DIRECT SPRAY SYSTEM FOR INLET AIR COOLING W 501 B5

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ABSTRACT

Cooling the inlet air utilizing a direct water spray system can increase the performance of a combustion turbine during hot weather. In a direct spray system, water is added to the air stream in the form of fine droplets. As the droplets absorb the latent heat of vaporization, heat is removed from the air stream thereby reducing its temperature. The objective of this paper is to discuss a direct spray system for cooling inlet air for Florida Power & Light's Westinghouse 501 B5 combustion turbine at the Putnam plant. The fogging is done in multiple stages – an external zone and an internal zone to control the humidity to a precise level. An overspray zone has been added for additional power augmentation. The water is sprayed into the incoming air stream through impingement nozzles placed at the cross-section of the incoming air. The size of the water droplets varies with the nozzle dimensions and water pressure. It is important to limit the size of the water droplets in order to allow for vaporization of water in a relatively short distance, thus minimizing water carryover and droplet agglomeration. Therefore selection of the nozzle type, their arrangement and placement, and the water discharge pressure is very important to control the stringent compressor inlet air requirements. These design requirements and actual cooling system performance are discussed in detail in this paper.

INTRODUCTION

ombustion Turbine Inlet Air Cooling (CTIAC) is a method of cooling inlet air at the combustion turbine's (CT) compressor intake. This cooling is accomplished to regain the megawatts lost due to turbine operation at higher ambient temperatures, typically well above ISO conditions (Fig. 1). There are several ways to accomplish CTIAC:

1) Evaporative cooling with wetted-media or direct-spray, whereby moisture is added to the air-stream to provide sensible cooling of the inlet air. As the water evaporates, it extracts the required latent heat of vaporization from the surrounding air causing the temperature of the air to decrease.
2) Continuous cooling with mechanical means of cooling below the dew point temperature. This method provides the maximum benefit of increased megawatts during hot weather conditions on a continuous basis. There are several ways of providing continuous cooling – direct refrigeration, absorption chillers, electrical chillers, etc.
3) Cooling with Thermal Energy Storage (TES), whereby a cold storage medium (ice, chilled water, etc.) is created during off-peak periods. Water is circulated through this cold storage medium to absorb heat from the inlet air during peak periods. In this case, the size of the system is smaller than that required for continuous cooling because the cooling is provided only during peak hours whereas the entire off-peak hours are used to build the cold energy reserve. The main advantage of a TES system is that almost the entire gain in the output is available, since the auxiliary power consumption during the peak hours is minimal.

This paper focuses on evaporative cooling by utilizing a direct spray in the inlet duct to cool the ambient air to near wet-

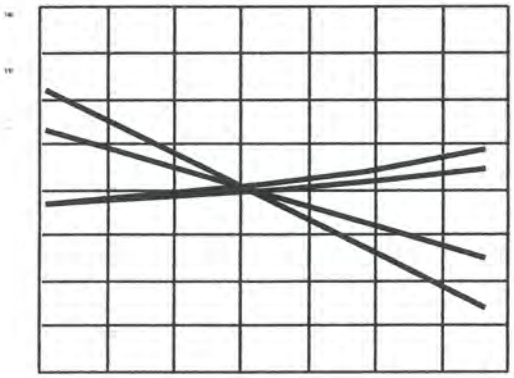

Figure 1: Effect of Compressor Inlet Air Temp on CT Performance

bulb temperature. The direct spray system is based on the same concept as a conventional media-type system, but without the penalty of a pressure drop incurred by the media placed in the air-stream and maintenance required for the media. Other key advantages of this spray system are better control over the humidity of the air and ease of installation for retrofit projects.

TYPES OF DIRECT SPRAY SYSTEMS

To achieve the desired adiabatic cooling of the airstream, water in the form of fine droplets (fog) is added. As the droplets extract the latent heat of vaporization (that energy required to convert the water from liquid to vapor), heat is removed from the air stream thereby reducing its temperature.

There are two basic methods of spraying water in the inlet air: 1) high pressure (HP) impingement nozzles and 2) ultrasonic nozzles (US). The droplet size is the critical parameter in evaporative cooling efficiency. The smaller the droplets, the shorter the evaporation time and corresponding efficiency.

High Pressure Impingement Nozzles

In an impingement type nozzle, water is supplied at a high pressure. When water passes through the nozzle, it is accelerated because of a reduction in area at the opening. The orifice of the nozzle is only a few thousandths of an inch in diameter. The impingement pin at the orifice is provided to help break down the water stream into finer particles. As the water strikes the tip of the impingement pin, it produces a fine mist or fog (see Fig. 2). The distance between the pin tip and the orifice can be adjusted to control the water droplet size. The supply water to the nozzles is controlled and pressurized by a high pressure pump. Typically, a plunger-type, fixed displacement pump is utilized.

The droplet size varies with water pressure, orifice diameter and location of the pin tip. Typically water pressures in the range of 1,000 to 3,000 psi are used for turbine inlet air cooling applications. Figure 3 shows a comparison of droplet sizes for two different nozzle sizes conducted at a water pressure of 3,000 psi and at the same impingement pin distance.

Ultrasonic Nozzles

A further enhancement to operation and performance over the impingement type nozzle system is achievable by using ultrasonic nozzles. In an ultrasonic nozzle, compressed air and water at relatively low pressures are used to maintain small water droplet size. The water under pressure is directed through an ultrasonic shock wave of air to break down the water particles into a finer mist / fog. The water is supplied at a much lower pressure than that of the impinge-

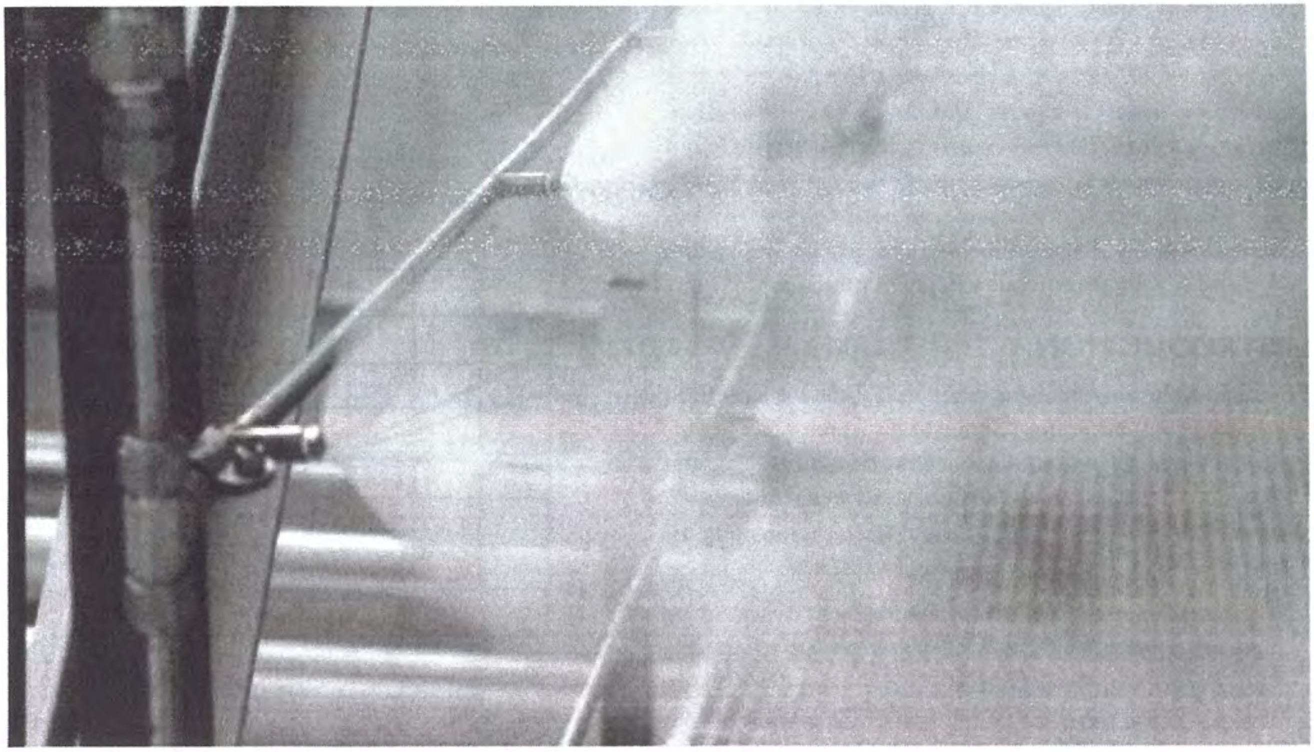

Fig.2: A zone array showing an actual nozzle mounted on stainless steel tubing.

ment nozzle. The orifice through which the water and air flows in the ultrasonic nozzle is much larger than the impingement nozzle making it much less susceptible to clogging. In addition, lower operating pressure means that normal piping, valves, hoses, gauges, etc. can be used and that less maintenance and replacement cost will be incurred. The longevity of the ultrasonic nozzles and system components is expected to be much greater than the impingement nozzles operating at 3,000 psi.

The ultrasonic nozzles can vary the amount of air and water reaching the nozzle to modulate capacity. At lower outputs, less compressed air is used thus saving energy. These nozzles are fully modulating from 0 to full capacity without appreciable enlargement of particle size. Another advantage of this system is that since the flow is controlled through each nozzle to meet cooling requirements, a uniform distribution of fog in the air stream is possible, thus eliminating any stratification in the air stream. However, the ultrasonic wave is set up with compressed air and this adds to the complexity of the system. The main drawback of this system is the compressed air requirement, which results in an auxiliary power consumption of up to 3 times that of the HP impingement nozzles.

The ultrasonic nozzles typically break down the water molecule into much finer fog with droplets ranging from 0.5-10 microns, depending upon the nozzle type.

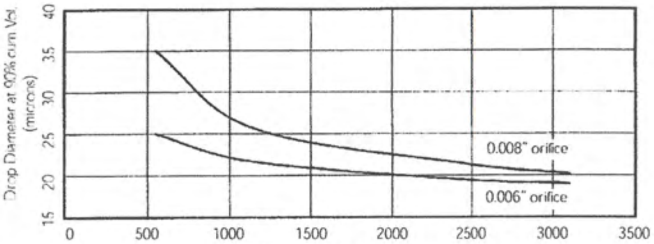

Figure 3: Nozzle Comparsion at Pressure of 3,000 psi.

CASE STUDY

This paper discusses the direct spray system recently installed by Caldwell Energy & Environmental, Inc. (CE&E) on a Westinghouse W 501 B5 CT at the Putnam Generating Station, in Palatka, Florida. The system is used to humidify and cool the turbine inlet air during hot days to increase capacity and efficiency of the gas turbine and the plant.

Design Conditions

The Putnam Plant is a combined cycle plant owned and operated by Florida Power & Light Company (FPL). It utilizes four Westinghouse 501B5 combustion turbines, four heat recovery steam generators (HRSGs) and two steam turbines. FPL and CE&E evaluated the performance of the

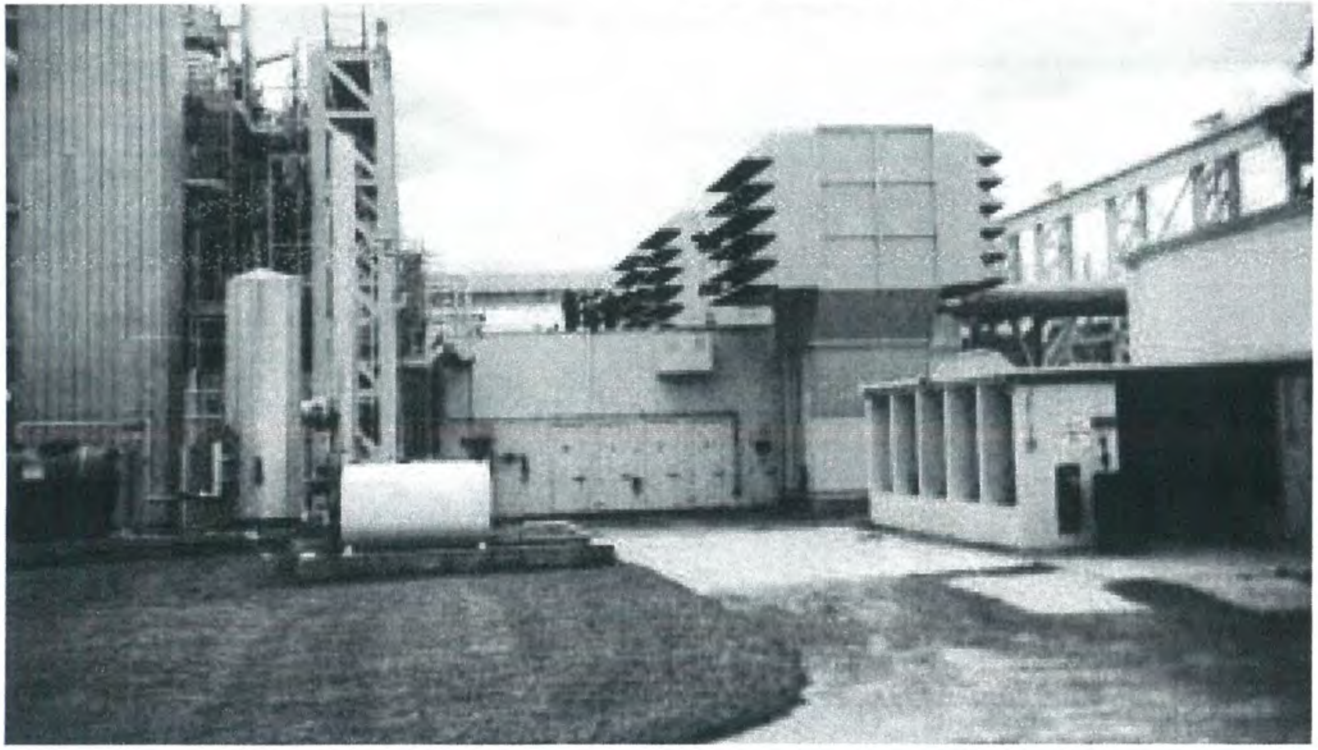

Fig. 4: Inlet housing of W 501 B5 at the Putnam jobsite before any modifications.

first turbine using the direct spray system. The original inlet duct housing of this turbine is shown in Fig. 4.

The design ambient temperature conditions were:

T dry bulb = 95°F
R.H. = 50%
T wet bulb = 79°F
Air Flow = 2,500,000 lbs./hr
Elevation: = 35 ft
T inlet air = 95% humidity for base load
T inlet air = 99% humidity for peak load

Another design requirement was to minimize any associated pressure drop with the installation of the inlet cooling system. The maximum allowable pressure drop was 0.25 in. of water column. An additional requirement was a droplet size of 20 microns or less for 90% of the volume. To meet this requirement with the selected nozzle system, design water pressure was increased to 3,000 psi.

System Description

The inlet fogging system consists of several arrays of impingement nozzles. The nozzles, mounted on manifold piping, were arranged in grids and segregated into multiple zones. The complete system was subdivided into three major zones -- external, internal and overspray. Each of these major zones is further subdivided into minor zones.

The external zone is located outside the inlet housing and is accessible for installation while the turbine is running.

This zone is positioned upstream of the prefilters to maximize the system efficiency by increasing the absorption distance for the majority of the humidification process (see Fig. 5). This primary nozzle zone humidifies the intake air to nearly 80% relative humidity before the air flows into new prefilter/demisters, which were installed on the turbine inlets to replace original spun fiberglass assemblies. The new prefilter/demister pads are permanent, washable mesh units with a lower pressure drop.

Downstream from the prefilters, humidistats are installed to detect higher than allowed RH and to prevent over humidification by shutting off arrays and/or throttling the external zone pump. When ambient humidity approaches the 80% limit, zones in the external array will cut off. A temperature element to monitor inlet air upstream of the final filters is included in the humidity dew point transmitter.

The internal zone is located on the downstream side of the final filter bank. This zone provides the final "topping off" humidification which takes the air stream relative humidity to 95% for the Base Load Condition, 99% for the Peak Load Condition and 100% for the Peak Load Reserve Condition. This zone is further subdivided into smaller zones to allow precise incremental stepping of temperature.

The purpose of the overspray zone is to supersaturate the

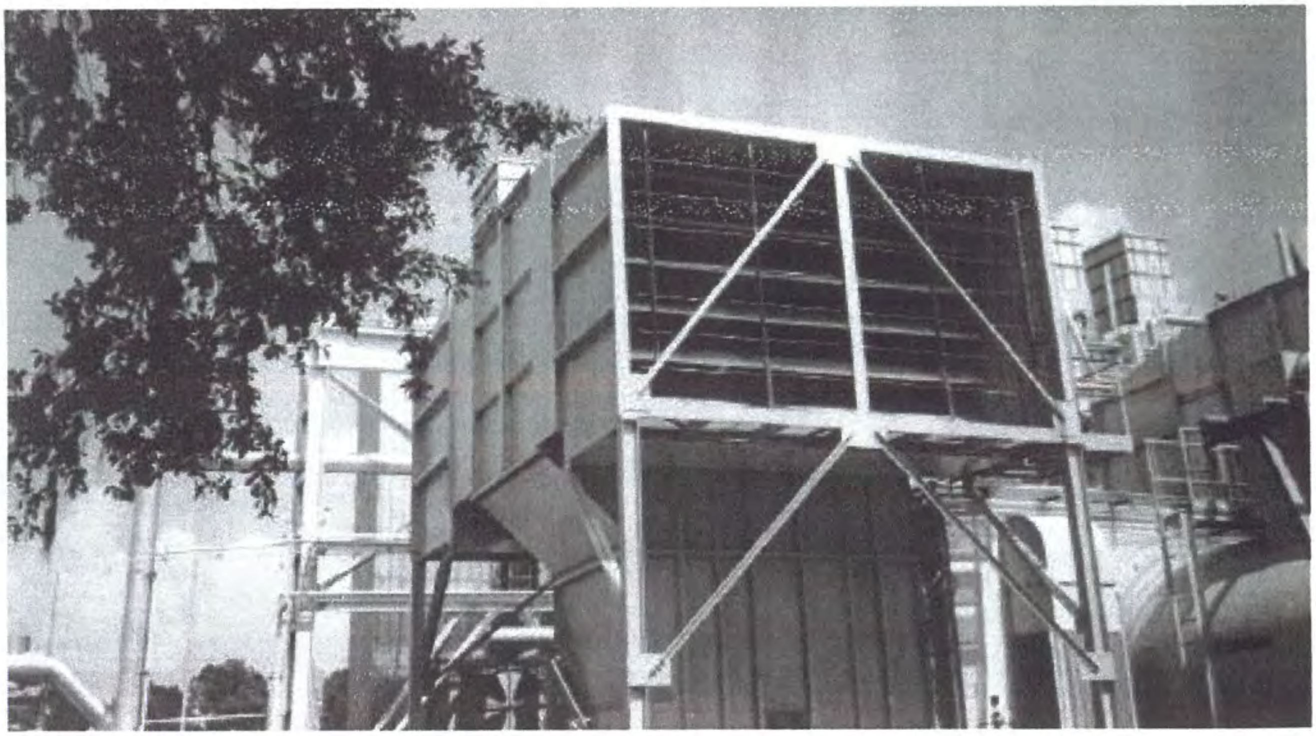

Fig.5: Modified inlet housing showing external nozzle arrays.

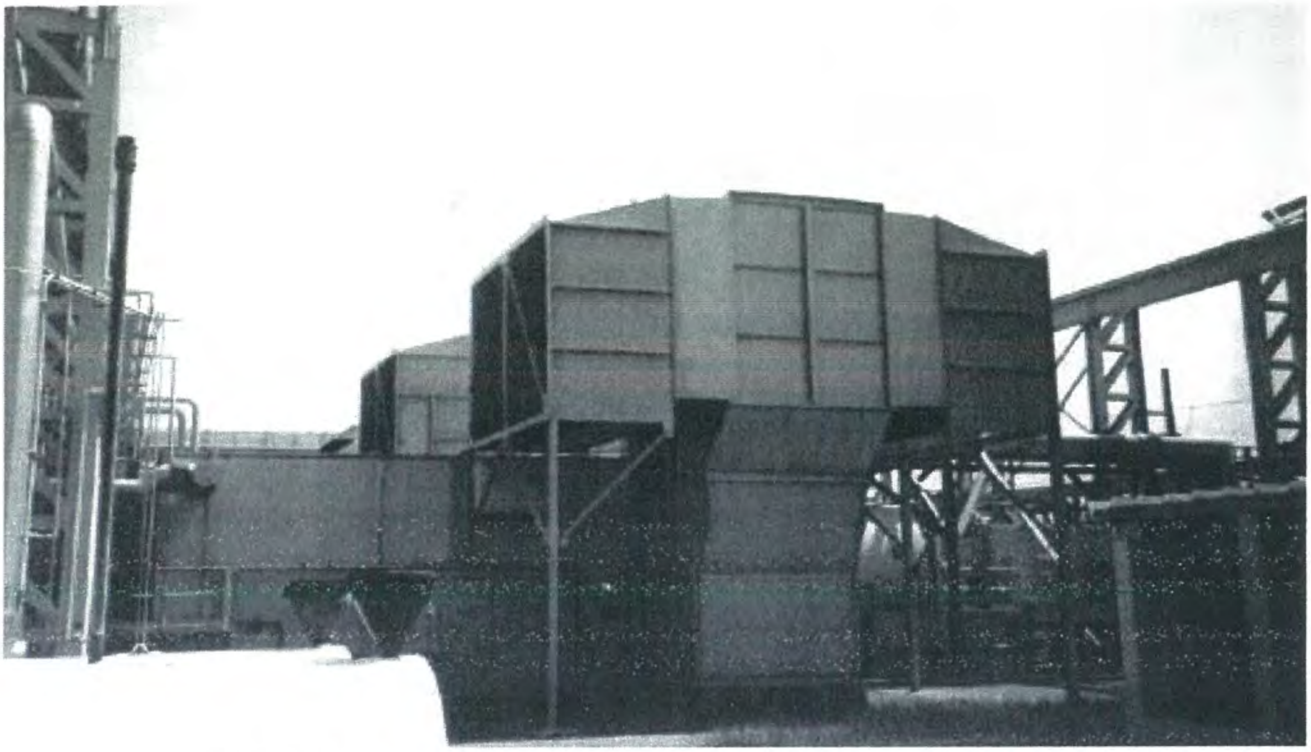

Fig.6: Inlet duct of the combustion turbine after modifications to add weather hoods.

inlet air with fine mist to increase the turbine capacity during those critical times when power is absolutely needed. Overspray is expressed as the ratio of excess mass of water sprayed to the mass of the air and is usually expressed on a percentage basis. The overspray zone is located downstream of the internal zone just prior to the trash screen and compressor inlet. With overspray, the water is not evaporated; instead it is carried to the compressor in the form of fine droplets. This results in additional gain as the water gets evaporated in the first few stages of the compressor.

System Components

The spray water system components are as follows:

1) Duct water spray delivery system
   - Nozzle arrays consisting of stainless steel tubes or pipe and pre-assembled nozzles
   - Hardware for supporting the tubes to the housing
   - Motor operated ball valves, fitted external to the duct to control zone flow
   - Stainless steel headers to distribute water to the nozzle arrays
   - Stainless steel piping from the water transfer skids to the nozzle arrays to supply demineralized water
2) Water transfer system
   - Steel skid
   - Water transfer pumps and belt drives
   - Electrical motor starter/breaker cabinet and control termination panel
   - Water filter
   - Water flow meters and pressure transducers with transmitters
   - All necessary water connections
   - All required piping, fittings and valves
3) Water piping from transfer skid to duct spray delivery system
4) Controls and instrumentation
5) Installation, start-up and commissioning
6) System design documentation
7) Operation and maintenance manuals

All control valve(s) are located external to the air flow. Each tube is connected to the array such that individual tubes can be removed from the inlet house for periodic cleaning and testing.

Inlet Structure Modifications

In order to enhance the effectiveness of the external zone, weather hoods were installed to protect the fog plume.

Fig.7: New pre-filters installed to reduce water carryover to final filters.

This is proprietary to the CE&E system and assures better fog control with less dispersion in high winds, thus reducing water consumption.

The existing inlet housing has four separate inlets flowing into two separate plenums for each turbine. Each inlet was extended with eight feet of ductwork. This length was optimized in order to assure proper evaporation of the water (see Fig. 6 on page 5).

The original fiberglass prefilters at the Putnam site were replaced with washable, permanent demister/prefilters. The prefilters at Putnam were replaced 3 to 4 times a year. By replacing the "throw away" prefilters with washable, permanent assemblies, we obtain better performance during fogging and eliminate the future replacement costs for the plant (see Fig.7).

With this design configuration, no downstream mist eliminators are needed, and therefore the turbine performance is not penalized during normal "unfogged" operation with additional pressure drop.

Each of the two inlet plenums has a trash screen just upstream of the bellmouth. These original trash screens made of carbon steel welded wire were replaced with all stainless steel woven wire. The condition of the old trash screens and the future exposure to DI water made this change-out necessary.

Pump Skid

Water pressure to the pumps is regulated down from plant pressure. The supply water to the nozzle arrays is controlled and pressurized by a three pump (water transfer) skid. The pump skid includes the pumps, motors and drive packages, pressure bypass valves,appropriate suction pipe provisions, water filter, motor starter, guages, pressure transmitters, flow transmitters and thermal protection for the pump(s) and motors(s). The pump(s) discharge pressure is 3,000 psi to ensure injection uniformity and a droplet size below 20 microns. The pumps have stainless steel bodies to handle the plant demineralized water.

The location of the pump skid should be convenient. This requires evaluation of tubing runs to the arrays, water supply, availability of electrical power (480V) and control cable routing to plant tie-in point. This particular skid was mounted near the inlet plenums to minimize tubing runs to the numerous zones and to make use of close proximity power feeds (see Fig. 8 & Fig. 9). Water supply was within fifty feet of the skid with the plant PLC requiring control cable and instruments to be run approximately 150 feet.

Instrumentation and Controls

Special instruments and controls are required for measuring the ambient humidity, dewpoint and the humidity upstream of the final filters. To accomplish precise control of the system, new thermocouples with better accuracy were installed in the ductwork upstream of the bellmouth. A complex system of logic was required to step the various zones into and out of service with just several degrees in temperature change being the target. The internal zone utilizes a learning subroutine, which also stores the learned temperature impact for the particular ambient conditions. This information can be accessed to step performance on future days with similar weather conditions.

The external zone pump utilizes variable frequency drive to throttle flow to either one third of the external zone or the full zone. The throttled speed and zoning is controlled by the proximity of ambient conditions to 80% RH.

PERFORMANCE

The goal of the performance test was to verify that the installed system is capable of humidifying the inlet air to 95% and 99% for the base load and peak load, respectively. Another requirement of a maximum pressure drop of 0.25 in. of water column was verified earlier and not included as part of this test on the basis that initial plant instrumentation showed no noticeable increase in the airside pressure drop after installation of the cooling system and new trash screen.

Humidistats are not reliable in the high velocity zones where they have an accuracy of ±3%. Placement of the humidistats in the high velocity region would require periodic replacement because of excessive wear. Therefore, temperature measurements at the compressor inlet was used to verify the humidity of air after spraying. In the test operating range, 95% humidity corresponds to a dry bulb temperature of 1°F higher than the wet bulb temperature, and 99% humidity corresponds to a dry bulb temperature nearly the same as the wet bulb temperature.

The performance test was conducted on the afternoon of August 25, 1998. During the test, the ambient dry bulb temperature varied from 91°F to 95°F with a steady wet bulb temperature of 79°F. This approximately corresponds to a relative humidity in the range of 50% to 60%. For the base load case, the inlet air temperature was brought down to within 1{ F of the wet bulb temperature and for the peak load, the inlet air temperature was brought down to about the same as the wet bulb temperature.

The performance guarantees were met with the 2/3rd external zone still off, demonstrating sufficient excess capacity to provide additional cooling on hot, arid days, when the ambient humidity is lower than the design conditions.

CONCLUSIONS

Direct water spray is an effective and economical means of cooling inlet air of combustion turbines. The successful implementation of a direct spray system for a Westinghouse W 501 B5 is discussed in detail. Multiple zones are employed to control and produce efficient evaporation of the fog droplets while operating near or below the saturation point for the air. Evaporative efficiency of near 100% is obtainable. By accomplishing a portion of the humidification outside the plenum at the lower capture velocity of the inlet housings, the need to spray a larger quantity of water into the high velocity of the plenum is eliminated. Thus, absorption is maximized and final spray flow in the high velocity area is minimized, resulting in a more efficient evaporation process and corresponding reduction in inlet air temperature.

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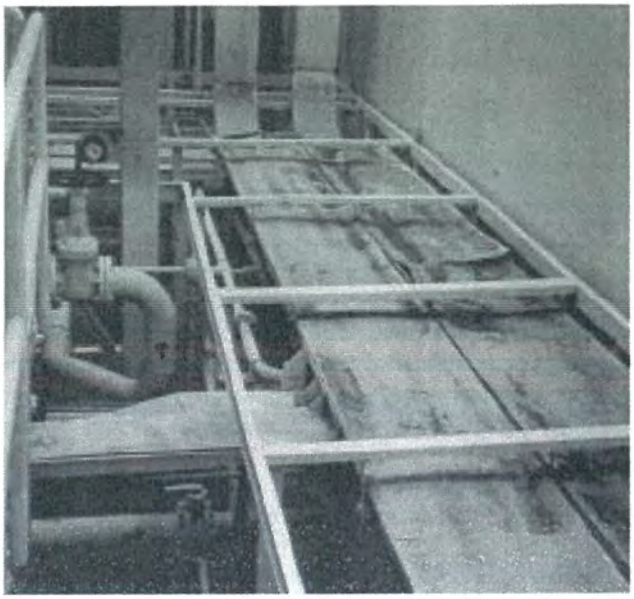

Fig.8: Space available for pump skid.

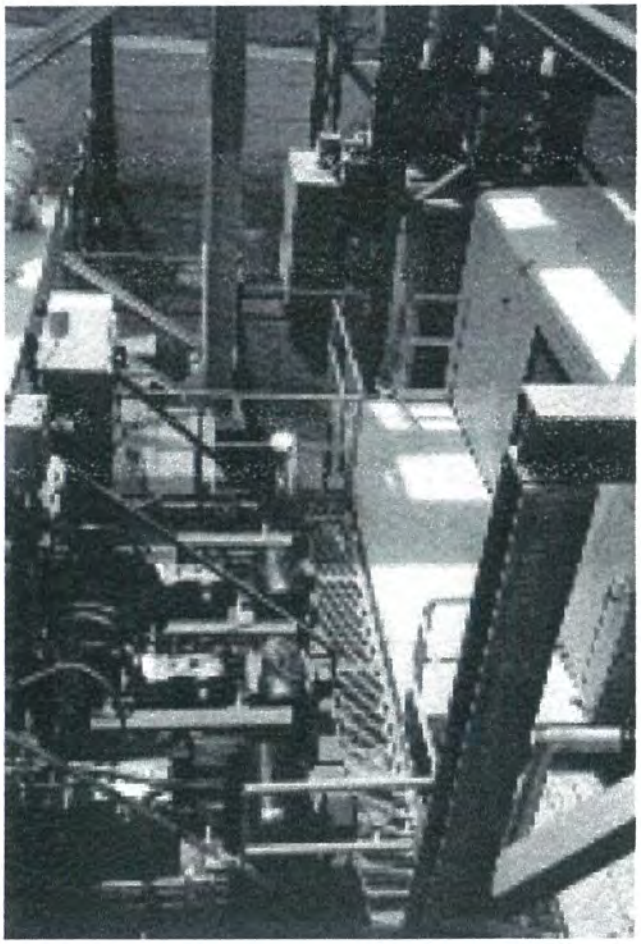

Fig.9: Pump skid for external, internal and overspray zones.

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