BULK AIR COOLING
THE OPTIMUM SOLUTION FOR TURBINE INLET AIR CHILLING

By Kurt Liebendorfer, Sr. Vice President – Stellar
and
Jim Furlong, Vice President – Baltimore AirCoil

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Over the past ten years, the vast majority of new electric capacity which has come on line in the United States has been in the form of natural gas-fired combustion turbine (CT) generating stations. The popularity of this technology has been driven largely by the environmental (emissions) advantages of CT generating stations versus other fossil fuel alternatives, which has enabled the siting and permitting of new plants to be completed in time-frames of as little as eighteen months. In addition, dramatic advances in CT technology have now enabled the efficiency of simple cycle CT plants to exceed 40%, and that of combined cycle CT plants (plants incorporating combustion turbines in conjunction with exhaust heat recovery steam generators and steam turbines) to exceed 60%, making them the most efficient fossil fuel generating technologies available.

Because most new CT generating stations have been driven by utilities' need to meet ever increasing peak loads, the ability of those stations to deliver maximum net power output during periods of peak demand is of utmost importance. Unfortunately, peak demand most often occurs when ambient temperatures are at their warmest, a condition which has a detrimental impact on combustion turbine net power output and heat rate (fuel consumption). This issue has given rise to a variety of power augmentation solutions which involve supplementary systems to enhance the net performance of CT generating stations across the full spectrum of ambient conditions a given station is likely to operate in across the course of a year. One such solution is Turbine Inlet Air Chilling (TIAC) which involves cooling the combustion air of the turbine during hot weather in order to increase the power output of the generating station. A TIAC system is typically twice as cost effective for increasing CT plant KW output as compared to buying and installing a new CT, thus making it very economically attractive.

This article will explore a new innovation related to TIAC called Bulk Air Cooling which can deliver a variety of economic and operational benefits not readily available with traditional TIAC technologies. Bulk Air Cooling is facilitated through water to air heat transfer devices (Bulk Air Coolers) which are used to directly cool the inlet air to the CT.

To date, the three most commonly employed methods of cooling the inlet air of a combustion turbine are:

- Wetted Media Evaporative Coolers
- Fogging Systems
- Mechanical Chilling Systems

Wetted Media Evaporative Coolers and Fogging Systems

The principal of operation for both wetted media evaporative coolers and fogging systems is adiabatic heat exchange - the exchange of sensible heat in the ambient airstream for latent heat related to the evaporation of water. Saturating the airstream and depressing the ambient dry bulb temperature to a temperature approaching the ambient wet bulb is the sole objective.

Wetted media evaporative coolers saturate the inlet air by having it pass through a semi permeable (cellulose based) media, enabling the air to come in direct contact with the water to enable mass transfer (evaporation) to take place.

Fogging systems inject very fine droplets of water (typically between 20 and 40 microns in diameter) directly into the inlet airstream by using a high pressure pumping system and specially designed nozzles. The droplets are supplied at a rate which should enable them to fully evaporate before reaching the compressor section of the CT. Unlike wetted media evaporative coolers, fogging systems typically require ultra pure (deionized) water to maintain nozzle performance.

Mechanical Chilling Systems

As opposed to evaporative systems which are constrained by the ambient wet bulb temperature for cooling, mechanical systems are capable of delivering inlet air temperatures as low as 42°F, independent of ambient wet bulb. Because a large capacity refrigeration system is required to facilitate this, mechanical chilling systems are associated with more capital equipment and higher first cost than evaporative systems. Cooling of the inlet air is typically accomplished indirectly, through a finned coil, wherein a cooling fluid (water or glycol) or refrigerant (ammonia, HFC, or HCFC) flow through the tubes of the coil as the inlet air passes over the outside. Mechanical chilling systems will consume more parasitic power than will evaporative systems although the additional power augmentation benefits derived from the CT operating at lower inlet air temperatures will usually more than offset the parasitic losses in all but the driest climates.

The new innovation of Bulk Air Cooling is a TIAC solution which can enable the benefits of both evaporative cooling as well as mechanical chilling to be exploited by a given CT generation station. See Figure 1 for a schematic of the Bulk Air Cooler connected to a Mechanical Chilling System.

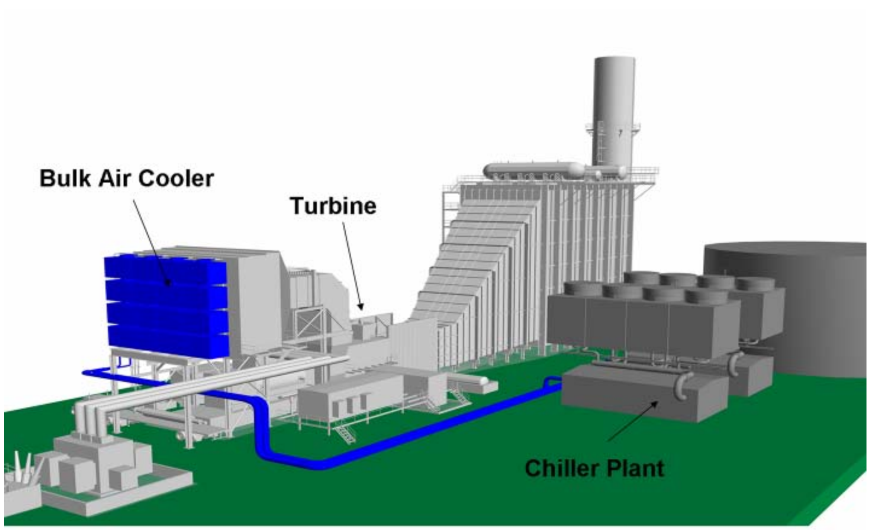


Figure 1: Gas Turbine power plant with inlet chilling utilizing the Bulk Air Cooler

General Description and Psychometrics

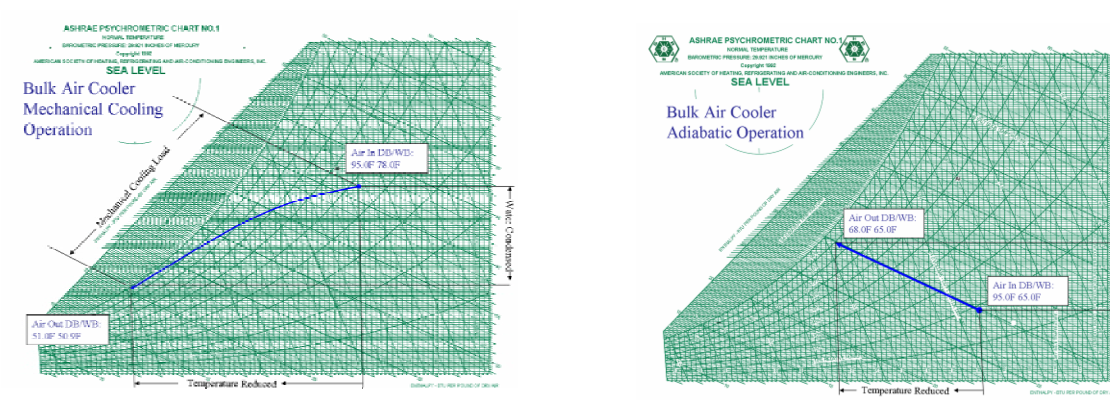
The Bulk Air Cooler is a heat transfer device designed to depress the dry bulb temperature of the inlet air of a combustion turbine to a level below ambient in order to augment the turbine's power output. As opposed to traditional inlet air cooling technologies, the Bulk Air Cooler can accomplish this by operating either in a mechanical cooling mode or in an adiabatic mode (evaporative cooling only with no chillers running). This flexibility can enable the plant operator to optimize energy efficiency, as well as plant capacity, by making use of evaporative cooling when ambient conditions support it and switching to mechanical cooling when elevated ambient wet bulb temperatures render evaporative cooling ineffective.

In addition to its thermal capabilities, the Bulk Air Cooler has the ability to filter most of the dust and other airborne contaminants out of the inlet air stream before they come in contact with the static filters of the combustion turbine. This capability reduces maintenance costs associated with filter changes and results in an overall improvement to combustion turbine operation.

Heat transfer within the Bulk Air Cooler is facilitated by direct contact between the inlet air and the cooling water. In the mechanical cooling mode, the cooling water contacting the air has been chilled to a temperature well below the ambient wet bulb while in the adiabatic mode the cooling water is at a temperature approaching, but slightly above, the ambient wet bulb. In both modes, the cooling water contacts the air after having been distributed over a bank of enhanced surface, wet deck fill sheets designed to maximize the effective surface area of the water while keeping airside pressure drops low. Two banks of mist eliminators are mounted within the Bulk Air Cooler to eliminate any water droplets from being carried downstream with the inlet air.

From a psychometric perspective, the Bulk Air Cooler operates much like a cooling coil when in the mechanical cooling mode. For example, if the Bulk Air Cooler is designed to cool combustion turbine inlet air from an entering ambient condition of 95°F dry bulb/ 78°F wet bulb to a leaving dry bulb of 51.0°F , the air would follow the path described in Figure 2. As would be the case with a cooling coil, both latent and sensible heat transfer will be taking place, resulting in a leaving condition which is both cooler and more saturated than was the entering condition. The heat being removed from the air is being transferred directly into the chilled water stream where, in turn, it will need to be removed by a mechanical cooling device, typically a water cooled chiller. Because of the latent load, condensate will be produced which will be commingled with the leaving chilled water. The production of water (condensate) in the cooling mode is a significant benefit for power plant applications where many plants are built with very restrictive water permits.

Figure 2



In the adiabatic mode, the psychometric profile of the air stream cooled by the Bulk Air Cooler appears much like a wetted media evaporative cooler. Figure 3 describes an example where a Bulk Air Cooler is operating adiabatically in order to cool ambient air from 95°F dry bulb/ 65.0°F wet bulb to a leaving dry bulb of 68°F . As the air stream becomes more saturated, it proceeds along a constant enthalpy line towards the leaving conditions. Water is being evaporated into the air stream, saturating it and driving down the dry bulb temperature. It is important to note that there is no net heat being removed from the air stream in the adiabatic mode. All that is taking place is an *exchange* of the air stream's sensible heat for latent heat as it approaches saturation. As such, no mechanical cooling (chiller) load is created. The only energy consuming device in the adiabatic mode is the recirculating pump required to return cooling water back to the top of the unit. An overview of the operating characteristics of the mechanical cooling mode and the adiabatic mode is shown in Figure 4.

	Mechanical Cooling	Adiabatic
Chiller Status	**Operating**	**Not Operating**
Leaving Air Temp Limit	**Chilled Water Temp**	**Ambient Wet Bulb Temp**
Water Evaporated?	**No (condensate produced)**	**Yes (to saturate air)**
Relative System Energy Consumption	**High (chiller plus pump energy)**	**Low (pump energy only)**

Figure 3: Comparison Mechanical Cooling and Adiabatic Modes of Operation

Components

An operating Bulk Air Cooler System consists of three (3) primary components:

- Bulk Air Cooler Modules
- Structural Support System and Piping
- Remote Sump

Bulk Air Cooler Modules are factory assembled modules containing all of the essential heat transfer components of the system including inlet water distribution basins, wet deck fill, outlet water basins, and integral dual mist eliminators. The modules are designed to dimensions which support economical overland transportation as well as efficient rigging.

The structural support system on which the modules are mounted is field erected. Supply and return piping headers are added after the structural support system has been erected and the Bulk Air Cooler modules rigged into place.

A Remote Sump System is employed to collect the water exiting the Bulk Air Cooler modules and pump it to either the chiller system when operating in the mechanical cooling mode or back to the Bulk Air Cooler modules when operating in the adiabatic mode. Makeup water and blowdown connections as well as water level controls are typically incorporated into the remote sump. In addition, a side-stream filtration system, involving either sand filters or centrifugal separators, can be added to remove suspended solids from the recirculating water.

Comparison with Evaporative Cooling Technologies

Wetted Media Evaporative Coolers

The Bulk Air Cooler is capable of delivering adiabatic efficiencies of up to 94%, roughly the same as wetted media technology from a dry bulb depression standpoint. However, unlike wetted media, the Bulk Air Cooler heat transfer media will not become fouled by airborne dirt and dust and the media will not require periodic replacement. One disadvantage the Bulk Air Cooler has with respect to wetted media is that it involves greater recirculating water flow rates which results in higher pumping horsepower during adiabatic operation.

Fogging Systems

Although fogging systems are capable of slightly higher adiabatic efficiencies (up to 98%) than the Bulk Air Cooler, they have the drawback of requiring demineralized water to operate. The Bulk Air Cooler is designed to use raw plant water. In addition, the Bulk Air Cooler does not introduce any un-evaporated water droplets to the inlet air stream, alleviating the concerns which have been raised by a number of combustion turbine OEM's with regard to combustion turbine compressor degradation being exacerbated by un-evaporated droplets of demineralized water from fogging systems coming in contact the compressor inlet vanes.

Comparison with Mechanical Cooling Technologies

The Bulk Air Cooler offers similar thermal performance to traditional finned coil technology commonly employed in CT inlet air cooling applications. With dual mist eliminators it is capable of operating with leaving face velocities of up to 600 fpm with zero water carryover. Typical airside pressure drop at 600 fpm is less than 0.75" w.c.

During the winter, the Bulk Air Coolers will be fully and automatically drained, eliminating the need for propylene glycol or other antifreeze in the chilled water system as is common on coil systems. This will be associated with a very positive impact on the chiller system, from both a first cost and operating cost of the chiller plant.

In retrofit applications, in which existing CT plants are considering the addition of inlet air cooling, the fact that the Bulk Air Cooler does not require filtered air to operate can offer a great advantage versus coil technologies. Retrofit Bulk Air Coolers can be installed upstream of an existing filter house, an option not possible with coils which must be mounted downstream from the filters. The face velocity limit for coils is typically 550 fpm to insure no moisture carryover. Existing, "non-coil ready" filterhouses are often designed for higher velocities, precluding their ability to accommodate a cooling coil without significant modifications.

Filtration Characteristics

A bench scale Bulk Air Cooler was fabricated to accommodate a typical ASHRAE Standard 52.1-1992 duct and dust feed arrangement and subsequently challenged with ISO fine (ISO 12103-1 “A2) synthetic dust at a concentration of 2 grams per 1000 ft3 of air (See Figure 4). Various air and water flow rates were applied and gravimetric arrestance values of the dust were determined using ASHRAE standard methodologies. Particle size analysis was completed on dust samples from the pre –test dust population and the filtrate effluent dust and used to assess performance by particle size.

Test results indicated that the average arrestance of the device, acting alone, was 73.2 %. Particulate analysis of samples taken upstream and downstream of the device shows a 100% removal efficiency of particulate above 15 micrometers (Figures 4 and 5).

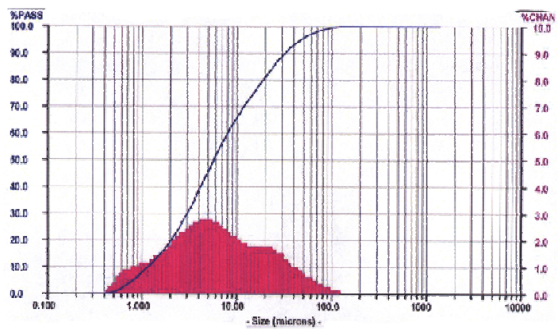


Figure 4: Particle Size Distribution – Pre Ecooler

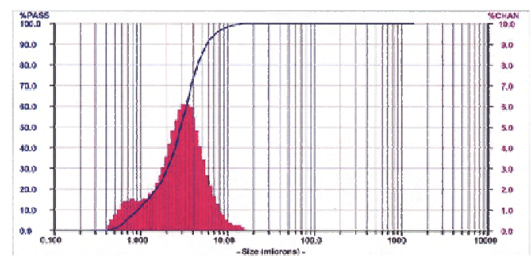


Figure 5: Particle Size Distribution – Post Ecooler

An additional arrestance test was performed with the addition of a secondary filter (45% efficient synthetic pocket filter 24”x24”x24”) mounted downstream of the Bulk Air Cooler. In this arrangement, the combination of the Bulk Air Cooler and pocket filter achieved an average arrestance of 96.7%.

One important operating characteristic of the Bulk Air Cooler is that its airside pressure drop will not increase as it removes dust from the entering air stream. Traditional disposable prefilters are typically designed to add 1.0” to 1.5” w.c. of airside pressure drop as they evolve from a clean to fully loaded condition. In addition, in the case of the Bulk Air Cooler, the possibility of filters becoming overloaded and subsequently bursting is eliminated.

Sodium Chloride Removal

Combustion turbine installations located in coastal areas have frequently suffered from compressor blade pitting corrosion and hot gas path component corrosion due to the introduction of airborne aerosols containing sea salt. Although traditional filtration techniques can help alleviate this problem, they have not been able to prevent it entirely. Condensing the chloride containing aerosols out of the air stream via inlet air cooling coils can be an effective means by which to address the problem although it typically involves the use of corrosion resistant materials of construction for the coil which can often prove cost prohibitive. The Bulk Air Cooler can represent a unique solution to this issue by having the ability to filter the inlet air as well as condense the chloride containing aerosols out of it when operating in the mechanical cooling mode. This is accomplished on a heat transfer surface (PVC) which is impervious to chloride attack.

Application and Case Studies

The **Channel Island Power Station** in Darwin, Australia was built in 1985 as a combined cycle plant and was retrofitted with inlet air cooling for its five (5) GE Frame 6B gas turbines in 1998. As part of the upgrade, the inlet air to three of the GE engines was cooled by (3) counterflow design “wet air coolers” (see Figure 6). Like the Bulk Air Cooler, the wet air coolers at Channel Island employ direct contact between cooling water and CT inlet air to facilitate heat transfer. The primary difference between the wet air coolers and Bulk Air Coolers is that the wet air coolers use a counterflow (airflow up, waterflow down) design whereas the Bulk Air Cooler uses a crossflow (airflow horizontal, waterflow down) design.

Figure 6: Wet Air Coolers at Channel Island Power Station

The wet air coolers were designed to operate in the adiabatic mode during Darwin’s dry season, and to operate in the mechanical cooling mode during the wet season. Chilled water for the mechanical cooling mode is supplied by an ammonia based ice thermal storage plant (36,932 ton-hours total storage) which allows ice to be built at night and subsequently melted during the peak hours of the day so that peak plant output will not be reduced by the parasitic energy of the ammonia compressors.

Now entering their tenth year of operation, the wet air coolers have performed without incident. The units typically operate six hours per day during the dry season and three hours per day during the wet season. “The wet air coolers have really been a non issue from a maintenance standpoint” says Ron Atwell, Generation Production Manager Channel Island. “The units continue to operate as when they were new, using the original fill and water distribution components with which they were supplied with.”

With respect to the ability of the wet air coolers to filter dust from the inlet air stream, Atwell reports, “The wet air cooler systems are noticeably cleaner in every respect than our other systems are. We have found that the interval between required primary filter changes is roughly twice as long on our wet air cooler systems. A pulse cleaning system was initially used to clean the primary filters on the wet air cooler systems but was eventually disabled it when we recognized it was providing us little value. We can also see the difference in our (turbine) compressors … they have less dirt and grime when we dismantle them for routine maintenance."

Phoenix Case Study

For a typical combined-cycle plant located in Phoenix, AZ and consisting of two 7FA combustion turbines turbine (with inlet and exhaust pressure drops of 4-inch and 10-inch WC, respectively) and one steam turbine, the GateCycle® software was used for estimating the benefits of Bulk Air Cooler over a conventional chiller system. For the purpose of this analysis the total annual operating hours are divided into the following three periods using the typical meteorological year (TMY) hourly data for Phoenix, AZ:

1. Ambient dry-bulb temperature is ≤ 50^{o}F and no TIAC is required: 1,038 hours/year

2. Ambient dry- and wet-bulb temperatures are such that evaporative cooling with 90% efficiency can cool the inlet air to ≤ 50^{o}F (i.e. a chiller system is not necessary): 1,677 hours/year

3. Ambient temperature conditions are such that only a chiller system can cool the air to 50^{o}F: 6,045 hours/year

Assuming that the air-side pressure drop across the cooling coil of a conventional chiller system is 1-inch of water column (WC) and that across the Bulk Air Cooler is only 0.8 inch WC, the results of the analysis show that the Bulk Air Cooler produces about 290 kW more than the conventional chiller system during all the three periods and totals over 2,540,000 kWh per year. In addition, during Period 2, when the Bulk Air Cooler system can operate in the adiabatic mode, it saves over 1,393,000 kWh of total parasitic load that the conventional chiller system would use during that period to cool the inlet air to 50^{o}F. Therefore, during Period 2, the Bulk Air Cooler system helps reduce emissions and carbon footprint because it eliminates the need for combusting the fuel equivalent (at heat rate of about 6,975 Btu/kWh) of the electric energy for this parasitic load. The economic benefit of the Bulk Air Cooler system over the conventional chiller system will vary depending on the definitions of on-peak and off-peak periods, cost of gas, and market values of generation capacity and electric energy during the on-peak and off-peak periods, but clearly a economic and environmental benefit is attained.

Summary

Bulk Air Cooling is a technology which is likely to have a promising future in the realm of TIAC power augmentation for CT generating stations because of its economic and environmental benefits. It can provide the plant operator the ultimate flexibility to optimize plant performance at a variety of ambient conditions in terms of net kW output and/or heat rate by making both adiabatic and mechanical chilling modes available. Improved annual heat rate will have a direct beneficial impact on the environment including conservation of fuel resources, emission reductions (SOx, NOx, particulates and Hydrocarbons), and reduction of greenhouse gases (CO_2).

From an operational standpoint, Bulk Air Cooling can provide a unique filtration solution for generating stations operating in dusty environments and can help alleviate the issue of chloride induced pitting corrosion for CT generating stations located adjacent to salt water.