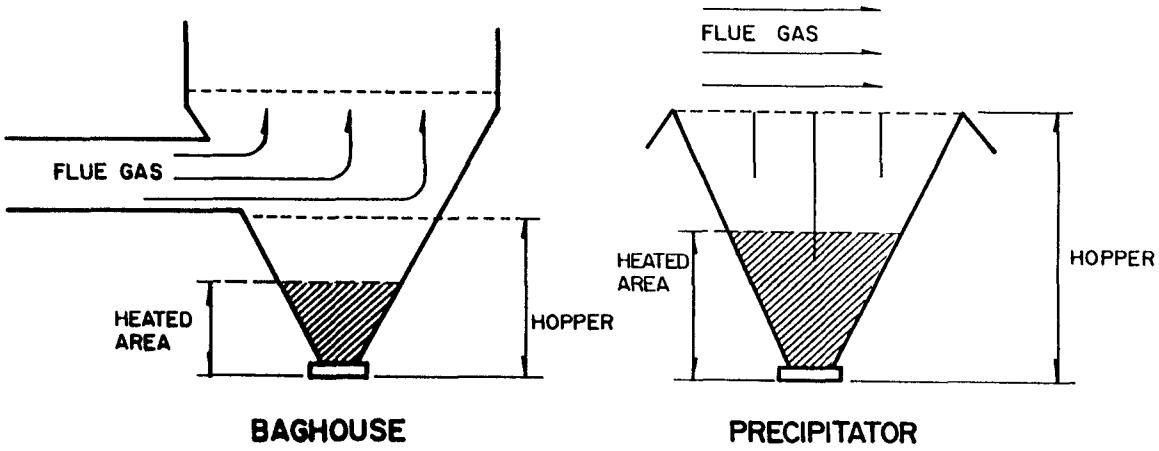


Figure 1—Hopper Definition for Hopper Heating Systems

3.1 Fuel, Flue Gas, and Fly Ash

Hopper heating requirements are affected by the type of fuel and the resulting flue gas and fly ash characteristics. Therefore, the design and application of the hopper heating system should consider the expected conditions of the flue gas and fly ash in order to successfully keep the fly ash in a state that allows for its easy removal from the hopper.

3.1.1 Flue Gas Characteristics

The primary flue gas characteristics that influence the design of the hopper heating system are its SO_2/SO_3 content and its moisture content. These characteristics change from one fuel to another.

Moisture dewpoints normally range from 90 °F–150 °F (32.2 °C–65.5 °C) dependent on the combustion air moisture content and the hydrogen content of the fuel.

Acid dewpoints normally range from 200 °F–300 °F (93.3 °C-148.8 °C) and are primarily dependent on the sulfur content of the fuel and the moisture content of the flue gas.

3.1.2 Fly Ash Characteristics

The type of fuel and boiler design used affect the fly ash characteristics. Typical fuels include western coals, eastern coals, lignite, solid wastes, fuel oils, and petroleum residuals.

Fly ash particles can range in size from submicron to over 10 microns. Fly ash composition includes silicas; sulfates; carbonates; oxides of sodium, magnesium, calcium, iron, and aluminum; and other trace elements. These fly ash components will vary from one fuel to another. The relative quantity of these components affects the fly ash characteristics during both accumulation in the hopper and evacuation from the hopper.

3.1.2.1 Compaction

Compaction results from fly ash settlement and is generally caused by hopper vibration when the fly ash evacuation is not operating. It can produce bridging across the lower portion of the hopper near the hopper throat.

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3.1.2.2 Agglomeration

When the temperature of the fly ash falls below the flue gas acid dewpoint, the hygroscopic nature of the various fly ash components causes adsorption of the flue gas water vapor. This promotes agglomeration in the hopper. Bridging then occurs and causes hopper pluggage.

Greater amounts of sodium compounds increase the tendency of the fly ash to agglomerate in the hopper. Flue gas conditioning systems may also affect the fly ash agglomeration problem.

3.1.2.3 Solidification

When fly ash particles mix with condensates that have accumulated in the hopper, a chemically reactive compound can result, which causes eventual solidification. The resultant solid fly ash blocks the hopper throat and causes hopper pluggage.

Solidification of fly ash can occur when the lower portion of the hopper is below the flue gas moisture dewpoint.

The most frequent solidification problems occur during boiler start-ups with unheated hoppers. Solidification has been known to cause plugging problems in hot-side precipitators as well as cold-side precipitators and baghouses.

3.1.3 Flue Gas Conditioning

These systems typically inject sulfur compounds, ammonia, or specialty chemicals into the flue gas stream to improve the precipitator's fly ash collection efficiency. The fly ash composition, electrical resistivity, and agglomeration tendencies in the hopper may change.

3.2 Hopper Temperature Requirements

The hopper maintenance temperatures should address the minimum temperature to be maintained during normal operation, during "low-load" boiler operation, and during boiler start-up.

3.3 Flue Gas Temperature Excursions

Upset conditions, such as an air preheater failure, can result in high flue gas temperatures (up to 800 °F [426.6 °C]) and should be considered when selecting hopper heating equipment.

3.4 Hopper Design

Fly ash settling and removal are affected by the dimensions and slope of the hopper walls. Any equipment located inside the hopper can be a physical impediment to fly ash removal from the hoppers. External equipment to the hopper (i.e., diffusion equipment, manways, strike plates, vibrators, poke tubes, other attachments to the hopper) also affect the heating system design.

3.4.1 Diffusion Systems

In an effort to reduce settling and to prevent compaction of the fly ash, diffusion air is sometimes employed to "fluff" the fly ash. The diffusion air temperature at the point of introduction to the hopper should be at or above the flue gas temperature. Otherwise, diffusion air can actually aggravate agglomeration and pluggage problems.

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3.4.2 Vibration Equipment

Vibrators are often used to assist fly ash flow when the fly ash removal valve is opened.

Electrical or pneumatic vibrators should be automated to operate only when the removal valve has fully opened. Strike plates are commonly added to hoppers to allow for manual rapping or vibration to induce fly ash flow out of the hopper.

3.4.3 Poke Tubes

The installation of poke tubes is commonly done to assist ash removal in a plugged hopper throat. All poke tubes should be tightly capped when not in use.

3.5 Insulation

A well designed and applied thermal insulation system is required for proper hopper heating system performance.

3.6 Long-Term Performance

The reliability and longevity of the fly ash hopper heating system components should be consistent with the life expectancy of the precipitator or baghouse.

4. Heat Transfer Analysis

4.1 Equipment Operating Conditions

The operation of a precipitator or baghouse includes various operating conditions, such as start-up condition, normal operation, upset condition (i.e., air preheater failure, boiler tube leak), and low-load operation. These various operating conditions require separate heat transfer analyses to prevent fly ash cooldown, which may result in hopper pluggage due to agglomeration or solidification.

In addition, the flue gas flow pattern through a precipitator are different than the flue gas flow pattern through a baghouse compartment. Normal and maximum design ash levels will also impact the heat transfer analysis.

4.2 Physical Properties

The information required to perform a heat transfer analysis include the following:

1) Minimum ambient temperature
2) Flue gas temperature range—Normal operation, start-up condition, upset condition, and any temperature variations across the flue gas stream
3) Flue gas acid dewpoint temperature
4) Flue gas moisture dewpoint temperature
5) Hopper arrangement defined, including stiffeners and throat dimensions, poke tubes, rappers, vibration equipment, diffusion equipment, and manways
6) Insulation material and thickness
7) Fly ash accumulation rates and levels
8) Fly ash thermal conductivity, density, and specific heat (may be estimated if not precisely known)
9) Wind velocity (enclosed or open hopper area)

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4.3 Start-Up Dynamics

To prevent moisture accumulation in the hopper and to prevent fly ash cooldown, the empty hopper should be preheated. The recommended design is to preheat the lower one-third of the hopper surface area (approximately half of the vertical height) to an average of 150 °F (65.5 °C) above the ambient air temperature in 8–10 hours. For the design basis, the hopper is defined as "the structure below normal flue gas flow patterns" (the entire hopper for precipitators and the area below the flue gas inlet for baghouses). Prior to the introduction of warm flue gas, the internal gas temperature is assumed to be the minimum ambient air temperature. When flue gas is introduced into the precipitator or baghouse, the hopper temperature will increase up to the desired hopper maintenance temperature. Any condensation will be revaporized, and the hopper walls will be hot enough to prevent fly ash agglomeration.

It should be noted that the start-up conditions normally determine the heating design load. Without preheating the hopper, lower hopper wall temperatures of 20 °F–40 °F (–6.6 °C–4.4 °C) above ambient can be expected; condensation accumulation will occur and any resultant fly ash solidification can plug the hopper throat. Preheating requirements are similar for cold-side precipitators, hot-side precipitators, and baghouses.

Some baghouse applications may require compartment preheating, which can be accomplished with a hopper heating system and peripheral compartment heating system.

A multidimensional heat transfer analysis is required to determine the external heat losses through the insulation and the uninsulated heat sinks (e.g., hopper throat, poke tubes, rapping anvils, vibrators, manways, diffusion equipment), the heat required to increase the hopper temperature and the internal convective heat losses. This assumes a clean internal hopper surface (worst case). Heat transfer occurs primarily via conduction and convection and, to a lesser degree, via radiation.

The complexity of the heat transfer analysis does not lend itself to simple heat transfer formulas and requires actual hopper temperature testing data to arrive at predictable hopper heating performance. Several experienced hopper heating system manufacturers have test data on file and have developed multidimensional heat transfer models to determine the heating requirements.

External heat loss from the hopper walls occurs through conduction and convection, and should be determined separately for the insulated and uninsulated heat sinks (e.g., hopper throat, poke tubes, pipe hangers, rapping anvils, manways) to ambient. This external heat loss will increase as the hopper wall temperature increases.

Thermal capacity determination should include the mass of the hopper walls and all stiffeners and appurtenances, so that the energy needed to raise the hopper from ambient to the preheat temperature can be determined.

Heat loss determinations to the inside of the hopper are made on the assumption of clean hopper walls and no air leaks into the system with natural convection of air at ambient temperature moving down the center of the hopper and sweeping up past the heated hopper surface (see Fig 2). Natural convection heat transfer coefficients should allow for laminar now turning into turbulent flow.

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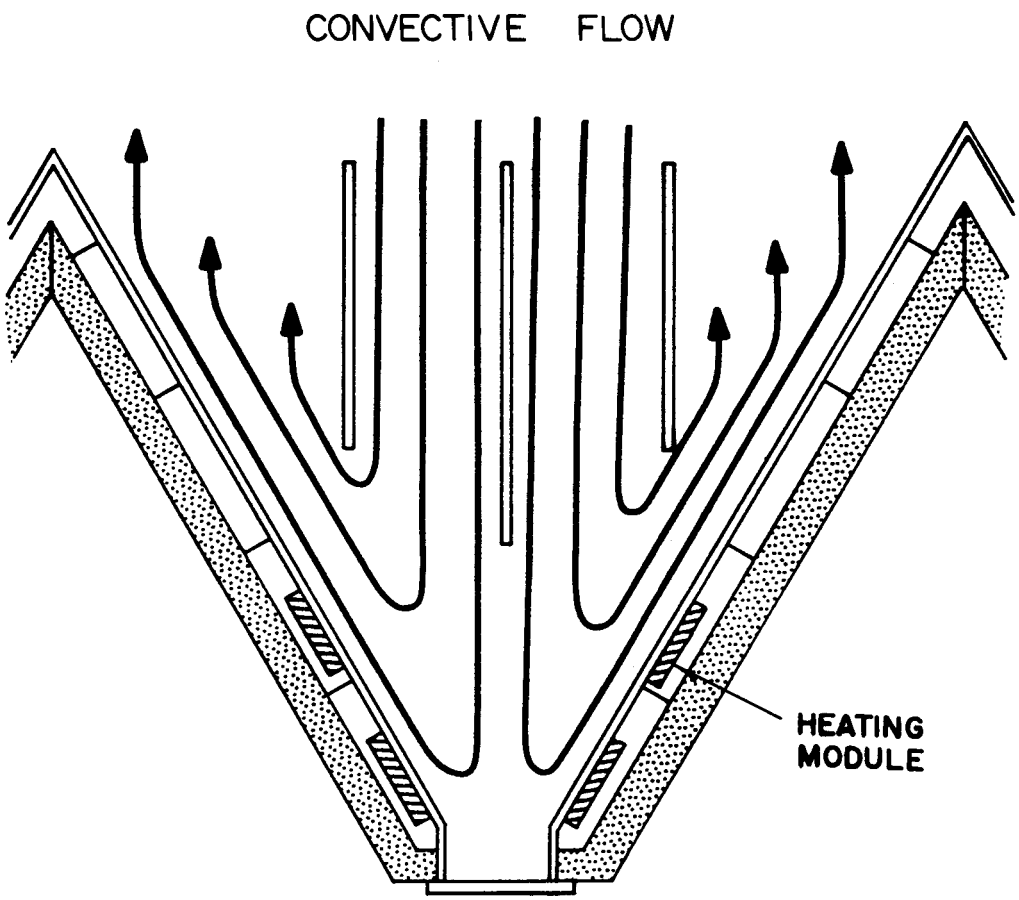


Figure 2—Start-Up Convection Flow Patterns

4.4 Normal Operating Heating Loads

For normal operation, heating requirements are determined by the heat loss from hopper walls through the insulation and uninsulated heat sinks, plus heat loss to the inside of the hopper with varying fly ash levels during a minimum ambient temperature condition. External heat loss determination should take into account the heater temperature between the hopper walls and the insulation, which will be higher than the hopper wall temperature (see Fig 3). When calculating heat loss to the inside of the hopper, some allowances for air leaks into the system should be considered.

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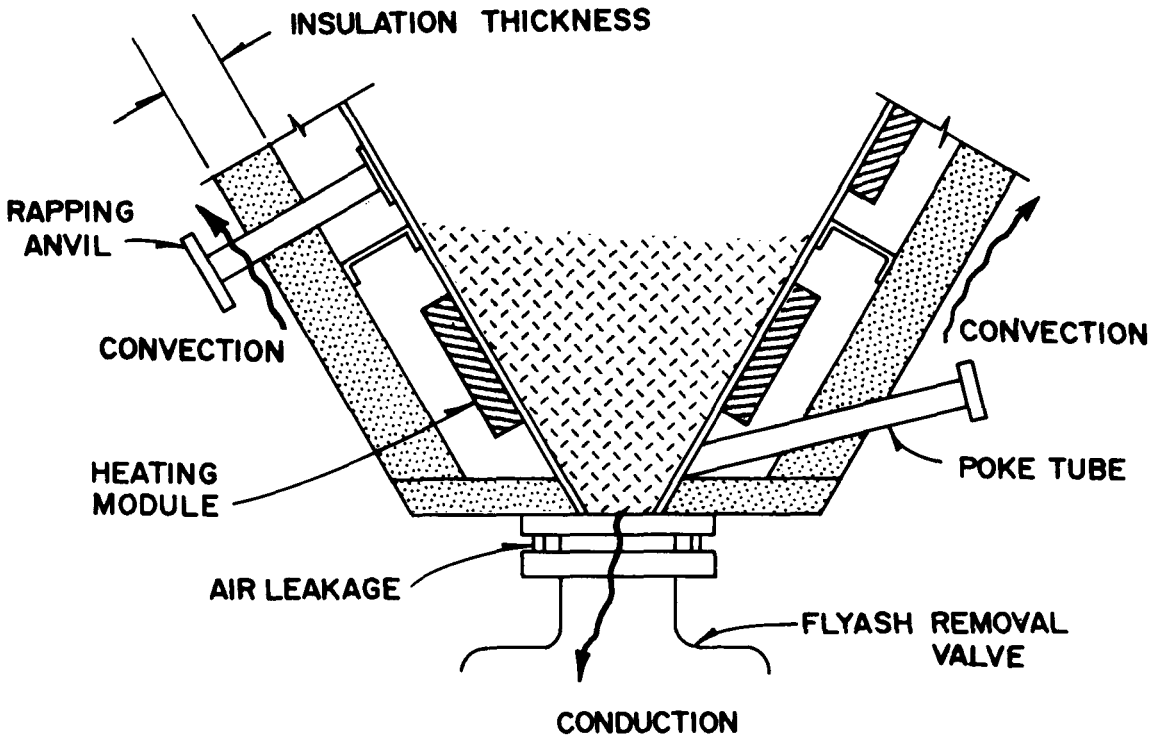


Figure 3—Hopper Heat Losses During Normal Operation

4.5 Low-Load or Upset Conditions

For low-load or upset conditions, heating needs are determined the same way as for normal operation. However, the flue gas temperature is lower at low boiler loads, which could increase convective losses. Thus, a higher hopper heating capacity may be needed.

Higher maintenance temperatures may also be needed if a different fuel source is used. For most designs, low-load or upset conditions normally will not affect the heating system design.

4.6 Hopper Wall Temperature Profiles

The majority of hopper heaters are attached directly to the hopper wall. When the heaters are energized, heat is transferred via

1) Conduction into the hopper wall and fly ash
2) Convection into the air space between the insulation and hopper wall from the back side of the heater
3) Convections from the hotter portion of the hopper wall adjacent to the heaters

The heater element temperature is dependent on the heater watt density, the thermal conductivity of the heater dielectric material and heater enclosure, the contact between the heater and the hopper wall, and the temperature of its surroundings. Since the hopper wall may have weld seams, rust, etc., that may affect heat transfer, most heater companies recommend heater watt densities that allow for less than perfect heater surface contact with the hopper wall. Hopper materials, including carbon steel, and corrosion resistant steel, as well as various wall thicknesses, have a minor impact on heat transfer profiles.

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The hopper wall temperatures will vary from the highest temperatures (under the heaters) to the lowest temperatures (hopper corners or near heat sinks) and whether fly ash is in the hopper behind the heater or a portion of the heater (the highest temperature condition). This temperature variation is based on heater size and heater watt densities and normally results in heating element operating temperatures of 400 °F–650 °F (204.4 °C–343.3 °C) when maintaining a hopper at 250 °F-300 °F (121.1 °C–148.8 °C). It is important to note that several companies have established criteria to prevent excessively high temperatures under the center of the heater when fly ash is in the hopper.

As fly ash accumulates in the hopper, a portion of the heater surface will have flue gas inside the hopper wall and a portion will have fly ash inside the hopper wall. The temperature profiles should be supported with the theoretical and empirical data to ensure that excessive temperatures and the resultant heater failures do not occur.

The heat transfer analysis assumes and requires that the insulation system be installed correctly with proper draft stops to prevent convective “chimney effects” and with proper sealing around the hopper throat and the noninsulated hopper appurtenances. A one-half inch thick insulating throat gasket (or a buildup of several gaskets) is recommended to reduce the conductive heat transfer to the uninsulated fly ash removal valve.

4.7 Special Design Considerations

Certain plant operating conditions may require a special heat transfer analysis to maintain the fly ash at its desired temperature. These conditions may include

1) Cycling plants with shorter start-up times and hopper temperature maintenance requirements during off-peak hours
2) Baghouse compartment preheating or compartment temperature maintenance when a compartment is taken out of service
3) Precipitator and baghouse hoppers downstream of flue gas desulfurization equipment, which will be collecting fly ash plus desulfurization components at lower temperatures (typically 140 °F–170 °F [60 °C–76.6 °C])
4) Large fly ash accumulation rates expected in lignite-fired units
5) The addition of a flue gas conditioning system (This may increase the maintenance temperature requirement.)

5. Heating Module Design Considerations

Since a properly operating hopper heating system is essential to efficient fly ash removal, the heating module design should provide for long-term reliable operation. Specific design consideration should be given to the following heating module features:

1) Electric heating element configuration and material
2) Heating element to lead wire connection method
3) Electrical lead wires (cold leads)
4) Electrical insulation around the heating element and connection system
5) Modular enclosure material and temperature rating
6) Attachment hardware material and design
7) Heating module watt density

These components should be designed for the conditions experienced during the life of the hopper heating system.

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5.1 Vibration/Impact Loading Exposure

The hoppers are subjected to both natural vibration caused by gas flow and induced vibration due to the use of pneumatic or electromechanical vibrators. Impact loading occurs when pounding lugs and strike plates are used.

The heating modules and the attachment method should be designed to withstand these conditions without failure or degradation. Heaters designed with magnesium oxide and other powder dielectric materials are not recommended for these vibration environments.

5.2 Maximum Temperature Exposure

The maximum temperature exposures described in Sections 3. and 4. should be considered in the selection of heating module components. Flue gas excursions of up to 800 °F (426.6 °C) can result from air preheater failure. The heating module design should account for this excursion as well as the maximum heater element operating temperature when the heating module is energized with and without fly ash inside the hopper. This maximum heating element temperature is a function of the heating element watt density and the heating module's capacity to transfer heat from the heating element to the hopper wall and its surroundings.

Heating module designs should allow for these maximum temperatures during normal operation and during flue gas excursion conditions.

5.3 Power Supply Voltage

Commonly available supply voltages include any voltage level up to 600 V, with 480 V as the most common voltage level. The heating module dielectric materials should not only be designed for these voltages; but the heating modules design should allow for any normal voltage fluctuations (±10%).

The heating module design should include a dielectric withstand capability of twice rated voltage plus 1000 V_{ac}.

5.4 Moisture/Humidity Resistance

During the pre-installation storage, installation, pre-commissioning, and shutdown periods, moisture or high humidity conditions may exist. The heating module design should allow for these conditions, and particular attention should be given to the design of the electrical lead wires and any exposed surfaces that are susceptible to moisture intrusion.

5.5 Hopper Walls

The hopper walls are typically constructed of carbon or corrosion-resistant steels. A hopper wall thickness of one-quarter inch is typical. Stiffeners of various designs (e.g., bars, channels, I-beams) are located at intervals and are required for structural support. The fabricated hoppers can have weld seams, rust, oil, weld splatter, and uneven surfaces.

The heating module design and its attachment method should allow for these physical variances of the hopper wall.

When heating curved surfaces (i.e., hopper throats, poke tubes, manways), flexible heating blankets, in addition to beating modules, may be used.

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5.6 Fly Ash Levels

Normal operation will include a cycle of fly ash accumulation in the hopper followed by evacuation out of the hopper throat. When fly ash is accumulating in the hopper, the poor thermal conductivity of the fly ash will affect the heater's operating temperature.

The heating module design should allow for the varying operating temperatures caused by the changes in fly ash levels.

5.7 Handling and Installation

Field handling and installation environments require special heating module designs. The lead wires should have strain reliefs to minimize internal module damage that might be caused by careless handling of the heating module and its lead wires. The installation method should incorporate techniques to minimize the variances of field installations that could cause subsequent heating system failure. Specific attention should be focused on module designs that minimize installation damage, which might be caused by vibration and temperature cycling.

6. Control, Monitoring, and Alarm Systems

An effective control system is critical to the proper operation of the total hopper heating system. The primary function of the system is to distribute energy from the power source to the individual heaters on each hopper, as required, to maintain the desired hopper temperature. As a minimum, each hopper should be independently controlled.

For large systems, the power distribution, monitoring and alarm, and control components (except the sensing elements) are located in a hopper system control panel or panels. This approach minimizes control cabling; facilitates checkout, operation, and maintenance; and provides for the distribution of power. For small systems, the controls can also be located locally at the hoppers or incorporated into other system control cabinets.

6.1 Power Distribution

The distribution of power to the heating elements can be accomplished by using many different methods and types of equipment; but the overall philosophy of all these methods is the same. Power is taken from an incoming electrical energy source through a network of main and branch distribution equipment to the control devices and then to the individual heaters (see Fig 4).

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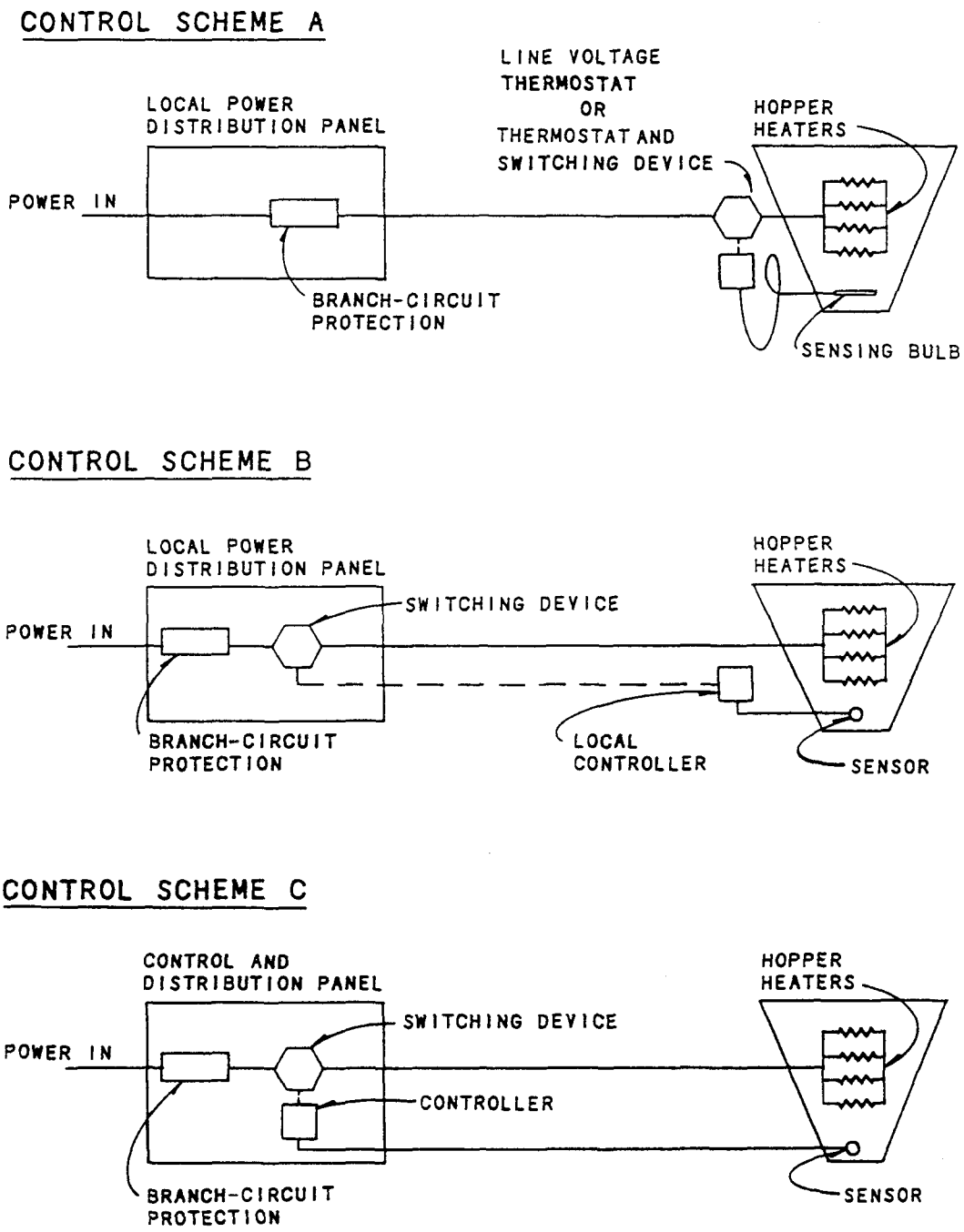


Figure 4—Power and Control Options

The recommended power distribution system for large applications consists of a hopper heater control panel with a main disconnect switch (usually one per panel) and branch circuit protection device and controller (usually one per hopper or one per heating zone). For smaller systems, power can be taken from panelboards or other power distribution sources.

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The main disconnect can be a fused or an unfused switch or a molded-case circuit breaker. The purpose of the main disconnect switch is to provide for the isolation of the panel from the power source for maintenance and testing. The branch-circuit protection devices are usually molded-case circuit breakers or fuses. This provides for the fault and overload protection of the feeder cable and electrical components for each heater branch circuit.

An alternate method of power distribution is to use individual branch-circuit protective devices to supply control devices installed locally at each hopper.

6.2 Temperature Controllers

Two basic types of temperature controllers are generally used for hopper heating control and monitoring: electromechanical and electronic. Before selecting the first or second specified type of controller, the required or desired temperature control parameters should be evaluated.

1) Controller location
   a) Local (on or near the hopper)
   b) Remote (in central control panel location)
2) Control system precision/accuracy
3) Controller and sensor environment
4) Operating temperature range
5) Maximum exposure temperature
6) Controller “fail-safe” operation requirements
7) Controller duty cycle (life)

6.2.1 Electromechanical Temperature Controllers

The most commonly used electromechanical temperature controller is the bulb and capillary thermostat because it incorporates an adjustable setpoint, fast snap action switching, wide temperature range, and multiple outputs.

When evaluating electromechanical-type temperature controllers, the following factors need to be considered:

1) Temperature range
2) Minimum and maximum exposure temperatures
3) Output switch
   a) Switch ratings for voltage and current
   b) Quantity of switches required for control and alarms
4) Temperature indication requirements
5) Bulb and capillary material
6) Accuracy, repeatability, and “on-off” differential

6.2.2 Electronic Temperature Controllers

Commonly used electronic temperature controllers may be solid-state devices that include the following modes of control:

1) On-off
2) Time proportioning
3) Current or voltage proportioning

Basic electronic temperature controllers are nonindicating but can also come with temperature readout indicating capability. Care should be taken to ensure that the sensor output is properly matched to the type of controller.

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Temperature sensors that are used for this application are thermocouples and resistance temperature detectors (RTDs). Each of these types of sensors is used in conjunction with a separate controller used.

Several factors need to be taken into account before deciding which combination of sensor and electronic controllers will be used in a given application. Some of these factors are as follows:

1) Operating environment of the sensor and controller
2) Distance between sensor and controller
3) Accuracy of the sensor/controller over the temperature range
4) The output mode of the controller
5) Susceptibility of the sensor output to induced noise
6) Sensor/controller reliability

Common types of thermocouples are ISA, Type E (chromel-constantan), Type J (iron-constantan), and Type K (chromel-alumel). When selecting RTDs, the platinum-type are preferred over the nickel-type because of their accuracy.

Thermocouple-type systems require the use of thermocouple extension wire to match the thermocouple to the controller. The use of shielded cable between electronic sensors and controllers is recommended to minimize or eliminate electrically induced interference from affecting the accuracy of the sensor output signal. Thermocouples and RTDs should be of the surface mounted type for installation on a stud attached to the hopper, or the weld pad type for tack welding to the hopper face. The sensor should be located within 18 inches of the throat or lower portion of the bopper control zone and away from the heaters and heat sinks.

6.3 Monitoring and Alarm Systems

The monitoring and alarm systems are provided to supervise the operation of the overall hopper heating system. These systems can then indicate either locally or remotely, or both, when abnormal conditions occur so that corrective action can be taken.

One of the most common types of monitoring and alarm systems uses indicating lights or annunciator windows, which are either energized or de-energized in response to certain parameters. These lights can be located on a local or remote indicating panel or be incorporated into a central hopper heating system control panel. Typical monitor and alarm functions are

1) Temperature monitoring
   a) Temperature indication (readout)
   b) Hopper low-temperature alarm
   c) Hopper high-temperature alarm
2) Circuit monitoring
   a) Main power on
   b) Heater circuit power on
   c) Current monitoring

Other types of monitoring can be provided by using digital or analog readout devices to indicate system conditions (i.e., hopper surface temperature, main or branch heater circuit power, heater system voltage).

The extent of hopper heating system monitoring should be consistent with and similar in overall control philosophy to the monitoring criteria established for the total precipitator or baghouse installation. In cases where the hopper heating system control utilizes local monitoring, it is advisable to provide a remote trouble alarm signal from the hopper heating system back to the nearest manned control area.

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7. Insulation

Thermal insulation is an essential element in the design of a hopper heating system. The basic purpose of thermal insulation is to reduce the rate of heat loss from the hopper wall to the environment. When properly combined with the hopper heating system, the desired hopper temperatures can be achieved. A suitable insulation system offers reductions in energy losses and the means to optimize the performance of the heating system.

This section discusses several considerations and practices in the design, installation, and maintenance of thermal insulation for fly ash hoppers.

7.1 Insulating Material Considerations

Each insulating material type has a thermal conductivity characteristic that varies with temperature. Thermal data of most generic insulating materials are readily available. Economics dictate that insulation be selected based on the consideration of the thermal conductivity and thickness required to achieve the desired hopper wall temperatures. The mechanical characteristics of the insulating material and its compressive and tensile strengths are important factors in providing sufficient structural stability for convenient installation.

While there are many materials suitable for this application, the most commonly used insulating materials are 3 or 4 inch thick fiberglass or mineral wool that have operating temperature ratings up to 1000 °F (537.7 °C).

7.2 Insulation System Design

With the material and thickness of insulation selected, an insulation system design can be developed that allows for the determination of heat loss out through the insulation and that also provides for effective installation.

The insulation panels are located on and attached to the hopper stiffeners, which results in an air space. A typical arrangement is shown in Fig 5. The air space allows convective heat transfer from the back of the heating module, thereby improving thermal efficiency and temperature uniformity.

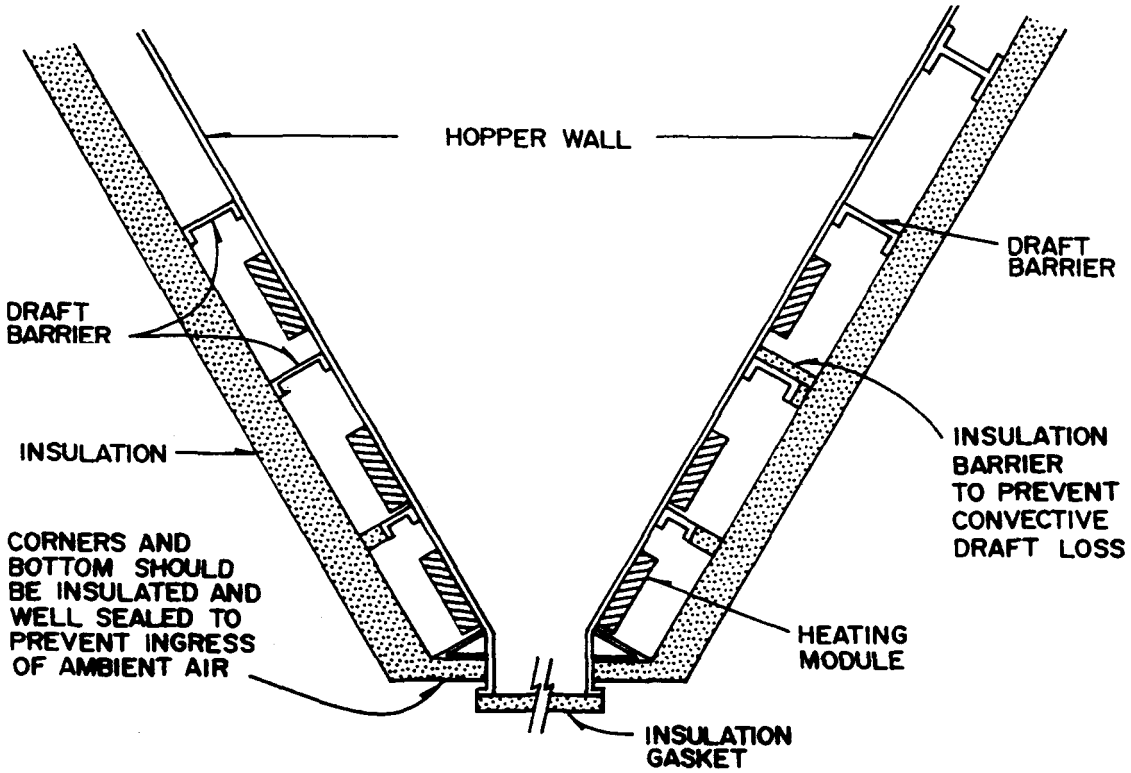


Figure 5—Hopper Insulation Design

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The insulation design should include a convection draft barrier at each stiffener level (including the corners) in the heated area of the hopper. These barriers prevent hot convective air from leaking into the upper portion of the hopper.

After installing the draft barriers, the insulation, weatherproof lagging, and all lagging joints and interfaces between the lagging and appurtenances (e.g., poke tubes, manways) should be carefully sealed with a flexible, high-temperature (300 °F [148.8 °C]) weatherproof sealant.

7.3 Installation Factors

A properly designed heating system and insulation system provide a cost-effective blend of beat input, heat loss, and temperature control. The insulation system should be installed with design features that are specified by the heating system manufacturer. To facilitate any future maintenance and repair, the insulation system over the heaters should be designed with convenient, easily removed insulation panels.

A checkout procedure should include verification that draft barriers have been correctly installed, that the hopper throat area has been correctly insulated and sealed, and that all appurtenances have been sealed.

8. Installation Considerations

The successful performance of the hopper heating system is dependent upon the proper installation of the heating system components. This section covers the major installation factors that are to be considered.

8.1 Field Environment

The majority of heating systems are installed on the hoppers at the end-user's job site. The field environment is most often an outdoor environment with associated weather conditions. Like other electrical equipment, the heaters and auxiliaries should be stored in a dry indoor location to prevent possible water damage and corrosion. During installation, the heating equipment should also be protected from water damage.

Most heating system manufacturers have field representative or factory field service engineers to provide assistance in the understanding of the heating system installation and checkout procedures.

8.2 Pre-Installation Review

Prior to installation, the field site engineer and installer should review the installation manual supplied by the heating system manufacturer. Specifically, they should review the heating module layout with the hopper configuration to verify that the heating modules will fit in their specific locations. Any additions (e.g., pipe support hangers) or changes to the hopper that affect the heating module locations should be reviewed with the manufacturer in order to determine design modification alternatives.

The hopper internals should also be inspected prior to heating module installation to verify that any lifting lugs have been removed. Any welding or use of torches on or in the hopper should be completed prior to mounting the heating modules in order to prevent module damage.

8.3 Locating Mounting Equipment

The location of mounting hardware for beating modules, temperature sensors, and junction boxes should utilize the manufacturer's installation drawings and instructions. The mounting studs for the heating modules are typically located with templates. The stud material should be compatible with the hopper wall material.

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8.4 Heating Module and Blanket Heater Installation

The heating modules should be installed in their proper locations as indicated on the installation drawings. Using the mounting hardware provided, the hopper wall surface should be inspected and then cleaned in accordance with the manufacturer's instructions.

The surface where blanket beaters may be located (typically hopper throats, poke tubes and manways) should be cleaned of weld splatter, rust, and oil to prevent damage to the blanket's dielectric material.

8.5 Lead Wire Routing

After installing the heating modules, the lead wires should be carefully routed to the junction box(es) for termination. The installers should follow the manufacturer's instructions to prevent lead wire insulation damage when the lead wires are routed over stiffeners, around corners, across other heating modules, and around vibrators and strike plates. Typical lead wire installation hardware includes lead wire guides that provide easy bundling and routing, or standard flex conduit for mechanical protection.

The lead wires should be routed without splices under the insulation to a common point and then routed through the insulation to the junction box. Where the leads enter the junction box, they should have adequate mechanical protection.

8.6 Junction Box and Temperature Sensor Installation

The junction box should be mounted off the hopper wall and outside the insulation in the location specified on the drawing. The heating module lead wires should then be tagged with the heater number and then wired to the terminal strips according to the design drawing.

The power wiring should be routed to each junction box and terminated according to the design drawing.

The temperature sensor should be located on the hopper wall within 18 inches of the hopper throat and away from heat sinks and heat sources (i.e., heating modules). The installation should be completed according to the manufacturer's instructions with care taken to prevent future damage that might be caused by vibration or impact loading.

8.7 Heating Module Checkout

After completing the heater installation and wiring and prior to installing the insulation, each heating module and heating circuit should be checked for correct electrical resistance and adequate electrical insulation dielectric integrity (MΩ test) according to the manufacturer's instructions. Any deviations from the specifications should be reviewed with the manufacturer.

8.8 Insulation Installation

The proper installation of the insulation system as outlined in Section 7. is critical to the successful performance of the hopper heating system. During installation, particular attention should be given to the following:

1) Draft barriers should be installed at each stiffener level in the heated area of each hopper. The draft barrier installation should seal each level to prevent convective hot air from moving to the upper portion of the hopper.
2) Special care should be given to the insulation around lead wires that go across and around stiffeners and where the lead wires penetrate the insulation. The manufacturer's instructions should be referenced.
3) The insulation panels and lagging should then be installed and sealed with a weatherproof sealant.

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8.9 Final Checkout and Energization

After completing the insulation installation, the heating system is ready for final checkout.

9. Operation and Maintenance of Precipitator/Baghouse Hopper Heating Systems

The proper operation and maintenance of the hopper heating system for a precipitator/baghouse is essential in order to maintain fly ash in a hot, dry, free-flowing condition. As a supplement to the information provided in this section, the heater manufacturer's operation and maintenance instructions should be consulted.

9.1 Initial Pre-Operational Checkout

Prior to initial energization, the following tests should be conducted.

9.1.1 Heater Modules

A MΩ test with a 1000 V_{dc} MΩ tester should be conducted on each installed heater module to ensure that the heater element is electrically insulated from ground in accordance with the heater manufacturer's specifications and drawings.

An element resistance check on each heater module should also be conducted and compared for agreement with the heater manufacturer's specifications. This resistance check should be conducted with an ohmmeter or by calculation from current and voltage data that is obtained by testing with an ac source.

If the results are appreciably different than the manufacturer's specifications and the prior checks defined in 8.7, the manufacturer's recommendations should be followed.

9.1.2 Circuit Checkout

A wire check should be conducted at the hopper heater junction box to verify that the correct wiring configuration of the heater modules has been achieved as compared to the appropriate circuit drawings. Following this wire check, each circuit power leg should be MΩ tested to ground from the control output.

The circuit from the power source to the hopper heater control should also be MΩ tested to ground. A phase-to-phase circuit resistance check on each circuit should be performed at the control output to ensure proper circuit resistances are present.

9.1.3 Control and Power Distribution Checkout

Correct operation of the control circuits should be verified. This requires inspection of the following components:

1) All power disconnects and branch-circuit protection
2) Power switching devices, such as contactors, silicon-controlled rectifiers (SCRs), or other devices
3) Monitoring devices, including indicating lights, alarms, and control switches
4) Temperature control devices (e.g., temperature setpoints, inputs, outputs)

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9.2 Initial Energization

Contingent upon satisfactory results from the MΩ and resistance tests, the hopper heater circuit can be energized. Following energization of these heating circuits, current measurements on each phase and the supply voltage should be recorded and kept for future reference. The results of the current measurements should be examined according to the following criteria:

1) The individual phase currents of a three-phase system should be balanced as close as possible within the manufacturer's tolerances and the heater module connection scheme.
2) The operating currents for similar hopper heating circuits should be similar.
3) Excessive current imbalance or dissimilar current readings from one heating circuit to another will require further dielectric and/or resistance testing to identify the source of the abnormality. If a significant current imbalance persists, the hopper heating system supplier should be contacted and corrective action pursued.

9.3 Normal Operations

The following procedures apply to hopper heater operation during the various boiler unit operating modes.

9.3.1 Unit Start-Up

The hopper heating circuits should be energized in accordance with the manufacturer's operating instructions before the precipitator or baghouse is exposed to flue gas. This is to ensure that the hoppers are preheated before accepting fly ash.

9.3.2 Online Operation

The hopper heating systems should remain in operation whenever the precipitator or baghouse is exposed to flue gas. This is intended to prevent moisture formation in the collected fly ash, which could result in solidification.

9.3.3 Short-Term Unit Outage

The hopper heating systems should remain energized during brief outages unless internal access to the precipitator/baghouse is required. An isolated hopper should only be accessed after the hopper heating system has been de-energized.

9.3.4 Extended Unit Outage

During long-term unit outages, when access is required inside the precipitator/baghouse, the hopper heating systems should be de-energized only after the hoppers have been completely emptied. After the outage, the procedure for restart in 9.3.1 should be followed. If the nature of the outage involves hopper maintenance or a possibility of moisture infiltration into the heater modules area exists, a complete hopper heating system checkout (described in 9.1) should be conducted. The MΩ test will indicate if moisture infiltration has affected the integrity of the electrical insulation.

9.4 Periodic Maintenance

The following maintenance checks should be performed on an annual basis (as a minimum).

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9.4.1 Mechanical Inspection

Inspect hopper lagging for evidence of mechanical damage that could affect the hopper heating system. Hopper insulation should be visually inspected to ensure that the original installation is intact. Particular attention should be given to the insulation around poke holes, manways, and the throat area. In addition, the integrity of the moisture sealing system should be checked. Any defects in the insulation and the lagging should be repaired and resealed.

9.4.2 Electrical Inspection

This inspection should include the following actions:

1) Inspection of the hopper heater control system to verify its correct operation and indications with respect to temperature and alarm setpoints.
2) Measure current for each heating system power feed and compare them to the values recorded at initial energization.
3) If any major discrepancies from start-up data are discovered, a module-by-module current check should be conducted to isolate any possible problems. Faulty beater modules should be replaced.
4) A record of current readings, operating voltages, and any heater module replacement should be maintained for future reference.

9.5 Troubleshooting

Troubleshooting hopper heating system problems should be undertaken in conjunction with the manufacturer's instructions.

The following occurrences may indicate potential heating system difficulties:

1) Hopper low temperature alarms
2) Repeated circuit breaker tripping
3) Chronic fly ash removal problems from a particular hopper
4) Repeated high fly ash level alarms from a particular hopper

Associated nonheating system equipment should also be checked for possible problems.

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Annex A Specification Guideline for Precipitator and Baghouse Hopper Heating Systems (Informative)

(This appendix is not a part of IEEE Std 1069–1991, IEEE Recommended Practice for Precipitator and Baghouse Hopper Heating Systems.)

The following specification guideline defines the minimum recommended specifications for precipitator and baghouse hopper heating systems. It covers the items discussed in Sections 1.–9. of IEEE Std 1069–1991 and assumes that the user will add his or her standard commercial and project design information to make a complete specification.

A1. Scope

The vendor shall provide a heating system for the precipitator (or baghouse) hoppers that will maintain the specified temperatures on the hopper wall. The heating system shall consist of equipment designed to provide long-term reliability.

A2. System Performance Requirements

The hopper heating system shall be designed according to the conditions listed in Table A-1.

A2.1 Hopper Configuration

The design of the heating system shall consider uninsulated heat sinks, such as the hopper throat, poke tubes, and vibration equipment. Diffusion air, when provided, shall be at or above the flue gas temperature and shall not be counted as a heat source or a beat sink. The hopper throat shall be fitted with a one-half inch thick insulating gasket (or series of gaskets) to minimize the conductive heat loss to the fly ash removal equipment.

A2.2 Special Operating Conditions

The hopper heating system shall be designed for the following special operating conditions:

1) List any special conditions (see 4.7).
2) List any additional conditions.

A3. Heating Module Design

The heating modules shall be designed for long-term reliability and shall be capable of withstanding the various conditions experienced during the operating life of the precipitator or baghouse. Special consideration shall be given to the following heating module features:

1) Electric heating element configuration and material
2) Heating element to lead wire connection method
3) Electrical lead wires (cold leads)
4) Electrical insulation around the heating element and connection system
5) Modular enclosure material and temperature rating
6) Attachment hardware material and design
7) Heating module watt density

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A3.1 Vibration/Impact Loading Exposure

The heating module design and installation shall consider the long-term effects of vibration and impact loading on the beating module's performance.

A3.2 Temperature Exposure

The heating module design shall consider maximum temperature exposure during energized and de-energized conditions. The heating module watt density and materials selection shall provide reliable operation during normal operation with and without fly ash in the hopper and during upset flue gas conditions such as air preheater failure.

A3.3 Power Supply Voltage

The heating module shall be designed for the voltage specified. Its insulation shall be dielectrically checked at twice rated voltage plus 1000 V by the vendor prior to shipment.

A3.4 Moisture/Humidity Resistance

The heating modules shall be designed for humidity and moisture conditions that are are experienced during installation and shutdown periods.

Table A-1—Hopper Heating System Design Specifications

(1) Heated area	Lower third of hopper area
(2) Minimum ambient temperature	_____°F
(3) Flue gas temperature (a) Normal	_____°F
(b) Excursion	_____°F
(4) Hopper wall maintenance temperature*	_____°F
(5) Start-up requirement*	150 °F (65.5 °C) above ambient in 8.–10 hours
(6) Hopper configuration	Dwg._____
(7) Voltage/phase/wires available	_____V _____phase _____wires
(8) Insulation (a) Type	_____
(b) Thickness	_____
(c) Thermal conductivity	_____
(9) Fly ash levels (from throat)	_____ft.

*On heated portion of hopper

A3.5 Hopper Wall Design

The heating module shall be designed to allow for installation on the hopper wall that may have weld seams, weld splatter, rust, oil, or other factors causing uneven mounting surfaces. For heating curved surfaces, such as the hopper throat and, when required, the manway and poke tubes, flexible heating blankets are acceptable.

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A3.6 Handling and Installation

The heating module shall be designed with features that minimize the risk of heating module damage during handling and installation (i.e., lead wire strain reliefs).

A4. Control, Monitoring, and Alarm Systems

The control, monitoring, and alarm system should be designed to provide for the effective and automatic operation of the hopper heating modules.

A4.1 Power Distribution Systems

A distribution panel with main disconnects (where required) and branch disconnects shall be designed for the hopper beating loads specified to meet the temperature requirements.

1) Main power disconnect (List molded-case circuit breaker or fuse.)
2) Branch power disconnect (List molded-case circuit breaker or fuse.)

A4.2 Temperature Controllers

Each hopper heating system shall have one (or more) heated zones; each of which will be controlled by a separate temperature controller.

1) Temperature controller type (see 6.2 and select)
2) Sensor type (see 6.2 and select)

A4.3 Monitoring and Alarm Systems

Each hopper heating system shall include a monitoring and alarm system that includes the following equipment:

1) Monitoring system (see 6.3 and select)
2) Alarm system (see 6.3 and select)

A5. Insulation Requirements

The vendor shall provide recommended insulation details that, at a minimum, include the following:

1) Insulation installed on hopper stiffeners, which provide an enclosed air space between the hopper wall and the insulation.
2) Draft barriers provided at each stiffener (including the corners) in the heated area to prevent convective air heat loss to the upper portions of the hopper.
3) Hopper throat insulation detail to prevent ambient air ingress into the lower portion of the hopper.

A6. Installation Considerations

The vendor shall provide an installation manual that includes engineering drawings and instructions to ensure a properly installed hopper heating system.

A6.1 Heating Module Templates

Templates for locating mounting equipment and heating modules shall be supplied to assist in properly locating all necessary heating equipment on the hopper walls.

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A6.2 Lead Wire Routing

The vendor shall provide engineering drawings that show the routing of the lead wires to the junction box(es) and the terminating requirements. Specific attention shall be given to prevent the lead wires from abrading against sharp edges or rough surfaces.

A7. Acceptable Suppliers

The vendor shall have demonstrated the capability to design and supply hopper heating systems that can satisfy the performance and reliability requirements for this application.

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