GE
Energy

Power Plant Layout Planning – Gas Turbine Inlet Air Quality Considerations

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Power Plant Layout Planning – Gas Turbine Inlet Air Quality Considerations

Introduction

GE heavy-duty gas turbines are able to operate successfully in a wide variety of climates and environments due to inlet air filtration systems that are specifically designed to suit the plant location—while also considering the impact of local air quality variation on the system design. This need for inlet air filtration and the impact of air quality on gas turbine performance and life is discussed in detail in GER-3419A (*Gas Turbine Inlet Air Treatment*).[1]

Under normal conditions the inlet system has the capability to process the air by removing contaminants to levels below those that are harmful to the compressor and turbine. Filtration systems, however, are not 100% effective and an increase in the inlet contaminant concentration will generally result in an increase in the contamination level of the air discharging from the filters. In some circumstances, the location of balance of plant (BOP) equipment or neighboring industrial activities may increase the incoming contaminant concentrations to such a degree that additional precautions may be necessary and require optional filtration or moisture removal equipment.

The purpose of this document is to review steps that may be taken during the initial site layout phase that will help to minimize the impact of local weather conditions and emission sources on the gas turbine's filter system effectiveness. The recommendations contained in this document are not requirements but are suggestions for minimizing the impact of air contaminants. Specific component installation and operating requirements may be found in GE documents that accompany the owner's instruction book.

A checklist is included in the appendix that will help facilitate the layout review process.

Air Quality and Particulates

Particle Size

A recent EPA report describes the current understanding of air quality and particulate emissions in the United States through 2003.[2] In this report, particulates are divided into four categories:

- Supercoarse: > 10 microns
- Coarse: 2.5 to 10 microns
- Fine: 0.1 to 2.5 microns
- Ultrafine: <0.1 microns

Similar surveys are available for other regions of the world, but concentrations and content will be strongly influenced by local topography, climate conditions and degree of industrialization.

Generally, particles larger than approximately 10 microns are less of a health concern and air regulations in the US have concentrated on the PM10 (concentration of particles with a diameter less than 10 microns) and PM2.5 (concentration of particles with a diameter less than 2.5 microns) categories. The particulates of interest for gas turbine applications are typically 3 microns and larger. Particles smaller than 3 microns will remain suspended and tend to follow the gas stream, eliminating issues with deposition or erosion.

Composition

The composition of particulates is wide ranging and will vary considerably with local emission sources. There are, however, general patterns within the US that show in western regions the particulates generally consist of carbon and nitrates and in the eastern region the particulates are largely composed of carbon and sulfates.[2] Seasonal variations are also present, with nitrates peaking in the fourth quarter and sulfate concentrations increasing in the period from July through September. Similar patterns may also be present in other regions and a literature search may provide useful information in preparation for site planning.

Locally, the composition will depend on the source, emission rate, particle size and weather conditions. Coastal regions will have elevated salt concentrations; locations with adjacent industrial or agricultural activities may see increased concentrations of organic and inorganic compounds.

Sources

There are two categories of sources. The *primary source* results in emissions that are discharged directly into the air. This category includes carbon from burning of waste material, forest fires, trucks, cars, quarries, unpaved roads and construction sites, industrial and agricultural processes.

A *secondary source* is one that emits matter that later combines with other material to form particulates or aerosols. Examples are sulfate and nitrate compounds formed from the interaction of SO_2 and NO_x gaseous emissions with other substances in the atmosphere.

Contaminants That Are of Concern to the Gas Turbine

Contaminants may be present in solid, liquid or vapor phase. In addition to contaminants, thermal plumes entrained into the gas turbine inlet air may result in a distortion of the flow at the compressor inlet or may raise the apparent ambient temperature.

Gas Phase Contaminants

In general, gas phase contaminants are only an issue if the source is relatively near the gas turbine, less than approximately one mile. This is because the natural dispersion tendency for gas phase components will quickly dilute the concentration of the contaminant to low levels. Exceptions to this are gas phase contaminants that condense shortly after discharge, forming a plume of aerosol droplet that can be carried by prevailing winds to the gas turbine inlet. These are rare and most likely would be associated with chemical or industrial processes. Gaseous contaminants include:

- Ammonia
- Chlorine
- Hydrocarbon gases
- Sulfur in the form of H_2S, SO_2
- Discharge from oil cooler vents

Solid Contaminants

Contaminants are spread from the source and transported by wind. The larger, denser particles will drop out relatively quickly, within a few hundred feet or less from the source. Particles less than approximately 30–50 microns will continue to remain airborne until the settling rate and turbulence eventually shifts the distribution mean to less than approximately 10 microns.

Examples of common solid contaminants are:

- Sand, alumina and silica
- Rust
- Road dust, alumina and silica
- Calcium sulfate
- Ammonia compounds from fertilizer and animal feed operations
- Vegetation, airborne seeds

Liquid Contaminants

Liquid aerosols may be generated by liquid agitation or condensation of vapor phase mixtures. Common sources are:

- Wave action at coastal sites
- Cooling tower drift
- Condensation of moist exhaust plumes in cold weather
- Petrochemical discharges
- Chiller condensate
- Rain

Contaminants that are commonly found in liquid aerosols are:

- Chloride salts dissolved in water (sodium, potassium)
- Nitrates
- Sulfates
- Hydrocarbons

Moisture droplets are not considered to be an air contaminant, but if allowed to pass through particulate filters, water-soluble salts will be leached from the dust cake and transported to the compressor. The use of static filters designed for liquid removal will minimize this risk.

Exhaust Plumes

The gas turbine inlet is typically isolated from any significant combustion sources. Discharge from small diesels or other combustion equipment should be routed away from the inlet to prevent the possibility of entrainment of the exhaust gas with the gas turbine intake air. A more significant emission source is the thermal plume rising from an air-cooled condenser. While not a contaminant, entrainment of portions of the condenser discharge plume will raise the apparent ambient temperature at the gas turbine inlet and temporarily reduce the base load generating capability. This topic is discussed in more detail in the Air-Cooled Condensers section.

Corrosive Agents

Chlorides, nitrates and sulfates can deposit on compressor blades and may result in stress corrosion attack and/or cause corrosion pitting. Removal of liquid aerosols and dry particulates by filtration will capture the majority of these corrosive agents. As discussed earlier, filters are not 100% effective and small concentrations of contaminants have been observed to deposit and collect on portions of the gas turbine compressor blading. The recommended control mechanism to avoid long-term contact with these and other corrosive deposits is daily on-line water washing.

Sodium and Potassium Chloride

Sodium and potassium are alkali metals that can combine with sulfur to form a highly corrosive agent that will attack portions of the hot gas path. As a salt, sodium and potassium chloride may result in the corrosion of compressor blades if deposits are not removed by water washing at the recommended intervals.

Salt is present in the ambient air and is derived from seawater aerosols carried by the wind. Appendix B describes the mineral content of seawater, which consists of more than 85% sodium chloride. The concentration is highest at the shore and falls rapidly until at a distance of approximately 8-12 miles it reaches an equilibrium value of approximately 2 to 3 ppbw. Concentrations of 0 to 12 miles from the coastline vary significantly with wind speed, direction, elevation and topography. The small aerosols that are carried further inland may eventually evaporate, leaving airborne dry salt crystals. Salt crystals will deliquesce absorbing moisture from the atmosphere and form concentrated brine droplets as the relative humidity rises above 70%. Dry salt crystals will not form until the relative humidity falls below 43%.

Nitrates (Water Soluble or Dry Particulates)

Nitrates are present in fertilizer products that can be released into the air from local agricultural activities. Ground preparation during dry periods can create two potential sources: airborne dust particles and drift carry-over from spray irrigation. Emissions from these sources are likely to be seasonal and may not be present in the air at the time of measurement, usually from analysis of the gas turbine filter catch.

Nitrates may also be released from chemical processing plants but emissions are likely to be controlled to low levels by local air pollution requirements.

Sulfates

Certain sulfates have limited solubility in water and are more likely to be found in the form of particulates in relatively dry climates. Calcium sulfate dust emissions from an adjacent wallboard manufacturing facility, for example, have been found to pass through inlet filters and plug turbine cooling passages.[3] Once recognized, the problem was resolved by upgrading the inlet filters.

Sulfates may also be formed by reaction of atmospheric SO_2 emissions with mineral dust particles. Examples are calcium and magnesium sulfate.

Methods of Removal

Solid Particulates

Solid particulates are removed with self-cleaning (pulse) filters or static filters. These are made from a fabric-type material and are effective over the entire gas turbine operating range with a degree of removal efficiency that varies with particle size. Particulate filters will not remove liquids.

Liquid Aerosols

Soluble alkali salts are removed with coalescing filters. These are also fabric-type filters with a small pore size that is designed to cause agglomeration of liquid droplets that are removed by gravity. Coalescing filters are effective over the entire gas turbine operating range with a degree of removal efficiency that varies with droplet size and filter face velocity.

The condition of the filters may be monitored by measuring the pressure drop and by regular visual inspection. As the pressure drop increases and exceeds the maximum design value, particles will pass through the filters or droplets will re-entrain with the airflow and efficiency falls. If not maintained, the filter elements may ultimately collapse, resulting in a seal failure and allowing contaminated air to by-pass the filter.

In dusty climates, a coalescing pre-filter is used to remove particulates and reduce the plugging rate of the coalescing filter.

Moisture separators may be used in extreme moisture carry-over conditions in combination with coalescing filters. The moisture separator removes the majority of larger droplets while the coalescing filters remove most of the remainder. High performance separators may be constructed from stainless steel or aluminum depending on the application. Drift eliminators may be constructed from plastic materials in the form of a mesh that provides a tortuous path and removes moisture by inertial separation.

Filters will remove approximately 99% of particles and droplets larger than 10 microns and approximately 90% for droplets and particles 4 microns in diameter. As a result, if the incoming particle concentration increases, even with a constant size distribution the air quality at the compressor inlet will decrease.

Gas phase contaminants such as ammonia or sulfur cannot be removed by filtration. As long as these contaminants remain in the gaseous phase there will be no impact on the compressor or hot gas path. Gas phases coming in contact with liquid water droplets from an evaporative cooler will be partially absorbed. A drift eliminator installed downstream of the cooler will remove excess moisture but a very small portion of the original gas phase contaminant will dissolve in the water droplet carry-over.

Gas phases coming in contact with moisture droplets introduced by inlet fogging systems will be partially absorbed and carry over as dilute sulfurous or nitrous acids. These are potentially harmful and may be combined with deposits, increasing the corrosive potential of the deposit. Daily on-line and periodic off-line water washing that follows the recommended schedule will remove the deposits and prevent or minimize corrosion issues.

Gas Turbine Inlet System Components and Function

The section that follows is a brief description of the main gas turbine inlet features. For additional information including the impact of weather conditions and filtration capability, please refer to GER-3419A.[1]

The inlet system is divided into four main components:

1. The intake weather hoods
2. The inlet filter compartment
3. The inlet ducting
4. The gas turbine inlet plenum

Intake Louvers and Weather Hoods

The function of the intake provides a path for air to enter the inlet filter compartment from the ambient surroundings. In relatively clean environments with light weather conditions, intake louvers reduce the concentration of entrained rain droplets and provide rudimentary protection against large objects from striking the filter media.

Figure 1. Gas turbine inlet with weather hoods

In regions of moderate to severe weather climates the intake may include weather hoods designed to minimize the entrainment of snow, rain, freezing rain or dust particles. An example of a weather hood is shown in *Figure 1*. Optional moisture separators and coalescing filters can be installed in the weather hoods in regions that experience high humidity and rainfall.

The weather hoods can be acoustically treated where necessary to minimize the acoustic emissions and meet local code requirements.

Immediately downstream of the louvers or hoods, moisture separators may be installed to remove the majority of entrained moisture droplets. A bank of coalescing filters can be installed downstream of the moisture separators if moisture carry-over from the separators is anticipated to be an issue. Guidelines for the use of moisture separators and coalescing filters may be found in GER-3419A.[1]

Steam Heaters

Self-cleaning pulse filters are effective in preventing ice formation and plugging except in the most severe of icing conditions that, for example, may be associated with cooling tower drift. If static filters are specified, plugging may become an issue in cold climates during periods that are favorable to icing conditions. While pulse filters are the preferred approach for these applications, steam heaters may be installed to provide protection from icing. An additional pressure drop penalty on gas turbine output will be observed year round due to the steam heater. Steam heaters remove contaminants from the air and will increase the moisture present by melting ice or snow that is drawn in through the weather hoods. Synthetic filter media is recommended for these applications where high levels of humidity or droplets may be experienced for extended periods.

Inlet Filter Compartment

The function of the inlet filter compartment is to provide a location for both coalescing and particulate filters. Coalescing filters remove liquids and are configured as replaceable pads located upstream of the particulate filters. The particulate filters may be either static replaceable pads or self-cleaning pulse filters in the form of cylindrical elements. The self-cleaning filters are periodically pulsed by high velocity air from the rear to dislodge the accumulated dust cake. The pulsing sequence is triggered when the measured filter pressure drop exceeds a preset value. The dust falls to the bottom of the inlet compartment and is removed to the outside of the compartment by a rotating auger and seal system for collection and disposal. It is recommend that the static filters be periodically replaced when the pressure drop exceeds a pre-set value. Pre-filters may also be installed to unload the coalescing filters and can be changed on line if necessary. Failure to pulse or replace filters will result in a loss of gas turbine performance and ultimately, failure of the filter elements.

An optional evaporative cooler module is located downstream of the primary filters. The evaporative cooler consists of a honeycomb-type cellulose media structure over which water is constantly recirculated from a collection sump. Water is evaporated from the surface of the media resulting in a reduction in the dry bulb temperature of the inlet air. Fine water droplets may be entrained in the air flowing across the media that is removed by a downstream mist eliminator.

Inlet Duct

The inlet duct is designed to contain the treated inlet air from the inlet filter compartment to the gas turbine inlet plenum. The intake duct contains acoustically treated silencing panels, the inlet bleed heat system, and the trash screen. Internal struts are used to strengthen the inlet ductwork.

Gas Turbine Inlet Plenum

The inlet plenum is located immediately upstream of the gas turbine inlet and contains the compressor inlet bellmouth. The purpose of the plenum is to provide a relatively turbulent-free region at the inlet to the compressor inlet guide vanes. The inlet bell mouth contains nozzles used for on and offline water washing.

Balance of Plant Impact on Gas Turbine Intake Air Quality

Cooling Water Tower Drift

A major localized emission source is the aerosol drift from cooling towers.

The discharge from the top of the cooling towers is warm moist air that is considered pollution-free. In vapor form, the water will not contain harmful chemicals or any solid material that is retained by the re-circulating water and returned to the warm water well at the base of the tower. In extreme cold climates however, the moisture content of the discharge air and ambient temperature may be favorable for the formation of ice fog. Ice fog or freezing fog consists of suspended super-cooled water droplets. The droplets will freeze on contact with solid objects, forming a build up of rime ice in a process that is similar to icing on aircraft wings. If the inlet filters ice up, the turbine will lose power and may eventually shut down due to excessive inlet filter pressure drop. Self-cleaning filters will help prevent ice formation on the filters, but elimination at the source is the preferred approach.

Some cooling tower suppliers offer options that minimize the formation of ice fog clouds, particularly for those installations located near highways where fog and ice would result in a major road hazard.[4] This option should be considered if there is a possibility of ice fog formation that may drift towards the inlet.

In addition to the plume discharge at the top of the tower, there is a secondary discharge from the louvered walls of the cooling tower structure. This discharge is the result of cross winds entraining re-circulating water droplets from within the tower. This effect will be localized and may extend only a few hundred feet depending on the wind speed and droplet size. The drift however may contain concentrated water treatment chemicals that in some cases could be corrosive. Cooling tower manufacturers offer advice on cooling tower orientation to prevailing winds and drift eliminators that can be installed to minimize this problem.

Estimates can be made of the drift and expressed in terms of contour plots of elevated wet bulb temperature. An example of this type of plot is shown in simplified form in *Figure 2*. Cooling towers are located along the southern border of the plant and two gas turbines are located to the north of the cooling towers and the predominant winds are from the southwest. The contours shown

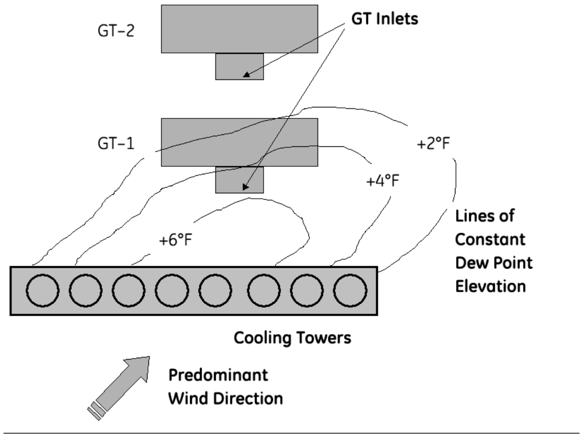

Figure 2. Example of cooling tower drift and gas turbine inlet ingestion

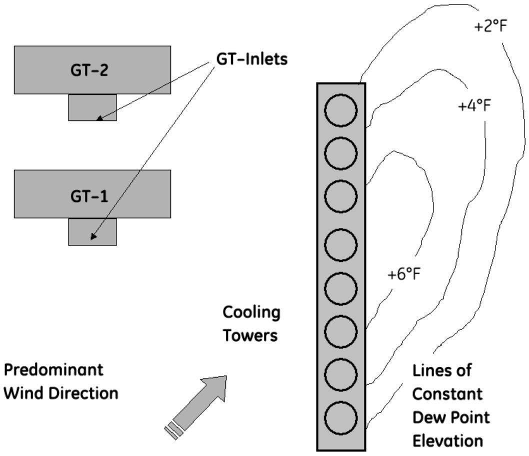

Figure 3. Cooling towers re-arranged to prevent gas turbine inlet ingestion of droplets

are lines of dew point elevation above the surrounding ambient level resulting from the drift from the cooling towers. In this example, GT1 will likely ingest droplets from the cooling towers during a significant portion of the operating period. GT2 will see some impact but will be affected to a lesser extent than GT1.

With this type of information available during the planning phase, a re-arrangement such as that shown in *Figure 3* could be made that would virtually eliminate all possibility of drift ingestion except during periods of unusual wind shifts.

Some coastal sites utilize seawater as the cooling water supply. Sodium chloride in the seawater will become concentrated as the cooling water is re-circulated. Manufacturer recommendations to control water chemistry by the use of additives and sump blow down should be followed to avoid excessive deposits on the tower media and concentration of harmful chemical build up. As discussed in the Corrosive Agents section, sodium is an alkali metal that is a highly corrosive agent and intake ingestion of brine droplets should be minimized as much as possible.

In a description of seawater cooling towers, the author states that the sodium chloride levels can be controlled by blow down to concentrations below 55,000 ppmw without serious scaling issues of the heat exchanger surfaces.[5] At concentrations above 55,000 ppmw, the cooling water pH must be neutralized to minimize deposit formation by adjustment of the water chemistry. In some cases this treatment includes the addition of sulfuric acid. Over-adjustment may result in a carry-over of highly corrosive sulfuric acid mist emitted from the wall louvers of the tower. Consideration should be given to more frequent blow downs if this situation exists to minimize the need for water treatment.

Air-Cooled Condensers

Large volumes of warm air are discharged from air-cooled condensers. When the prevailing winds pass above the cooling air discharge fans, dispersion of the warm air takes place. If the wind speed is of a sufficient velocity and direction—and the location of the gas turbine inlet is near the air-cooled condenser discharge—it is possible to raise the gas turbine intake air temperature by several degrees.

Figure 4 shows a typical air-cooled condenser. Ambient air is drawn in from the bottom by horizontal fans and directed vertically upwards across the heat exchanger tubes. Air flowing across and through the tube bundles removes heat from low temperature steam, resulting in condensation and a rise in the cooling air temperature.

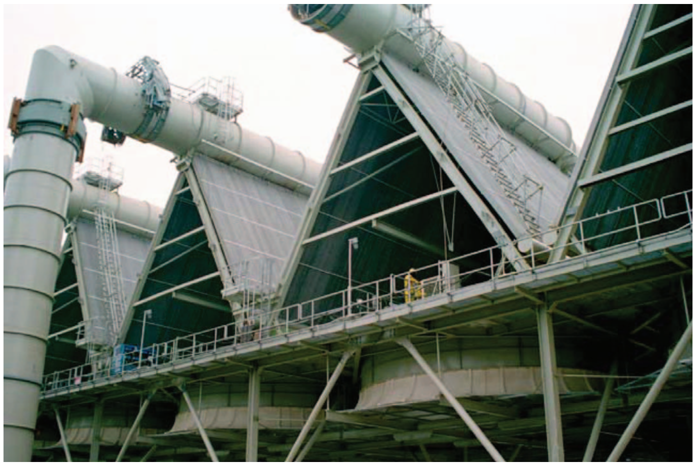

Figure 4. Air-cooled condenser showing horizontal cooling fans and heat exchanger tubes

Winds will pass above the condenser and disperse the heated cooling air. If the gas turbine is in the path of the prevailing wind, then a rise in inlet temperature will be experienced that is proportional to the wind speed and inversely proportional to the distance from the intake to the condenser.

Figure 5 shows an example of how the heated discharge air from an air-cooled condenser could result in an elevated gas turbine inlet temperature.

The increase in inlet temperature will adversely impact the gas turbine output and result in the loss of several megawatts in base load generating capacity. The potential loss in annual revenue could significantly affect profit margins, depending on the severity of the problem.

Figure 6 shows the typical reduction in power output, referenced to ISO conditions, with a rise in ambient temperature, assuming no inlet chilling or evaporative cooling is in effect.

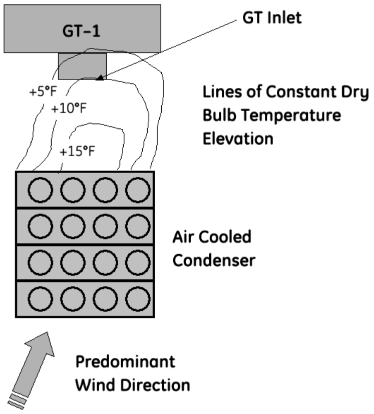

Figure 5. Ingestion of discharge plume from air-cooled condenser

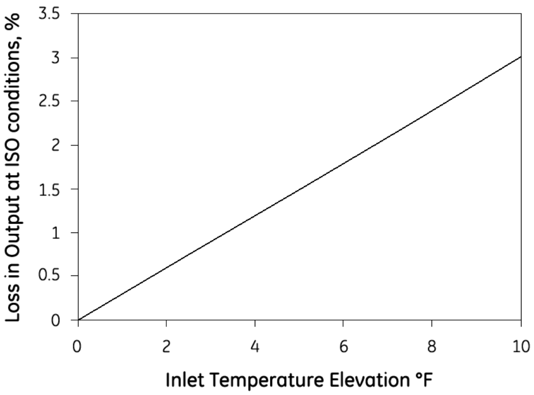

Figure 6. Output loss at ISO conditions resulting from inlet temperature increase

Pressure Relief Valves and Flanged Gas Pipe Joints

Pressure relief valves installed on gas supply lines and process equipment may intermittently or continuously vent natural gas. It is critical that natural gas vents from all pressure vessels are discharged to a safe area well away from the gas turbine air intake. The gas turbine inlet filters will not remove gas phase contaminants and large volumes of entrained gas may lead to turbine control problems and operation leading to out-of-compliance emissions or turbine damage.

Gas, steam or other fluid piping with flanged connections may leak after years of safe operation. By routing piping away from the inlet, the potential issues associated with entrained gases or fluids aerosols with the intake air can be avoided.

Impact of Local Weather Conditions and Emission Sources

The transport mechanism for solid air contaminants is through entrainment of small particles and droplets or dispersion of gases in the compressor intake air. The contaminants are carried by wind currents from their source and drawn into the gas turbine intake.

Particles and droplets are maintained aloft by turbulent air patterns. Depending on the settling velocity of the contaminant and wind speed, the contaminant concentration will gradually decrease along the flow path until a minimum value is reached. The further the source and the higher the settling rate (or dispersion rate for gas phase contaminants), the lower the contaminant concentration.

Winter Lake Effects

One of the most common localized weather effects in the US is observed on the eastern shores of the Great Lakes during the early winter. At this time the water temperature may be above the ambient air temperature and evaporation takes place from the surface of the lake. Cold air from the north combines with the moisture, becomes rapidly saturated and leads to the formation of snow and ice crystals, creating lake-effect snowstorms. The lake-affected region may extend from a few miles to 50 or 100 miles from the shoreline depending on the time of year, lake temperature, wind direction and strength. Large quantities of snow may precipitate in a few hours. For these locations, careful orientation of the air inlet intake away from the prevailing fall and early winter winds will help to minimize the ingestion of snow and ice crystals. The impact of local buildings, walls, roofs fuel tanks or other obstructions that may re-direct wind towards the inlet or create a snow fence effect that deposits large quantities of snow near the inlet should also be considered.

Coastal Effects

Most coastal locations will experience onshore winds all year or part of the year. GER-3419A reports that at locations within 8 to 12 miles of the coast the concentration of sea salt droplets in the atmosphere will increase with wind speed and nearness to the shoreline.[1] At distances of 100–200 feet, the concentration will rapidly increase due to the entrainment of larger droplets produced by the wave action of the surf. Further inland beyond approximately 8–12 miles, the alkali salt concentration falls and remains essentially constant except in extreme weather conditions or in the presence of local sources such as dry lakebeds or heavily salted highways.

Inland Dry Lake Beds

Dry lakebeds are a potential source of alkali salts. They are typically found in dry desert climates and the salt is entrained in the air as a solid particulate. If static filters are used and the weather conditions are seasonably variable, there is a possibility that the salt particles trapped on the static filter will deliquesce, absorbing moisture as the relative humidity exceeds 70%. The soluble salts will then pass through the filter in droplet form and enter the compressor and hot gas path. To minimize this impact, self-cleaning filters are recommended for this situation. While salt particles will build up on the filter, they will be periodically removed during the pulsing cleaning process, limiting the carry-over during periods of high humidity.

Inland Salt Lakes

Inland salt lakes will have a similar impact on air quality as coastal locations, except the aerosol production from wave action will be less. This will be offset, to some extent, by the naturally higher saline concentration of inland lakes produced by evaporation.

New Emission Sources

New emission sources may result from nearby new construction or a change in local industrial or agricultural activities. In some cases the new source emissions may be obvious; in others involving colorless gaseous or trace metal emissions, the new source emissions may not be immediately recognized. If a new local emission source is suspected, plant owners should consider performing an air quality survey to confirm or eliminate the need for action or additional protection.

ISO Standards for Classification of Corrosive Atmospheres

The International Standards Organization has developed a standard for classifying the corrosivity of an atmosphere, ISO 9223.[6] It is based on the presence of sulfur dioxide, airborne chlorides and the time the location is exposed to moisture, defined as the time of wetness. Five classifications are identified, C1 through C5, ranging from very low to very high. The classification is determined from the concentration of sulfur dioxide and airborne chlorides and the time of wetness. The time of wetness is similarly classified as T1 through T5, ranging from indoors to tropical outdoors or surf. The classification is expressed in terms of a 1-year corrosion rate in g/m^2 for various metals. In addition, the following three other standards are used to supplement ISO 9223:

- ISO 9924[7] provides guidance on corrosion values, terms and definitions for categories defined in ISO 9223
- ISO 9925[8] provide methods for measuring deposition rates of sulfur dioxide and airborne salts
- ISO 9226[9] specifies preparation of test specimen coupons, exposure and expression of results

The ISO classification method is useful for evaluating the corrosivity of an atmosphere, particularly for static structures and can provide guidance for determination of the need for protective coatings or alternate material selection. It is not directly applicable to gas turbine internal components that are exposed to vibratory stresses and frequent water washing, but does provide some insight to the relative corrosivity potential.

Plant Layout Considerations

When considering the plant layout, year-round ambient conditions and the influence on air quality of nearby large bodies of water (salt or fresh water), industrial or agricultural operations, cooling towers or others sources of moisture should be considered. The potential air quality variations will impact the operational efficiency of the gas turbine inlet filtration system. An inlet system that is designed primarily for dusty climates, for example, may not perform well if steam or water droplets are continuously entrained with the gas turbine inlet air.

Questionnaire

GE can assist with the selection of suitable inlet options for a given range of expected site air quality conditions. To aid with this task, a questionnaire has been developed that will provide the basic information required to determine the type of inlet filtration system best suited for the application. After a review of the site conditions, additional information may be requested before the design is finalized. The questionnaire may be found in Appendix C. Customers are encouraged to include additional information that may impact local air quality but not specifically requested.

The following provides background information on why the topics covered in the questionnaire are critical to providing proper protection to the gas turbine.

Distance to the Nearest Coastal Water

For all coastal locations, the entrained salt in the ambient air will be in droplet form. As discussed earlier, the concentration will vary significantly with distance from the source, the prevailing wind direction and speed. Beyond approximately 8 to 12 miles from the coast, the ambient salt concentration falls to a typical inland average value of 8 ppbw (an average sodium equivalent of 2.6 ppbw).

For further details of costal effects on ambient salt concentration refer to GER-3419A.[1]

Dry Lake Beds

Salt originating from inland dry salt-lake beds may be in particulate form for portions of the year and liquid form at other times as the relative humidity rises and falls. Because there is no wave action to generate aerosols, the issue may be less severe than in coastal regions. Periods of high winds and a prolonged dry climate however will contribute to the generation of airborne salt particles. The use of self-cleaning filters is better suited to these conditions if the climate remains dry, since the filter cake is periodically removed. If the humidity rises or rain occurs after a long dry period, the increased moisture content will extract salt from the filters in a liquid aerosol form. Static filters will retain significantly more salt than self-cleaning filters for a given inlet concentration, but may be acceptable if the overall ambient salt concentration is low.

Heavily Traveled Highways

Highways are a source of particulates generated by the passage of traffic. In northern climates where road sand and salting is common to provide traction in winter weather, the carry-over of salt aerosols or particulates must be addressed.

Neighboring Activities

The following are examples of neighboring activities that may produce air contaminants that are potentially harmful to the gas turbine flow path or may result in rapid filter fouling:

Agricultural activities

- Dust
- Plant material processing by-products
- Pesticide drift
- Fertilizers – nitrates, phosphates
- Spray irrigation drift
- Animal feeding by-products

Coal Fired Power Plants

- Fly ash
- Coal dust

Industrial Plants

- Fertilizer manufacturing and processing
  - Ammonia
  - Phosphates
  - Nitrates
  - Calcium
- Wallboard manufacturing[3]
  - Calcium sulfate
- Metal smelting
  - Waste products – slag piles
- Mining activities
  - Coal, closed pit
    - Coal waste from slag piles

  - Coal, strip mining
    - Dirt, dust, coal
  - Open-cast, metal ore
    - Mineral dust, metal ore
- Petrochemicals
  - Sulfur emissions
  - Hydrocarbons emissions
- Waste incinerators
  - Heavy metals
- Waste recycling and reclamation
  - Airborne "fluff" from automobile crushing

Meteorological Data

Meteorological data records are available from numerous sources, including local airports, universities and web sites. It is important, however, when reviewing the data that the plant local conditions are considered. Average wind speeds and direction may not correspond well with airport data taken 10 or more miles away due to changes in elevation and differences in the local terrain. This is particularly important when considering drift from local cooling towers or nearby emission sources. To provide reliable data for plume modeling, it may be necessary to take several months of data using an on-site weather station. If a good correlation can be obtained with data from a local airport or other local weather records, the expected monthly variations can be extracted from historical data.

The following maximum, minimum and average meteorological information must be obtained on a monthly basis:

- The predominant wind speed and direction
- Dry bulb temperature
- Relative humidity
- Rainfall
- Snowfall

If possible, the frequency of fog formation and icing conditions should also be provided.

Air Quality Survey

An air quality survey can be conducted prior to new plant construction or additions. The results from the survey will help with inlet selection and establish a baseline for future reference. This data will be useful if new emission sources are introduced nearby that subsequently require additional inlet protection or that may lead to legal action against the emitter.

There are a number of consulting companies that offer air quality survey services, or air-sampling equipment may be purchased if frequent samples are required. Air quality will vary with weather conditions, including wind speed and direction. It is important that air quality surveys be performed when the prevailing wind is from the direction of the suspected contaminant source. Several air quality samples may be required over a period of several days or weeks if the emission source is not immediately apparent.

The potential air contaminants that are of interest are shown in *Table 1*.

Specie	Phase	Source
Na	Solid or liquid[a]	Sea Water Aerosols
K		
Cl		
Ca	Solid, Partially Soluble	Quarrying, Industrial Manufacturing
S	Solid or Liquid[b]	Petrochemical Processing
Phosphates	Solid or Liquid	Fertilizers
Nitrates		
V	Solid	Industrial Manufacturing
Pb		
Mg		

(a) Mostly present as sodium or potassium chloride. Can be a solid in dry climates relative humidity < 43% or as a dissolved salt in liquid form, RH > 70%

(b) Can be present as a sulfuric acid liquid aerosol, as a calcium sulfate solid particulate. Gaseous forms such as H_2S, SO_2, SO_3 etc., may also be present

Table 1. Potential airborne contaminants

Batch Filter Sampling

Air quality measurements can be performed using batch type filter sampling devices or by means of a continuous air sampler. Filtration type instruments work well but the results may only be representative of air quality at the time that the sample was taken. Judgment is required when to take samples in order that average and seasonal peaks can be identified with reasonable accuracy. Some guidance on this topic is provided in ASTM D1357.[10]

The main purpose of filter sampling is for the catch to be analyzed and compounds identified. The mass concentration and, to some aspect, the contaminant species, will depend on the local weather conditions, possibly requiring multiple samples.

Information on the method for using a high volume filtration sampling system and general procedures may be found in an EPA report,[11] ASTM D4096,[12] and ASTM D3249[13].

Useful information on common terminology used in air sampling practice may be found in ASTM D1356.[14]

To obtain an understanding of the air quality variation throughout the year, frequent samples must be taken, particularly when the prevailing wind direction and speed changes are significant. Local wind speed will vary daily, weekly and monthly, making this type of measurement tedious and time consuming. If the local sources of contaminants are well known—cooling tower drift, for example—sampling frequency could be reduced by monitoring air quality when the prevailing winds at the gas turbine inlet fall within a quadrant that is in line with the emission source. This approach will not provide a complete understanding of the air quality at the site, but will provide an indication of the maximum contaminant concentration and composition.

Continuous Mass Concentration Sampling

Continuous mass monitoring air sampling is preferable in order to correlate air quality with weather conditions. At least one commercially available continuous monitoring instrument is available.[15] This instrument measures mass concentrations, but does not identify species. It may be combined with a programmable filter system that can be triggered by wind speed, direction, concentration or other digital input.[16] The filters can be analyzed to identify species that were captured during the periods that are of interest.

It is important to take meteorological measurements simultaneously in order to correlate the impact of wind speed, direction, etc., on air quality. It is also important to note the operating status of any local equipment or process that may be a potential emission source.

Recommendations

Field experience has shown that corrosion and plugging of filter and hot gas components by contaminants contained in the ambient air can become an issue that adversely affects maintenance intervals. In many cases these issues can be minimized or avoided by appropriate planning during the site layout phase. The following section includes suggestions for key engineering studies that will be beneficial in assessing risks and developing optional arrangements. For additional recommendations, see the checklist in *Appendix A*.

Satellite Imagery

Prior to preliminary site layout planning, it is recommended that satellite imagery of the surrounding region be studied. Several subscriber-based commercial services are available as well as free services. The subscriber services typically offer enhanced resolution to as little as two meters or less. The images can provide additional information to that available from local sources and are relatively inexpensive.

Survey of Local Industrial or Agricultural Operations

Prior to locating the gas turbine inlets, a survey of the local industrial or agricultural activities and terrain should be performed to understand the potential for air contaminant carry-over. Agricultural activities, for example, may generate contaminants for short periods once or twice per year that are rich in nitrates.

Industrial emissions are more likely to be year round and ingestion can be minimized by proper location of the inlet. In an example reported by Johnson and Thomas an adjacent wallboard plant resulted in an elevated concentration of very small calcium sulfate particles that passed through the conventional particulate filter.[3] The particles plugged the turbine cooling passages and caused hot gas path damage that was subsequently prevented by installation of an improved filtration system.

A unit located on a steep hillside with the inlet facing the hill may entrain a higher quantity of wind blown dust and other contaminants because the effective height of the inlet is essentially at or near ground level. This may significantly decrease the life of the filters and increase maintenance frequency. GER-3419A states that particulate concentration may decrease by a factor of 2:1 above an elevation of 20 feet.[1] Where possible, the intake to the filter house should face away from the hillside. Other factors such as prevailing winds must also be taken into account and a compromise solution may be necessary

Severe icing of pulse filters has been reported in which the turbines were located downwind of the cooling towers. During certain periods of the winter months, drift from the cooling tower resulted in the formation of ice fog that deposited rime ice on cold surfaces and the filter media. Where possible, the gas turbine intakes should be located outside of the expected plume originating from cooling towers and other industrial or thermal processes.

CFD Modeling

Computational fluid dynamic modeling can be used to determine the impact of weather conditions and emission sources on inlet air quality. Reports of contaminant concentrations measured in mass/unit area/unit time are useful indicators of a potential problem, but do not take into account the sink effect of the gas turbine drawing in large quantities of air from the surroundings. This will greatly increase the contaminant mass passing through the compressor and turbine in a given time than would otherwise be estimated from a simple surface concentration and settling rate calculation. Cooling tower drift and contaminants from emission sources can be modeled to explore the potential impact on filtration requirements. Similarly, the increase in inlet temperature resulting from the partial entrainment of the discharge of an air-cooled condenser can be modeled to determine the expected annual loss in total output and to identify and justify equipment re-arrangement prior to construction.

In another example where CFD would provide some insight, a turbine inlet was located facing a wall in a region of known heavy snowfall. The geometry and orientation of the wall was such that it acted as a snow fence, causing significant accumulation of snow being deposited and drawn into the gas turbine inlet. Modeling of this type of configuration could help identify potential issues prior to construction and avoid costly field modifications.

Air Quality Survey

The details and types of air quality surveys are discussed in a prior section. The purpose of performing a survey prior to layout planning is to identify the concentration and sources of suspected contaminants. This is particularly important in heavily industrialized localities where there may be a variety of contaminant types and sources. Surveys must be combined with measured weather data to be of use and may require several months of planning with periodic measurements if large seasonal changes are expected.

Site Planning

A review of local emission sources and weather conditions is recommended during the plant preliminary layout phase. By taking these factors into account, location and orientation of the gas turbine intake can be arranged to minimize the impact of known corrosive agents on the inlet filtration system and turbine components. Field modifications to an installation after an air quality problem has been recognized will likely be expensive and require an extended outage. In addition, the final result may not be as effective as appropriate site planning and locating of balance of plant equipment.

Summary

As gas turbine materials engineering and design techniques improve, greater performance and maintainability benefits are realized. Experience has shown that along with these gains there is need to better protect the internal components from erosion and corrosion. In order to meet expected maintenance intervals it is necessary to remove solids and liquids that are considered harmful to the compressor and turbine flow path. Advances in filtration technology, media materials and system design are able to provide the necessary protection from most naturally occurring airborne contaminants. Emissions from local sources, however, may increase the concentration levels downstream of the filters significantly. With careful site planning and consideration of the impact of these on and offsite sources, the effect on gas turbine overall performance can be minimized. A failure to do so may result in costly field modifications, repairs and loss in revenue.

Appendix

A. Checklist

The following simplified checklist is intended as an aid for the preparation of site layout plans. It is recognized that many factors such as available space, access roads, and cooling water access may have a higher priority and dictate the orientation and relative location of the gas turbine and auxiliary equipment. The information provided below, however, will help to minimize intake contaminant concentrations and offer some long term benefits if applied judiciously.

Preliminary Checklist for Preparation of Site Layout Plans	
1	Obtain meteorological data showing the prevailing wind patterns, speed, relative humidity, dry and wet bulb temperature, rainfall and snowfall throughout the year.
2	Identify potential sources of particulate, liquid and gaseous emissions both on site and off site.
3	Locate the off site sources on the plot plan showing distance, direction, known or expected emission type and concentration.
4	Develop plume models for each significant on and off site emission source for each predicted major wind shift, i.e., seasonal variations.
5	Show plan and elevation concentration contours.
6	Perform CFD modeling in the region around the gas turbine inlet to estimate the potential for elevating the concentration at the filter inlet.
7	If some concentration levels appear consistently higher than normal ambient levels, identify the emission source and consider relocating the source or install barrier walls to minimize carry-over to the turbine.
8	Contact GE Application Engineering staff to determine the best inlet configuration for this application.

B. Seawater Composition

The salinity of seawater varies significantly depending on the water temperature. The salinity is defined as the total dissolved solids measured in grams per kilogram, or parts per thousand by weight (pptw). In the Baltic Sea it is approximately 7 pptw (7000 ppmw) and that of the Red Sea is approximately 45 pptw (45 ppmw). An average composition is generally taken as 35 pptw (35000 ppmw). Of this, approximately 85.6% is sodium chloride and 30.6% is sodium. Potassium is approximately 1.1%. Seawater aerosols produced near the ocean before evaporation contains an average of 11100 ppmw of sodium plus potassium.

C. Site Questionnaire

The following questionnaire is intended to provide GE with pre-proposal information concerning local air quality conditions that impact the design of the inlet air filtration system. An understanding of the site environmental conditions is critical to the selection of an efficient and robust filtration system.

Location		
1.	**Is there sufficient information available to categorize the corrosion potential by ISO 9223?[6] If not, or in addition, is there information available concerning the following?**	
	a. Corrosive chemicals are known or may be present:	
	Coastal, within 12 miles of surf	
	Heavy industrial	
	Agricultural with spray irrigation, frequent harvesting, soil preparation	
	Dry salt lake nearby	
	Other	
	b. No known corrosive chemicals present:	
	Inland, rural	
	Light industrial	
	Light agricultural	
	Desert	
	Other	
Local Emission Sources		
2.	**List nearby (< 2 miles) potential sources of particulates:**	
	Coal piles	
	Major highways	
	Reclamation centers	
	Mining operations	
	Foundries	
	Sawmills	
	Wallboard manufacturing	
	Agricultural activities	
	Other	
3.	**List nearby (< 2 miles) potential sources of liquid aerosols:**	
	Cooling water towers	
	Spray irrigation systems	
	Petrochemical processing	
	Other	
Weather		
4.	**What are the monthly average, maximum and minimum values for the following?**	
	Wind speed	
	Wind direction (wind rose if available)	
	Relative humidity	
	Temperature	
	Rainfall	
	Snowfall	
	Fogging conditions, number of days	
	Icing conditions, number of days	
Additional Emission Sources		
5.	**List additional emission sources not included above.**	

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