

**IMPACT OF HEAT RATE, EMISSIONS, AND
RELIABILITY FROM THE APPLICATION OF
WET COMPRESSION ON COMBUSTION TURBINES**

Presented at Power-Gen International

Las Vegas, Nevada

2005



CALDWELL ENERGY COMPANY

4020 Tower Road
Louisville, KY 40219
(502) 964-6450
(502) 964-7444 (fax)
www.caldwellenergy.com

IMPACT OF HEAT RATE, EMISSIONS AND RELIABILITY FROM THE APPLICATION OF WET COMPRESSION ON COMBUSTION TURBINES

by

Donald W. Shepherd
Caldwell Energy Company
Louisville, Kentucky

Donald Fraser
Siemens Westinghouse
Orlando, Florida

ABSTRACT:

Wet compression technology has been successfully installed on over 40 combustion turbines around the world. Wet compression systems have been justified due to the significant power gains achieved. What has not been discussed is the impact this technology has on the efficiency (heat rate), emissions and reliability of the combustion turbine.

One significant advantage of wet compression systems over other turbine inlet cooling power augmentation technologies is that gains are not restricted by ambient conditions. As a result, the megawatt-hours during the year are much higher than with any other technology, resulting in quicker payback and maximum net present value. Another benefit is that the application of wet compression is complementary to other turbine inlet cooling technologies like evaporative cooling, fogging or chilling. There are also benefits relating to heat rate, emissions and reliability for a properly designed and installed system.

This paper presents computational and field data that illustrates that there is more to gain than merely addition power output. Experience will be drawn from all types of combustion turbines: aeroderivative, mature and advanced. The information will be presented in a format that will accurately depict all the benefits of wet compression technology allowing users to fully understand these benefits.

INTRODUCTION

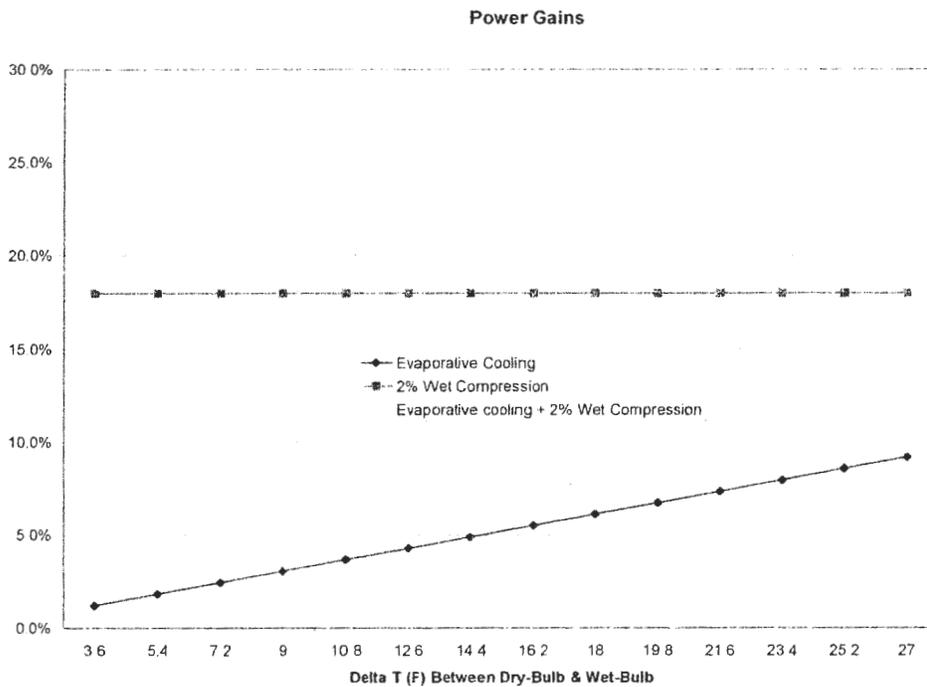
As air is compressed in the compressor of a combustion turbine it is heated due to the work of compression which increases its ability to absorb moisture. Wet compression is the process in which excessive amount of water in the form of fine droplets is intentionally sprayed into the compressor inlet, which evaporates within the blade path to provide thermodynamic inter-cooling affect. The resulting adiabatic process causes the air temperature to drop. Since it takes less energy to compress relatively cooler air, there is savings in compressor work. Any reduction in compressor work translates to increase in net turbine output because one-half to two-thirds of turbine output is typically used to drive the compressor. Additionally, the water sprayed in the inlet duct cools the air to wet bulb temperature prior to entering the compressor. This paper focuses on the benefits of the wet compression in the compressor section of the turbine.

Early experimentation with the continuous injection of large volumes of water into a compressor inlet, now referred to as Wet Compression (aka High Fogging, Overspray, super-saturation, inter-cooling, Inlet Fog Boost and Continuous Water Washing) began in the early 1990's. Being pioneers in the use of on-line compressor water wash systems, the Dow Chemical Company Employees began a program to determine how much water could be injected into the inlet of a W501A combustion turbine, a 1968 vintage turbine rated at 40 MW. Working together with engineers from Westinghouse Electric Corporation, an astounding increase in base load power output of 25% was achieved. The Dow Chemical Company was awarded Patents for this work and wet compression technology. Since that first system was designed and installed, there have been many design enhancements to the injection system, spray atomization nozzles, system controls, rotor grounding devices, and turbine hardware to reliably apply wet compression systems to combustion turbines. System and spray technologies applied to the wet compression process continue to be improved.

Since this early application of Wet Compression and the experience gained from it, Wet Compression has been successfully applied to more than 40 units. These units include; GE Frame 6B, LM2500PE, Alstom GT-24, Alstom GT-26, Siemens Power Generation W501D5, W501D5A, W501FC, V84.2. While there are concerns with the application of wet compression, if applied correctly it has been shown to reduce NOx, improve heat rate, and is a reliable source of additional power regardless of ambient conditions.

Ambient Effects Combustion Turbines

Power gains from all inlet cooling technologies are limited by ambient conditions, thus limiting the amount of reliable power gain. Evaporative cooling systems must have a temperature difference between the dry-bulb and wet-bulb temperatures in order for power gains to be achieved. Chiller based systems are typically designed to ASHRAE 1% or 2% conditions, thus the system becomes limited when it is warmer or more humid than the design point. With Wet Compression, gains are not limited due to increased ambient conditions. Graph 1 below depicts typical percent power gains for combustion turbines, with evaporative cooling, with wet compression, and with wet compression and evaporative cooling.

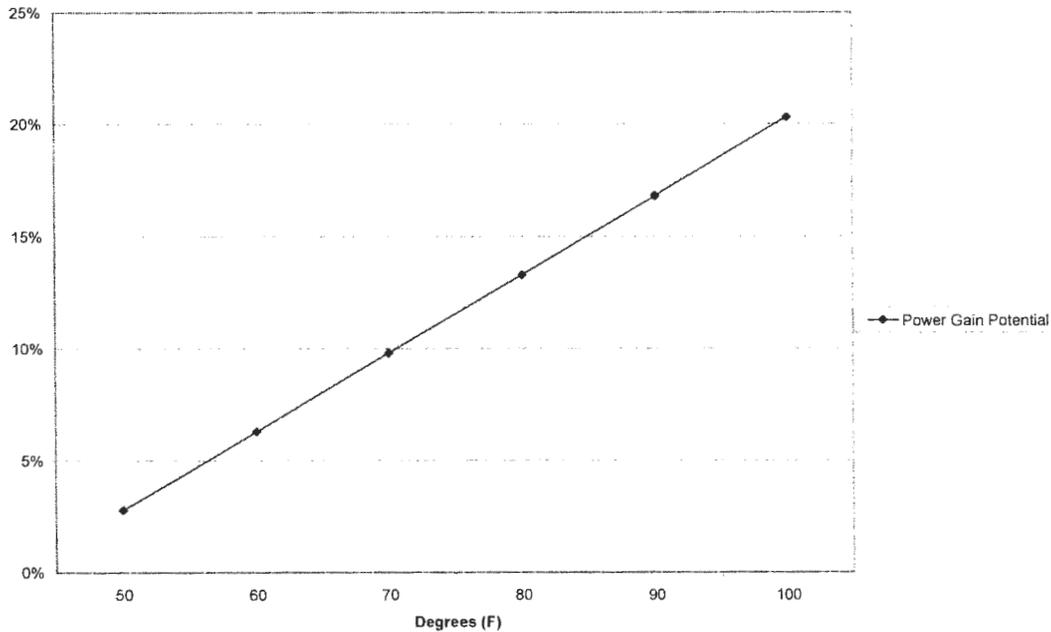


Graph 1.

From Graph 1 it can be seen that wet compression gives a constant increase in power regardless of the ambient conditions, thus a very reliable increase in capacity. Note that wet compression is typically not utilized in temperatures below 45F. The reason for limiting the system to operating above these temperatures is due to increased blade loading on the rear compressor blades.

With a chiller system the power gain is limited by the difference between the ambient temperature and the minimum inlet temperature set by the manufacturer, usually set at 42°F or higher. Graph 2, depicts how the potential power gain decreases as ambient temperatures decrease.

Power Augmentation Potential



As ambient temperatures increase the heat rate for combustion turbines increase (degrade). For a typical combustion turbine for each degree in Fahrenheit increase in temperature the heat rate degrades by approximately 0.1%. Even without the current increase in fuel cost, improvements in heat rate are an important aspect of power plant operation, as fuel costs increase they become even more important.

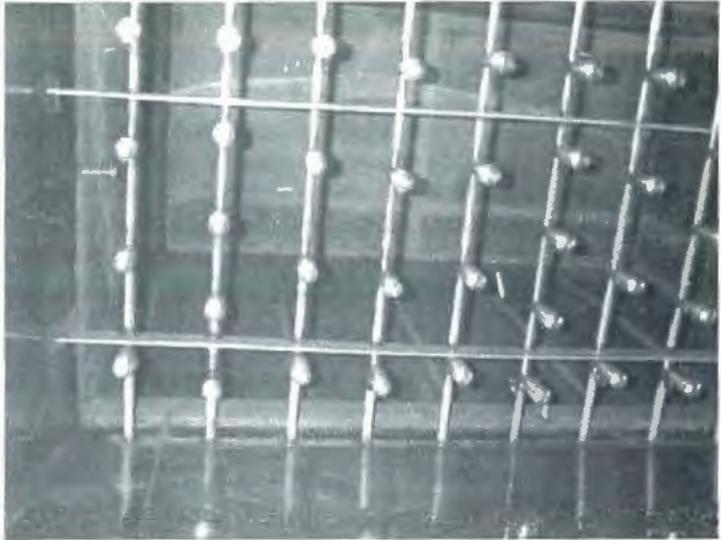
The data in Table 1 are actual results from testing of wet compression systems installed on the various units. This data clearly shows that in addition to the power gain, the heat rate for the CT was reduced for these units, by up to 2%.

Combustion Turbine	Siemens W501FC	Siemens V84.2	GE LM2500PE	GE Frame 6B	SWPC W501D5A	Alstom GT-24
Overspray, %	1.3	1.0	2	1	2	1.2
Compressor Discharge Temperature Reduction, °F	90	50	Data not available	50	100	48
Fuel Flow Increase, %	N.D.	N.D.	4	8.2	13.2	5.5
Change in Base Load Firing Temperature, °F	No Change	No Change	No Change	No Change	No Change	No Change
CT Power Increase, MW	17	5.2	1.6	3.3	15	11.5
Steam Turbine Power Increase, MW	Simple Cycle	Simple Cycle	-5	0.3 (est.)	2 (est.)	1.8(est.)
CT Heat Rate Improvement, %	N.D.	2	0	1	2	2
NOx Info	10%	N.D.	-14%	DLN	DLN	No Change

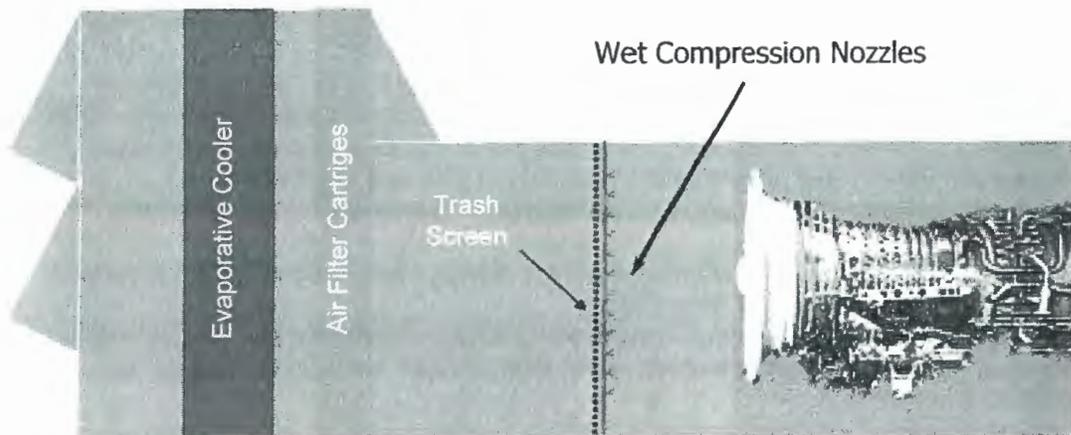
The combustion turbine models listed in Table 1, have in excess of 30,000 hours of operating experience. The V84.2 removed water from the water injection into the combustors for power augmentation; it was changed from a 1.5 to .5 ratio.



GT-24 Blades after 7000 hours



Arrays install in 6B



Location of Wet Compression Arrays on LM2500

Effects on Emissions

With the application of wet compression it has been shown that NO_x emissions are reduced on a per kW basis for conventional combustors. The amount of reduction is approximately half of what is seen for same amount of water injection in the combustor for NO_x control. However this reduction in NO_x comes without the heat rate increase associated with water injection. For the LM2500 the amount of ammonia being used in the SCR was reduced by 14% after the application of the wet compression system. For steam and water injected combustion systems, there is a decrease in the amount of mass required for NO_x control.

Conclusions

Wet compression technology is a turbine inlet cooling and compressor intercooling system that has been successfully demonstrated on aeroderivative, mature and advanced combustion turbines. This technology has shown that with proper application it is the most reliable means of power augmentation that reduces NO_x emissions, and improves heat rate and is not ambient temperature dependent like other turbine inlet cooling technologies. The application of wet compression systems should address the risks associated with spraying water into a CT compressor inlet. The primary components of such risk included: (i) water distribution, (ii) degradation of compressor inlet duct materials and fouling of the compressor, (iii) compressor casing distortion, (iv) Combustion dynamic pressure, and (v) control system integration.

REFERENCES:

1. M. R. Sexton, H. B. Urbach and D. T. Knauss, "Evaporative Compressor Cooling for NO_x Suppression and Enhanced Engine Performance for Naval Gas Turbine Propulsion Plants", Presented at the International Gas Turbine & Aeroengine Congress & Exhibition, Stockholm, Sweden, June 2-5, 1998.
2. B. Rising, S. Cloyd, et. al., "Wet Compression for Gas Turbines: Power Augmentation and Efficiency Upgrade", Presented at the Power-Gen International, Orlando, FL, November 1999.
3. S. Jolly, J. Nitzken and D. Shepherd, "Evaluation of Combustion Turbine Inlet Air Cooling Systems", Presented at the Power-Gen Asia, New Delhi, India, September 29-October 1, 1998.
4. R. Schick, K. Knasiak, "Spray Characterization for Wet Compression Gas Cooling Applications", Presented at the Eighth International Conference on Liquid Atomization and Spray Systems, Pasadena, CA, July 2000.
5. S. Jolly, "Wet Compression – A Powerful Means of Enhancing Combustion Turbine Capacity", Presented at Power-Gen International, Orlando, FL, December 10-12, 2002.
6. S. Jolly and S. Cloyd, "Performance Enhancement of GT 24 with Wet Compression", Presented at Power-Gen International, Dec. 9-11, 2003, Las Vegas, NV.
7. J. Kraft, "Evaporative Cooling and Wet Compression Technologies", Energy-Tech, February 2004.
8. M. Mercer, "Wet Compression Technologies for Combustion Turbines", Diesel and Gas Turbine Worldwide, pp. 27-29, May 2004.
9. W. R. Sexton and M. R. Sexton, "The Effects of Wet Compression on Gas Turbine Engine Operating Performance", Proceedings of the ASME Turbo Expo 2003, Atlanta, GA, June 16-19, 2003.
10. S. Jolly and James Hinrichs, "Application of Wet Compression for Aeroderivative Combustion Turbines" Presented at Power-Gen International, Orlando, FL December 6-8 2004.