Validation of Patented Wet Compression Technology

Caldwell Energy Completes 1 Year Commercial Operation
for General Electric and Alstom Combustion Turbines

Combustion turbine inlet air-cooling has become fairly common for increasing the output of CT's during hot ambient conditions. This includes chilling, evaporative cooling with media and evaporative cooling with fog. To take the concept of evaporative cooling a step further, spraying water into the compressor of the CT is a viable and now proven technology for increasing turbine power output by up to 25%. This method of power augmentation is referred to as wet compression, overspray, super saturation, high fogging and many other names, however they all are all encompassed by the wet compression patents that involve systematic spraying of water into the compressor in order to intercool the compression stages, enhancing the efficiency and output of the machine. The systems can be used in high humidity environments such as downstream of evaporative cooling or chilling systems.

The methods and apparatus for the proper application of wet compression technology are patented by The Dow Chemical Company, of Midland, Michigan. Dow has developed, tested and successfully applied this technology to several of its combustion turbines. Caldwell Energy, of Louisville, Kentucky, is a licensee of this technology, as well as Siemens Westinghouse Power Corporation.

Wet compression is much more than spraying water into the turbine. Wet compression on a combustion turbine must be applied systematically and only after a thorough evaluation of the effects on the combustion turbine and all the auxiliaries. The improper design and application of wet compression can cause significant damage to the combustion turbine. The licensees of this technology share in a broad base of know-how and proof testing acquired over the past 10 years relative to the application.

Siemens Westinghouse has applied this power augmentation technology to almost 30 combustion turbines, including the W501 A, W501 D5, 501 D5A, V84.2 and the V84.3A2. They have recently released this for some F-Class combustion turbines. Caldwell Energy has recently developed and supplied wet compression systems and completed one-year commercial operation testing for Alstom and General Electric combustion turbines.

The particular models tested are the Alstom GT24 and GT26 machines and the GE Frame 6B machine. These applications have undergone inspections to evaluate the effects of wet compression operation. The results are summarized herein and prove that the proper application of wet compression is a safe technology with the most upside for power enhancement and improved efficiency for combustion turbines.

Summary Results

	GE Frame 6B	**Alstom GT24** (Single Shaft Combined Cycle)
Site Location	Stanford, California	Hermosillo, Mexico
Installation Date	March 2002	March 2002
Water Injection (% air)	1%	1.2%
Total Wet Run Hours (est.)	1200	3500
Power Output (dry) - MW	35.2	241.1
Power Output (wet) – MW	38.7	254.4
Incremental Power Output - MW	3.5 (10%)	13.3 (6%)
Incremental Gain w/ Evaporative Cooling – MW	5 (15%)	22 (9%)

Water Staging Valves – GT24

Nozzles Rack Installation – GT24

Detailed Inspection

Both the GT24 and the Frame 6B have been thoroughly evaluated after one year of wet compression and both have been returned to service for full power augmentation. In March 2003, Caldwell Energy performed a thorough investigation of the Frame 6B combustion turbine. The inspection was performed in conjunction with a planned combustion system maintenance outage. This outage occurred one year after installation of fogging and wet compression systems. Each of these power augmentation systems was operated for more than 1,100 hours during the past year. The combustion turbine has accumulated more than 124,500 total hours of operation since it was commissioned.

During this outage Caldwell Energy was provided the opportunity to perform a borescope inspection of the compressor to evaluate compressor blade erosion, visually inspect combustion system hardware for signs of increased wear at contact surfaces and to perform general maintenance and inspection of the PowerFog and CWCT systems. Details of the inspection, including borescope images from the compressor inspection are summarized in this report, further details can be provided upon request.
The result of the inspection is a recommendation to continue operation of these power augmentation systems.

"Recommendation to continue use of Fogging and Wet Compression systems for Power Augmentation exceeding 15%".

Installation Description - 2002

The GE Frame 6B Combustion turbine was retrofit with CE&E PowerFog and CWCT systems during a one-week outage in March 2002. The retrofit of these systems included a redesign of the inlet air filtration systems that included the removal and replacement of inertial separators and media based evaporative cooling system with new pleated inlet air filter elements and fogging system. The resulting inlet system modifications reduced inlet pressure losses by over two (2) inches of water resulting in a permanent improvement in power plant performance and efficiency.

The fog nozzles were installed in the inlet filter house, downstream of the inlet filters and upstream of the inlet silencing panels. Water is introduced to the inlet air stream in the form of finely atomized water droplets through arrays of pressure atomizing nozzles. Because the silencing panels were fabricated from galvanized steel, the leading edges of the silencing panels were covered with stainless steel to protect them from coming in contact with demineralized water, which would further corrode them and result in rust or zinc being carried downstream into the compressor.

Downstream of the silencing panels the inlet duct takes a ninety-degree turn downward toward the compressor inlet. It is just downstream of this elbow where an array of spray nozzles (See Figures 1 and 2) were installed, which are specifically designed for this high velocity airflow rate and proximity to the compressor inlet. The inlet duct surfaces downstream of the CWCT nozzles were lined with stainless steel to prevent any negative affects of the demineralized water contacting the existing galvanized, perforated plate in the compressor manifold.

Wet compression systems spray controlled amounts of water into the inlet air of the compressor for the intentional purpose of augmenting power output. The performance gain associated with this system is much more consistent than fogging systems where the performance gain is more dependent on ambient weather conditions. Wet compression systems are compatible and complimentary with chilling and fogging systems.

Figure 1 - CWCT Nozzle Arrays

Figure 2 - CWCT Nozzle

Another benefit of combining the fogging and wet compression systems is that the control temperature algorithms in the PowerFog control system can be adjusted to keep a greater separation between compressor inlet temperature and ambient wet bulb temperature than is frequently used with fogging systems to help minimize the deterioration of the galvanized silencing panels from being wetted with demineralized water. The combined installation of PowerFog and CWCT systems allows this to be done without a significant performance penalty since the water spray from the CWCT system will fully saturate the inlet air. This combination thereby helps prevent compressor performance degradation associated with fouling from these potential sources.

Site Inspection - 2003

The site inspection of the combustion turbine began with a review of the inlet air system. The silencing section of the inlet duct did not appear to have been affected by the use of the PowerFog system, as there were no new signs of corrosion or panel deterioration. Moving further into the inlet duct, the wet compression nozzle arrays and stainless steel liner that were added as part of the retrofit were verified to be in good condition.

Prior experience with wet compression systems that have operated on other large frame industrial combustion turbines has shown that most erosion occurs on the leading edge of the row 1 compressor blade producing a slight change in chord length (approximately 1mm) over 24,000 hours of wet compression system operation. However, this wear was not extensive enough to require blade replacement at that interval. Stationary compressor vanes are expected to see some loss of coatings and roughening of the surfaces that are wetted, but have not shown a change in chord length. Downstream stages of rotating compressor blades will also show signs of erosion in the tip region over time, as the water droplets are centrifugally forced outward. This continues until the water is fully evaporated around the 5th or 6th compressor stage.

Visual observations of the inlet guide vanes on the Cardinal Cogen compressor did not reveal signs of wear. Some erosion of the leading edge of the row 1 compressor blade could be seen. A borescope evaluation of the compressor was performed to more closely evaluate the condition of the row 1 compressor blade and downstream stages.

A digital image of the row 1 compressor blade as taken with the borescope equipment is provided below in Figures 3-5. These images show that some blade erosion is present, but manageable. A benchmark borescope examination of the compressor was not taken prior to the system operation to evaluate the exact change from wet compression (it was noted that there was prior water carryover from the media based evaporative cooling system).

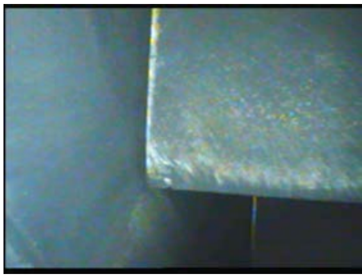 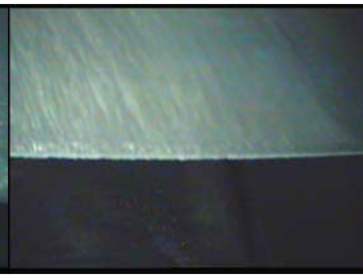 

Figure 3 - Blade Tip   Figure 4 - Mid-Span   Figure 5 - Hub

Leading Edge of Row 1 Compressor Blade

Proceeding further back into the compressor with the borescope examination, the compressor exhibited similar wear patterns as experienced with other combustion turbines that have been equipped with wet compression. Specifically, that the observed erosion was primarily on the leading edge of the row 1 compressor blade and that vane segments and downstream stages were not as affected by the system operation. The front stages of the compressor were cleaned by wet compression while the middle stages of the compressor were not. Access to the back end of the compressor through the 17th borescope access hole showed this region of the compressor to be in good condition also.

Combustion system hardware was also visually inspected to look for signs of increased wear as a result of combustion system dynamic pressures. During the commissioning of the CWCT system, the dynamic pressure of the General Electric DLN 1.0 combustion system were measured by Caldwell Energy in a dry condition, with CWCT operation, and with CWCT system and steam augmentation systems in service. Both of these augmentation systems increased the dynamic pressure oscillations of the combustion system. Wear marks were observed on the fuel nozzle interface to the liners and. localized thinning on some of the inner seal rails of the transition piece exit mouth was observed. Overall, the combustion system components were in good condition and were not reported to be significantly different from the hardware conditions noted during combustion system inspections performed before the CE&E systems were retrofit. These components did not have the GE Extender Package modifications.

Caldwell Energy engineers completed the inspection work with a thorough checkout of the PowerFog and CWCT systems, verifying the performance of the spray nozzles since the performance of these components are important to the performance and reliability of the systems and combustion turbine.

The combustion turbine inspection results showed that the compressor and combustion system were in good condition and that fogging and wet compression system operation can resume. Following these checks and completion of the planned combustion system maintenance work, the systems and engine were returned to service with full augmentation capabilities (>15%) from the CE&E PowerFog and CWCT systems.

For further details on the inspection results and benefits of these power augmentation systems to your turbines, please contact Caldwell Energy, 4020 Tower Road, Louisville, Kentucky, 40219 (502) 964-6450.