GT inlet-air cooling boosts output on warm days to increase revenue

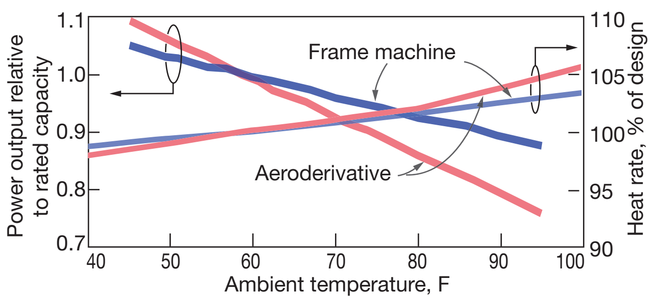
By **Dharam V Punwani,** Avalon Consulting Inc
and **Ray Pasteris,** Strategic Energy Services Inc

Today's competitive generation market presents many challenges to the developers, owners, and operators of combined-cycle powerplants. One is maximizing output and revenue, especially during the warm months when power prices typically are highest. Perhaps the most efficient way to boost output is by cooling the inlet air to the gas turbine's (GT) compressor.

Recall that the power output of a GT is directly proportional to, and limited by, the mass of a volumetric flow rate of air. But while the volumetric capacity is fixed, the mass flow rate of air delivered to the combustor decreases as ambient temperature rises above the rated-capacity design point (so-called ISO conditions, 59F at sea level).

The actual impact of ambient air temperature on output depends on GT type. Fig 1 illustrates that aeroderivative engines are more sensitive to ambient temperature than frame machines. Note that an increase in ambient temperature from 59F to 95F can reduce the output of an aeroderivative by as much as 25% of rated capacity. If you want your GT to maintain its rated capacity during warm weather, the inlet must be cooled to 59F.

1. Impact of ambient temperature on GT output, heat rate



It is possible to increase the power output of a GT above its rated capacity by cooling inlet air to below 59F. For example, if you cool the air to 50F the power output of an aeroderivative increases by about 5%. However, the generator also must be capable of operating above the rated output.

Heat rate also increases as ambient temperature rises. Referring again to Fig 1, note that an increase in ambient temperature from 59F to 95F increases the heat rate of a typical aeroderivative by about 4%. Cooling the inlet air from 95F to 50F reduces the heat rate from 104% to 98% of the design value at ISO conditions.

Options for cooling inlet air

Many technologies are commercially available for cooling air prior to compression. They are described in capsule form below. More details are available in the publications listed in the bibliography posted on the Web site of the Turbine Inlet Cooling Association (TICA) at www.turbineinletcooling.org (visit the "Library").

Wetted media, the most popular of the technology alternatives for GT inlet cooling, cools via evaporation of water from the wetted media into the GT inlet air. Humidification is accomplished as water flows over the wetted media and air passes through it. A honeycomb-type medium is most common. The water may require treatment depending on the GT manufacturer's specifications.

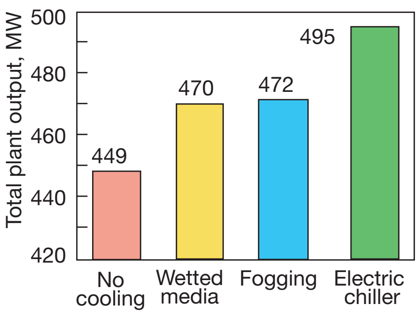
Wetted media can cool the inlet air to within 85% to 95% of the difference between the ambient dry-bulb and wet-bulb temperatures. It is one of the least-cost cooling options, despite its high water consumption. Primary disadvantage is that the extent of cooling is limited by the wet-bulb temperature and is, therefore, weather- and climate-dependent. Wetted media is most efficient in hot, dry climates and less effective when ambient humidity is high.

Fogging is the second most popular evaporative technology. It saturates the GT inlet air by spraying very fine droplets of water into the stream. Fogging systems can be designed to produce droplets of variable sizes, depending on the desired evaporation time and ambient conditions. The water droplet size generally is less than 40 microns and averages about 20 microns. The water used for fogging typically requires demineralization. Fogging systems can cool the inlet air to within 95% to 98% of the difference between ambient dry-bulb and wet-bulb temperatures, so it's slightly more effective than the wetted media. The capital cost is comparable to that for the wetted media and the technology has similar limitations and disadvantages.

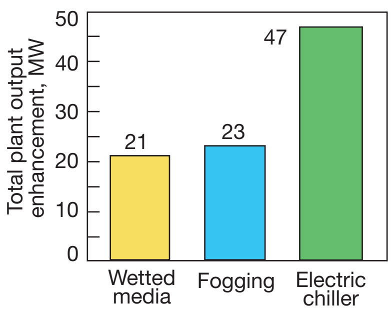
Overspraying, also known as wet compression, adds more "fog" to the inlet air than can be evaporated under ambient conditions. The air stream carries the excess fog into the compressor section of the GT where it evaporates, cooling the compressed air further and creating extra mass for boosting the GT output beyond that possible with the other two evaporative technologies discussed above.

Mechanical refrigeration systems can cool the inlet air to much lower temperatures than those possible with evaporative cooling and can maintain any desired inlet air temperature down

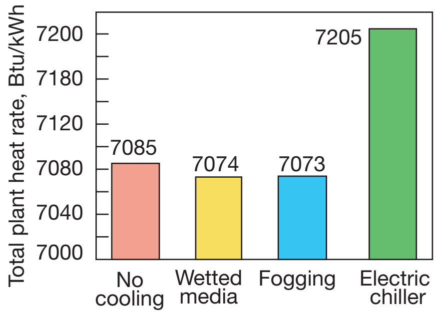
2. Impact of cooling method on total plant output



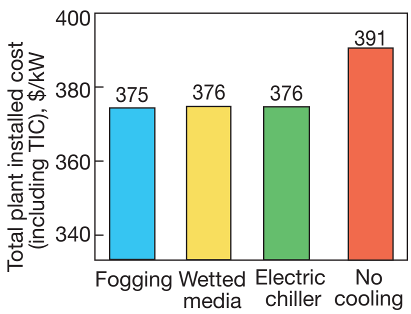
3. Gain in GT output for alternative cooling technologies



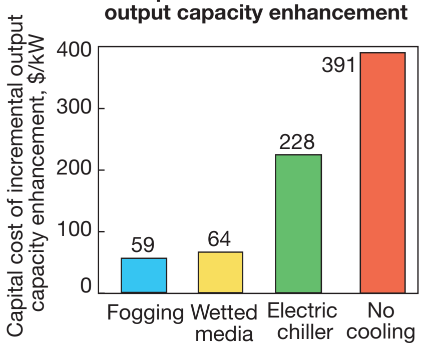
4. Impact of cooling method on plant heat rate



5. Impact of cooling technology on total plant installed cost



6. Capital cost of incremental output capacity enhancement



to 42F, independent of ambient wet-bulb temperature. It works this way: Inlet air flows across cooling coils within which either chilled water or refrigerant is circulated. The mechanical chillers used in these systems usually are driven by electric motors or steam turbines.

Cold water can be supplied directly from a chiller or from a thermal energy storage (TES) tank containing ice or only chilled water. TES typically is specified when inlet-air cooling is required for a limited number of on-peak hours, because it reduces the chiller plant's installed capacity requirements and overall capital cost. Also, TES allows the plant to export maximum power on peak because the TES system is charged at night using off-peak electricity.

The primary disadvantages of mechanical refrigeration compared to evaporative cooling technologies: It has a higher capital cost, a larger footprint, and a higher parasitic power load. The impact of its power requirement may increase overall plant heat rate if TES is not used.

Absorption cooling uses thermal energy (steam or hot water) to drive the cooling process and requires much less electric power than mechanical chillers. Absorption systems can be used to economically cool inlet air to about 50F. These systems can be used with or without TES.

Chillers can be single- or double-effect technology. The single-effect chiller uses hot water or 15-psig steam. For steam, the requirement is 18 lb per ton of refrigeration, presented as 18 lb/RT. The double-effect chiller uses less steam (10 lb/RT) but needs the steam at higher pressure (115 psig). Major disadvantage of absorption chilling is that its capital cost is higher than that for mechanical refrigeration systems. Furthermore, in combined-cycle applications the absorption system may decrease the output of the steam turbine/generator if some of its steam is diverted to the chiller.

Hybrid systems incorporate some combination of mechanical refrigeration, absorption cooling, and/or TES systems. Such systems are optimized for a specific plant based on the power demand, time-of-day electric prices, and the availability of thermal energy.

LNG vaporization systems are useful for combined-cycle plants located near a liquefied natural gas (LNG) facility. LNG is vaporized for pipeline transport by removing heat from the GT inlet air.

Case study

To illustrate the impact of wetted media, fogging, and electric chillers on combined-cycle plant performance, consider the following example for a unit located in Houston. It consists of two identical frame GTs, each rated 170 MW (gross), one 172-MW (gross) steam turbine, and a total plant parasitic load of 11.5 MW. Net plant production at ISO conditions is 501 MW.

When the ambient temperature in Houston is 95F

Impact of GT inlet-air cooling on plant output

	Rated Capacity @ISO	No Cooling	Wetted Media	Fogging	Electric Chiller
Single Gas Turbine Output (kW)	170,130	147,880	156,890	157,670	173,570
Total Gas Turbine Output (kW)	340,260	295,760	313,780	315,340	347,140
Steam Turbine Output (kW)	172,657	164,362	167,494	167,782	170,307
Plant Gross Output (kW)	512,917	460,122	481,274	483,122	517,447
Base Plant Plant Parasitics (kW)	11,500	11,500	11,500	11,500	11,500
Chiller Plant Load (kW)	0	0	0	0	10,763
Plant Net Output (kW)	**501,417**	**448,622**	**469,774**	**471,622**	**495,183**

dry-bulb and coincident wet-bulb temperature is 80F, the output of the plant without inlet cooling drops from 501 MW to about 448 MW—a loss of 52 MW, or more than 10% of rated capacity at ISO conditions (see table for details). Data presented indicate that increases in ambient temperature decrease the power output of both the GT and the ST—the latter because of reduced GT exhaust-gas mass flow.

Modeling plant operation using GateCycle software, which is widely accepted for this type of analysis begins by assuming an approach of 90% of the difference between the dry-bulb and wet-bulb temperatures for the wetted-media case and 98% for the fogging system. These two technologies can cool the inlet air to 81.4F and 80.2F, respectively, for this situation.

The electric-chiller case assumes a system designed for cooling the inlet air to 50F. Such a chiller would require a total cooling capacity of 13,288 RT. The chiller plant's power requirements would be approximately 0.65 kW/RT for the chiller, plus an additional 0.16 kW/RT for chilled-water, condenser-water, and cooling-tower pumps, yielding a total chiller-plant demand of 10,763 kW. Table and Figs 2 and 3 summarize these results and show that the electric chiller maximizes power output, even after accounting for its significant parasitic power load. Compared to the base case, the GT cooled by wetted media, fogging, and electric chiller enhances new power output by 4.6%, 5.1%, and 10.5%, respectively.

Fig 4 shows the effects of the alternative cooling technologies on heat rate. Observe that the heat rates for the wetted-media and fogging technologies are slightly lower than that for the uncooled base-case GT, while the heat rate for the electric chiller is higher. Even though the chiller improves the heat rate of the GT, the net heat rate for the entire plant is higher because of its parasitic power requirement.

The impact of the alternative cooling technologies on total plant capital cost and on the installed cost of the incremental capacity enhancement are shown in Figs 5 and 6, respectively. These numbers reflect the following assumptions for installed costs:

■ Uncooled GT-based combined cycle, $350/kW at ISO conditions.

■ Wetted media, $4/kW of GT capacity at ISO.

■ Fogging system, $4/kW of GT capacity at ISO.

■ Electric chiller system (including the inlet cooling coil), $800/RT.

The last two illustrations show that the total plant capital cost, expressed in $/kW of net output, is lower with inlet cooling and that the capital cost for the incremental capacity enhancements, also in $/kW, is lowest for the fogging system.

Bear in mind that even though the total capital cost of the plant is higher for a system with inlet cooling, its cost per unit of net power output is lower because of the enhanced output that cooling provides. Fig 6 shows that the capital cost for the enhanced capacity achieved by all inlet cooling technologies is at least 40% less than that of the cost for the uncooled system. Note, too, that the capital cost shown in Fig 6 for the uncooled system is the same as that for the 501-MW base-case plant. Were a new peaking gas turbine installed to produce the additional 47 MW possible with the electric-chiller option, it would cost more than $700/kW—twice as much as the uncooled base-case combined cycle.

As stated earlier, this example relates only to a situation when the ambient dry-bulb and wet-bulb temperatures are 95F and 80F, respectively. The numbers generated by GateCycle for this case, by themselves, are not sufficient to decide whether GT inlet cooling is economically attractive and, if so, which technology is most favorable. Such estimates require calculations using comprehensive data—hourly, for example—on weather, fuel cost, power demand, and the market value of power for an entire year or more.

Finally, keep in mind that GT inlet cooling has proven its economic benefit at many combined-cycle plants nationwide. A database of some installations is available in the Experience Database section at www.turbineinletcooling.org. **CCJ**

Dharam V Punwani is President of Avalon Consulting Inc, Naperville, Ill, a member of the Turbine Inlet Cooling Association. Avalon provides feasibility and optimization services for turbine inlet cooling and distributed power generation. Punwani has nearly 40 years of experience in energy technologies.

Raymond M Pasteris is President of East Coast-based Strategic Energy Services Inc. The company provides services to firms involved in district heating and cooling, independent power generation, CHP, and thermal energy production, as well as to government and financial institutions.