Gas Turbine Inlet Air Cooling System

Presented by

Bob Omidvar
Heavy Duty GT - Effects of Ambient Temp

- Heat rate kJ/kWh
- Power output MW
- Exhaust flow t/h
- Exhaust temperature °C
Aero-Derivative GT - Effects of Ambient Temp

The graph shows the effects of ambient temperature on various parameters of a gas turbine. Key measurements include:

- **GT Inlet Temp (deg C)**
- **Exhaust temperature C**
- **Heat rate kJ/kWh**
- **Power output MW**
- **Exhaust flow t/h**

The graph illustrates how these parameters change with increasing inlet temperature. For instance, the exhaust temperature and power output seem to decrease, while the heat rate increases with higher inlet temperatures.
Gas Turbine Performance Design Basis

What Does ISO Condition Mean?

- Dry bulb 15°C
- Relative humidity 60%
- Wet bulb temperature 7.2°C
- Atmospheric pressure 1 bar (sea level)

Most of the gas turbine installations are not in ISO standard locations, they are in the real world
Ambient Air and Gas Turbine Performance

1. Air density is inversely related to the dry bulb temperature
2. Gas turbine output depends on mass flow and not the volume of air
3. Ambient temperature affects the following points drastically
   - Air flow
   - Output
   - Heat rate
   - Exhaust temperature
Gas Turbine Inlet Air Cooling
Available Technologies

1. Evaporative cooler
2. Fogging system
3. Mechanical refrigeration system (direct type)
4. Mechanical refrigeration system (indirect type)
5. Mechanical refrigeration with ice storage
6. Mechanical refrigeration system with chilled water storage
7. Single stage Lithium Bromide Absorption chiller
8. Two stage Lithium Bromide Absorption chiller
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Schematic of Evaporative Air Cooling shown with Optional Water Treatment
Evaporative Cooler

Applications: Areas where RH and wet bulb temperature is rather low

**Advantage**
- Lowest capital cost
- Lowest O&M cost
- Can operate on raw water
- Quick delivery and installation time
- Operates as an air washer and cleans the inlet air

**Disadvantage**
- Limitation on capacity improvement
- Highly influenced by the site wet bulb
Gas Turbine Inlet Air Cooling

Available Technologies

1. Evaporative cooler
2. **Fogging system**
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Schematic of Fog Inlet Air Cooling System Utilizing Demineralised Water

Raw Water → Demineralised Water Treatment Plant → Demineralised Water Tank → Air Filter → Combustion Air

Exhaust Gas → Fuel → Combustion Turbine
Fog Systems
## Demineralised Water Quality For Fog System Inlet Air Cooling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximum Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total dissolved solids</td>
<td>5 PPM maximum</td>
</tr>
<tr>
<td>pH</td>
<td>6-8</td>
</tr>
<tr>
<td>Na + K</td>
<td>0.1 PPM maximum</td>
</tr>
<tr>
<td>Silica (SiO₂)</td>
<td>0.1 PPM maximum</td>
</tr>
<tr>
<td>Chlorides</td>
<td>0.5 PPM maximum</td>
</tr>
<tr>
<td>Sulphate</td>
<td>0.5 PPM maximum</td>
</tr>
</tbody>
</table>
Fogging System Demin. Water Consumption
Inlet air 36°C DB, 25°C WB
Chilled air temp 25.5°C DB 25°C WB, 96%RH
### Fogging System

**Applications:** Areas where RH and wet bulb temperature is rather low

<table>
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<tr>
<th><strong>Advantage</strong></th>
<th><strong>Disadvantage</strong></th>
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<tr>
<td>Low capital cost</td>
<td>Limitation on capacity improvement</td>
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<td>Highly influenced by the site wet bulb</td>
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<td>Can increase gas turbine performance better than evaporative cooling</td>
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Gas Turbine Inlet Air Cooling

Available Technologies

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Schematic of a Direct System Using an Ammonia Refrigeration Machine

Exhaust Gas

Fuel

Combustion Turbine

Mechanical Refrigeration Machine

Ammonia Suction Line

Air Filter

Combustion Air

Condensate Drip Pan

Ammonia Liquid Line
**Mechanical Refrigeration System (Direct Type)**

*Applications: Areas where relative humidity is rather high*

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<tr>
<th><strong>Advantage</strong></th>
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<tr>
<td>- Can increase gas turbine performance better than evaporative cooling, and fog system</td>
<td>- High initial capital cost</td>
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<td>- High O&amp;M cost</td>
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<td>- Longer delivery and installation time</td>
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<td>- Expertise is needed to operate and maintain the plant</td>
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Schematic of an Indirect System Using a Mechanical Chiller

- Fuel
- Combustion Turbine
- Chilled Water Pump
- Mechanical Chiller
- Combustion Air
- Air Cooling Coil
- Condensate Drip Pan
- Exhaust Gas
- Fuel
- Combustion Turbine
- Chilled Water Pump
Mechanical Refrigeration System (Indirect Type)

Applications: Areas where relative humidity is rather high

**Advantage**
- Can increase gas turbine performance better than evaporative cooling, and fog system
- Not very sensitive to ambient air wet bulb temperature

**Disadvantage**
- High initial capital cost
- High O&M cost
- Long delivery and installation time
- Expertise is needed to operate and maintain the plant
- Requires extra chilled water cooling circuit
- Higher parasitic load than direct type
- Higher energy input compared to direct type chiller
Gas Turbine Inlet Air Cooling
Available Technologies

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Inlet Air Cooling With Ice Storage, Chilled Water Storage System Schematic

Fuel Combustion Turbine

Chilled Water Pump

Mechanical Chiller/Ice Maker

Ice Storage Tank

Exhaust Gas

Combustion Turbine

Condensate Drip Pan

Air Cooling Coil

Combustion Air

Air Filter
Inlet Air Cooling With Chilled Water Storage System Schematic
**Mechanical Refrigeration System With Ice Storage**

*Applications: Areas where RH is rather high, plus a wide variation in electricity tariff between peak and non-peak hours*

**Advantage**

- Can increase gas turbine performance better than evaporative cooling, and fog system
- Not very sensitive to ambient air wet bulb temperature
- Can utilise low night time tariff to produce and store ice for peak hours operation

**Disadvantage**

- High initial capital cost
- High O&M cost
- Longer delivery and installation time
- Higher expertise is needed to operate and maintain the plant
Chiller Electrical Load MW
36°C DB, 25°C WB, 10°C Chilled Air Temp

Dia: Chiller load vs. GT output with steady chilled air temp.
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Absorption Chiller Inlet Air Cooling System Schematic

- Absorption Chiller
- Air Filter
- Combustion Air Cooling Coil
- Condensate Drip Pan
- Chilled Water Pump
- Fuel
- Combustion Turbine
- Exhaust Gas
- Return Condensate
- LP Steam
- Heat Recovery Steam Generator
Absorption Chiller Steam Consumption
36°C DB, 25°C WB, 10°C Chilled Air Temp
## Single Stage Lithium Bromide Absorption Chiller

**Applications:** Areas where relative humidity is rather high, and the plant is going to operate in a combined cycle or cogeneration mode and has access to low pressure steam.

### Advantage
- Can increase gas turbine performance better than evaporative cooling, and fog system.
- Not very sensitive to ambient air wet bulb temperature.
- Low electrical parasitic load.

### Disadvantage
- High initial capital cost.
- High O&M cost.
- Longer delivery and installation time.
- High expertise is needed to operate and maintain the plant.
- In case of a steam operated chiller, cannot be applied in an open cycle gas turbine plant.
Two Stage Lithium Bromide Absorption Chiller

Applications: Areas where relative humidity is rather high, and the plant is going to operate in a combined cycle or cogeneration mode and has access to low pressure steam

**Advantage**
- Can increase gas turbine performance better than evaporative cooling, and fog system
- Not very sensitive to ambient air wet bulb temperature
- Low electrical parasitic load
- Requires less steam per unit of refrigeration than single stage chiller

**Disadvantage**
- High initial capital cost
- High O&M cost
- Longer delivery and installation time
- High expertise is needed to operate and maintain the plant
- In case of a steam operated chiller, cannot be applied in an open cycle gas turbine plant
Condensate Formation on the Chilled Water Coil t/h
Based on 36°C DB, 25°C WB, 10°C Chilled Inlet Air Temperature
Performance Evaluation
Of Different Inlet Air Cooling Systems

*Base Condition*

- 35°C Dry bulb
- 25°C Dry bulb (Real world condition)
- 44.7% Relative humidity

*Increase in power output*

<table>
<thead>
<tr>
<th>Description</th>
<th>Output</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas turbine output before inlet air cooling</td>
<td>108.23 MW (net)</td>
<td>0%</td>
</tr>
<tr>
<td>Gas turbine output with mechanical refrigeration system and inlet air</td>
<td>124.8 MW (net including</td>
<td>15.3%</td>
</tr>
<tr>
<td>temperature of 10°C</td>
<td>chiller electrical load)</td>
<td></td>
</tr>
<tr>
<td>Gas turbine with evaporative cooler running at 85% RH</td>
<td>114.8 MW (net)</td>
<td>6%</td>
</tr>
<tr>
<td>Gas turbine with fog system running at 100% RH</td>
<td>116.65 MW (net)</td>
<td>7.69%</td>
</tr>
</tbody>
</table>
## Capital Cost Comparisons of Inlet Cooling Systems

<table>
<thead>
<tr>
<th>Options</th>
<th>Relative Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporative cooler</td>
<td>1</td>
</tr>
<tr>
<td>Fog system (excluding water treatment plant)</td>
<td>2</td>
</tr>
<tr>
<td>Single stage LiBr absorption chiller</td>
<td>8</td>
</tr>
<tr>
<td>Two stage LiBr absorption chiller</td>
<td>10</td>
</tr>
<tr>
<td>Ammonia mechanical refrigeration system</td>
<td>9.5</td>
</tr>
</tbody>
</table>
## Major Contributors To The O&M Costs

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<th>Options</th>
<th>O&amp;M Costs</th>
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<tbody>
<tr>
<td>Evaporative cooler</td>
<td>- Make up water&lt;br&gt; - Water treatment (if applicable)</td>
</tr>
<tr>
<td>Fog system (excluding water treatment plant)</td>
<td>- Make up water&lt;br&gt; - Demineralised water treatment&lt;br&gt; - Injection pump power consumption</td>
</tr>
<tr>
<td>Single stage LiBr absorption chiller</td>
<td>- Steam&lt;br&gt; - Cooling tower chemical treatment&lt;br&gt; - Chiller maintenance&lt;br&gt; - Electric power consumption</td>
</tr>
<tr>
<td>Two stage LiBr absorption chiller</td>
<td>- Steam&lt;br&gt; - Cooling tower chemical treatment and make up water&lt;br&gt; - Chiller maintenance&lt;br&gt; - Electric power consumption</td>
</tr>
<tr>
<td>Ammonia mechanical refrigeration system</td>
<td>- Electric power consumption&lt;br&gt; - Cooling tower chemical treatment and make up water&lt;br&gt; - Chiller maintenance</td>
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Heavy Duty Gas Turbine NO$_x$ Emission kg/MWh

GT with Dry Low NOx burner

![Graph showing the relationship between ambient temperature and NO$_x$ emission]
Heavy Duty Gas Turbine CO\textsubscript{2} Emission kg/MWh
Aero-Derivative Gas Turbine NO$_X$ Emission kg/MWh

GT with Dry Low NOx burner
Aero-Derivative Gas Turbine CO₂ Emission kg/MWh
In Selecting Inlet Air Cooling As A Retrofit To An Existing Plant

*Points to watch:*

- Check the generator capacity in order not to overload the generator
- Quality of raw water for the evaporative cooler
- When using an existing demineralised water treatment plant, be careful about the capacity and quality of available demineralised water
- With an existing heat recovery steam generator, inlet air cooling will change the behaviour of the existing HRSG, leading to a drop in steam production at high pressure and increase in intermediate and low pressure steam