BENEFITS OF COMBUSTION TURBINE INLET AIR COOLING, THEIR PROPERTIES AND POSSIBILITIES OF APPLICATION IN EXISTING PLANTS

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ABSTRACT:

Increasing the combustion turbine inlet airflow rate is a common modification to increase the power and net efficiency of power-generating equipment, including automotive engines with inlet air compressors (turbos) and power-producing combustion turbines with supercharging or inlet air cooling. There are many designs available for combustion turbine inlet air cooling. This paper is intended to provide some of the information that needs to be considered in applying technologies to combustion turbine inlet air cooling (CTIAC) systems.

SHORT SUMMARY:

Cooling the combustion air in turbine-generator systems is a widely used method undisputable in its capacity of increasing total energy generation and the overall efficiency of the system.

Many turbine/generator systems have been installed at the onset without CTIAC (combustion turbine inlet air cooling) systems in order to lower the cost of installation and due to the fact that capacities seemed adequate for conditions of the day.

By virtue of cooling the inlet air without the investment for a new unit in parallel with the evolving additional production demand, the energy generation capacity of the system can be increased by 10-26 %.

In applications made at a later date, it is possible to apply a combination of direct cooling with refrigerant or a chiller package with a cooling coil with secondary coolant.

When systems where energy is stored as ice/water is used in combination with another cooling coil, they offer significant advantages in terms of providing compensation in the system.

FRITERM has been manufacturing the cooling coils of this package as part of a complete package including the air filter and drop eliminator since 2001. This provides the manufacturer with great advantages both in economy and in measurement, project development and manufacturing appropriate for the location due to application on an existing system.

How and to what extent does capacity increase with (CTIAC) COMBUSTION TURBINE INLET AIR COOLING?

Almost all turbine-generator systems have constant volumetric flow. Thus the increase in density of the cooling air will lead to an increase in weight of the charge air of the system, which in turn leads to an increase in energy generation capacity of the turbine-generator system.

Significant capacity losses are observed in the turbine-generator system, particularly in summer months. Even accounting for all additional parasitic loads used for cooling the inlet air, inlet air cooling increases the generated energy and lowers the heat.

Although the energy generation capacity increases almost linearly with dropping inlet air temperature, design should ensure that the air temperature will not drop below approximately 5-6 °C to avoid the risk of icing.

The variation curve of the combustion turbine capacity and heat generation as a function of air inlet temperature has been given in Figure 1. Energy capacity measurement figures versus air inlet temperature for a GE Frame 7B combustion turbine installed in Lincoln, Nebraska have been given in Figure 2.

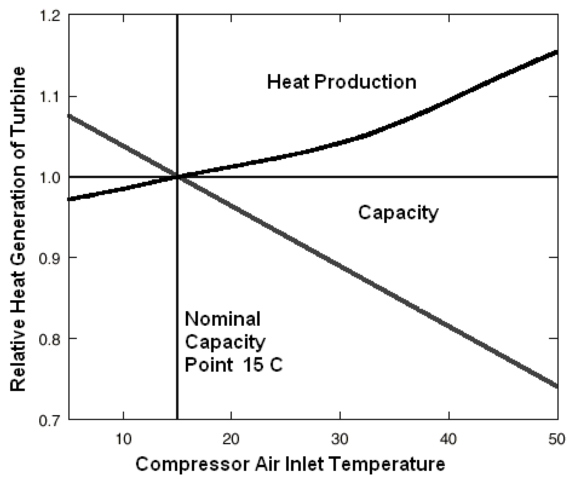

FIGURE 1: Combustion turbine capacity and ratio of heat generation versus air inlet temperature

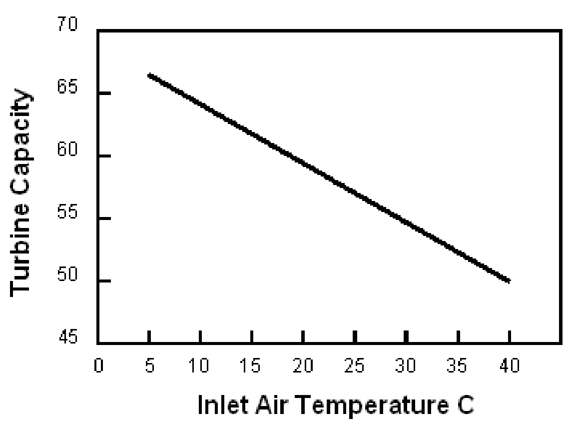

FIGURE 2: Effect of Air Inlet Temperature on Capacity for the 7B Combustion Turbine, *NEBRASKA*

The gas turbine capacities have been given for the 15°C temperature, 60% relative humidity and sea level as specified by ISO. Rectification factors for capacities under other conditions must be obtained from the manufacturing firm. However, the following factors may me used for a general approach.

- Each 10°C rise in air inlet temperature causes a power loss of 8%.
- Each 300 m rise in elevation reduces power output by 3.5%.
- Each 1 kpa additional pressure loss in the filter, silencer and channels during entry, reduces power output by 2%.
- Each 1 kpa additional pressure loss in the boiler, silencer and channels during exit, reduces power output by 1.2%.

Figure 3 shows a typical performance curve for a 7.5 MW turbine engine. Here, the efficiency of the turbine at various speeds can be seen as a function of air temperature.

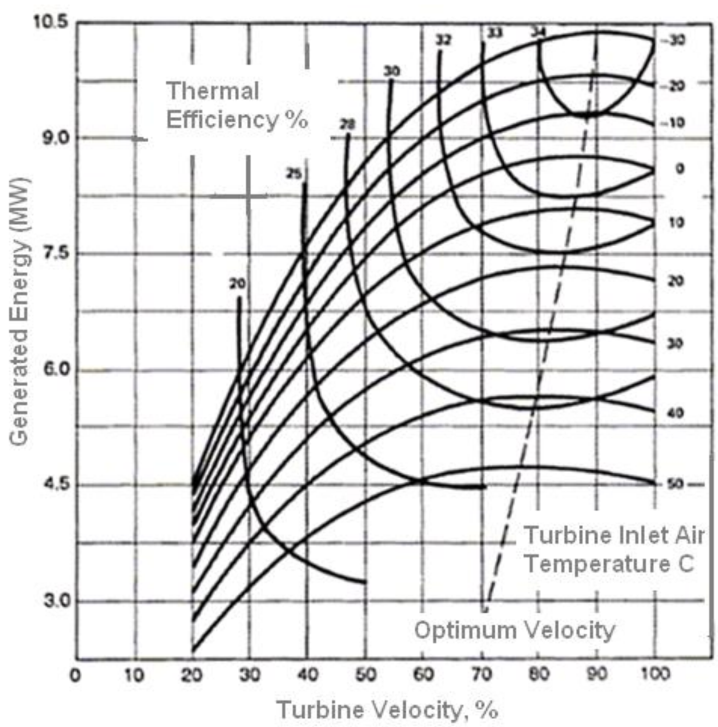

Figure 3: Performance Characteristics Depending on Combustion Turbine Inlet Air Temperature

ADVANTAGES OF THE CTIAC SYSTEM:

Increase in capacity: The quantity of inlet air in new turbines is lower as compared to older ones. Consequently, the lower capacity is calculated for the energy and cooling group required for cooling. Thus, inlet air cooling is more appealing in new turbines than it is for older ones.

Offers fuel economy: Although the system uses more inlet air and fuel, the increase in efficiency lowers the quantity of fuel per unit of energy.

Extends the life of the combustion turbine: Turbines operating at lower inlet air temperatures have extended life and reduced maintenance. Lower and constant inlet air temperature reduce the wear on turbines and turbine components.

Increased Combined-Cycle Efficiency. Lower inlet air temperatures essentially result in lower exhaust gas temperatures. This decreases the capacity of the (HRSG) heat recovery steam generator. However, the greater airflow rate also increases exhaust mass flow rate, which is more than enough to make up for the capacity lost because of the drop in temperature.

Delayed Capacity Addition: The increase in capacity enables new investments to be delayed.

Increase in Baseload Efficiency of the System: Increases the total efficiency of the system by storing energy using electric chiller equipment during off-peak periods. Also, electric chillers operated during the night are more efficient due to reduced condenser temperatures.
When maximum power and heat generation is desired on a continuous basis, continuously operating systems must be used in stead of systems that store energy.

Eliminates the need for spraying water/steam: Water/steam spraying applications are used to increase mass flow and decrease NOx emission of the turbines. However, in some cases spraying steam reduces turbine capacity or increases CO emission. Low inlet air temperature achieved through the CTIAC application cuts NOx emissions by reducing combustion air temperature, thus eliminating the need for spraying water/steam for NOx control. CTIAC also eliminates the need for various capacity increase actions leading to increased Co emission. Its control is also straightforward and saves the operator from having to use complicated control systems.

Other benefits of the system include:

The evaporative media also filter the inlet air
Cooling coils condense a significant amount of water, which is a valuable source of makeup water for cooling towers or evaporative condensers
It is a simple system, and can be used solely when needed
Emissions decrease due to increased overall efficiency
The air inlet temperature can be matched to the required turbine capacity. In this way, 100% open inlet guiding wing eliminate inlet guiding wing pressure loss penalties

Disadvantages:

They require additional space and increase maintenance.
Cooling coils or evaporative media placed on inlet air, pose a constant pressure loss.

FACTORS THAT NEED TO BE CONSIDERED WHILE DECIDING TO INSTALL A CTIAC SYSTEM:

Turbine type: Industrial single shaft, aeroderivative
Climate conditions of the region
Ratio of air flow to the energy output
The ratio of the increase in energy output to be gained from decreased temperature
The method used in cooling air
Pressure loss resulting from cooling coils or evaporative media
The control system
The availability and cost of fuel
Repair and maintenance costs
The need for pumping

Energy storage type and charge/discharge strategy
Sales value of the generated electrical power
The cost of the generated electrical power

Tables 1 and 2 can be used to provide a general outline on the benefits and cost of the system.

TABLE 1: Ratio of the New System Manufacture Cost to that Achieved with Inlet Air Cooling

THE SYSTEM	Relative Cost
Simple Circuit CT	200 %
Combined Circuit CT	275 %
Pulverized Coal	700 %
Fluidized Bed Coal	800 %

TABLE 2: The Relative Cost of Required Cooling Equipment and Power Expenditure for Each Ton of Cooling

	Relative Cost	Power
Evaporative Cooling	1	0.1 kW/ton
LiBr Single Effect	8	18 lb*/h/ton , 103.4 kPa steam.
LiBr Double Effect	10	12 lb/h/ton , 758.4 kPa steam.
Absorption Ammoniac	30	18 lb/h/ton, 103,4 kPa – 344.7 kPa steam
Mechanical Chiller with Ammonia	9.5	0.6 kW/ton
Centrifuge Chiller	8	0.7 kW/ton

*0.454 kg/lb

INLET AIR COOLING METHODS AND FACTORS EFFECTING SYSTEM SELECTION

Beside the cooling application, the water/steam spray application can also be done in conditions of low relative humidity.

Three main methods of cooling are applied.

- Evaporative cooling
- Direct refrigerant cooling
- Secondary refrigerant (cold water-ice/brine) cooling

    1. Energy storage system
    2. Systems fed directly from the chiller group

For basic system selection, primarily the working hours of the turbine should be considered.

If the turbine is energized only as a redundant unit as it were, for limited periods of peak demand, evaporative cooling and energy storage systems should be preferred. In this case, there will not be parasitic loss during the operation of the turbine other than pumping losses.

However, if the system is operated for a significant amount of time as a basic unit, a continuous and energy storage system should be carefully evaluated with respect to physical conditions.

Evaporative cooling:

This is a system that is considered first due to low installation and operation costs. However, ideal evaporative cooling occurs at wet-bulb temperature, and in practice the wet-bulb temperature can be approached by up to 85-95% of the temperature differential between the Dry-Bulb and Wet-Bulb Temperatures. This limits the benefit gained from the system. This system can also be used with the Secondary Fluid Cooling system. In this case, the sensable heat should initially be removed with the cooling coil, and evaporative cooling should be applied subsequently. In this way, the minimum temperature can be reached without removing the latent heat with the cooling coil. In cooling coil or DX cooling, the quantity of moisture in the air remains fixed until the dew-point temperature is reached. As cooling continues, condensation begins and the air approaches 100% humidity.

DX Cooling:

Refrigerant circulates directly within air cooling coils. An absorption or steam compression cycle can be used. This system must be capable of accommodating the peak capacity. There is risk of leakage etc. due to the fact that refrigerant circulates directly within the cooling coil and the installation between the group and the coil; so this system is not popular.

Secondary fluid (Cold water-ice/brine) cooling:

A secondary fluid system can be installed in conjunction with an energy storage system (ice or cold water/brine storage) or as a stand alone cooling coil combination that is fed by the chiller.

This system used the pumping energy as an addition as opposed to the direct refrigerant system. However, the fact that the tubing of direct refrigerant tubing is scarce, that it is limited to the modular cooling unit and that water or brine circulates within the tube circuits of the system rather than primary refrigerant, it has relatively low sensitivity to leaks and is easy to maintain and operate. Due to all these reasons, cold water/brine systems are predominantly preferred in systems operating for long stretches.

In case it is used in conjunction with the ice/water storage system, a lower capacity as opposed to maximum capacity is selected for the cooling unit, the stored energy is utilized in times of increased demand.

For turbines operating for short durations like a few hours per week, the energy storage system is usually preferred. Furthermore, these systems offer quite interesting advantages in cases where energy use varies with time and where prices fluctuate.

For example, less energy is used over the weekend and the value of energy drops; likewise, energy prices increase in specific times of the day when use increases.

Storing energy eliminates the need for operating the cooling group for the electrical chillers in times of peak demand and highest prices; using the stored cold energy during these periods also provides extra production. Although sales and buying evaluations for energy are not yet made in this way in our country, the signs are there and it is apparent from practices in other countries that this is the point where things will lead. Achieving efficiency and profitability in energy generation is sure to require greater sensibility.

The energy storage system can be operated by weekly, daily, etc. scenarios in terms of energy generation and consumption. A weekly operation scenario has been given in Figure 4.

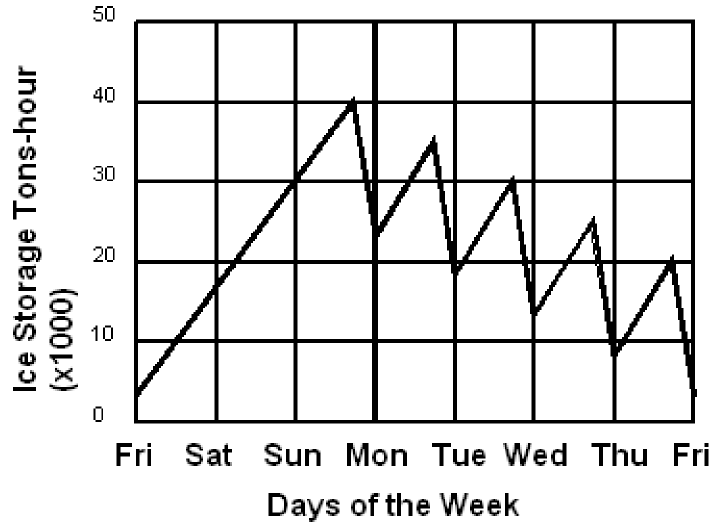

Figure 4: Week Ice Storage Scenario, the Gilroy GT Plant

Table 3 show some test results pertaining to the same plant.

TABLE 3: Some test results from the Gilroy GT Plant

<table>
<tr><td colspan="3">Combustion turbine air inlet temperature</td><td>6°C</td></tr>
<tr><td colspan="3">Cooling coil pressure loss</td><td>167 Pa</td></tr>
<tr><td colspan="3">Requirement of the ice machine during minimum production</td><td>1219.2 kW</td></tr>
<tr><td colspan="3">Requirement of the ice machine during maximum production (pumps)</td><td>323.6 kw</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Ambient Conditions</td><td>Turbine Capacity</td><td>CTIAC Turbine Capacity</td><td>% Difference</td></tr>
<tr><td>90^0F (32.2˚C), 20% RH</td><td>75.7 MW</td><td>90.5 MW</td><td>19.6</td></tr>
<tr><td>100˚F (37.8˚C), 30% RH</td><td>72.7 MW</td><td>90.5 MW</td><td>24.5</td></tr>
</table>

As opposed to all these advantages of the energy storage system, the most important drawback is the relatively high installation cost. Consequently, system selection should be made after careful deliberations for each unique application.

Below are the results of the results pertaining to another application and they offer us important data for the comparison and selection of systems.

TABLE 4: The benefit/cost table for various cooling applications for the W501AB Turbine

Relative humidity of the environment	60% RH		40% RH		10% RH	
The cooling system	%W	$/KW	%W	$/KW	%W	$/KW
Spraying water that has not been cooled	7.5	13	12.2	8	21.4	5
Evaporative media	7.6	141	11.5	88	20	52
Ice storage * (0.6 C water)	34	201	34.5	166	34.5	122
Cold water storage (5.6 C water)	30.7	196	30.9	178	31.1	158
Direct cooling	26.9	336	29	256	31.8	157

*An outdoor ambient temperature of 37.8°C has been assumed.
*The cost includes the cost of installation but not the cost of water conditioning.
*%W indicates the increase in work capacity according to ISO conditions.
*For the ice water operation, 4 hours of storage per day and 5 days of operation per week have been assumed.

ISSUSES THAT SHOULD BE CONSIDERED FOR THE SELECTION AND APPLICATION OF INLET AIR COOLING COILS:

PROPERTIES RELATED TO PERFORMANCE AND PRESSURE LOSSES

- Pressure losses should be kept at minimum, since they have a direct bearing on capacity.
- The fin spacing of the coil selected should be wide. A fin spacing below 3.2 mm is not recommended. Narrower spacing mat provide higher capacity with a more compact structure and economy in the coil, however the pressure loss it has a damaging effect which accounts for more than the economy attained with the coil. In designs, the total pressure loss of the coil and subsequent drop eliminator should not exceed 254 Pascal.
- The velocity of the air passing over the coil should be optimally 2 m/s and no more than 2.5 m/s. Low air velocity offers a significant advantage in terms of both pressure loss and the fact that droplets are not carried by air. Increased air velocity will shrink the required coil cross section through which air passes, increase heat transfer, reduce the size and price of the coil, but will cause risk of carrying droplets to the compressor. For this reason, so-called economic or miracle designs with high air velocity had best be avoided.
- For the performance figures of the cooling coil to be approved by independent laboratories and organizations will prevent unforeseen circumstances.
- The water condensing from fins of the coil must be easily able to flow to the tray below and leave the tray with a drainage pipe of appropriate diameter. Any other case may lead to unforeseen pressure losses.
- The use of glycol in the cooling coil is a necessity to prevent freezing. In seasonal use and water-side applications, it must be ensured that all of the water within the coil can be purged. For this reason, it is a common practice to use coils with vertical tubes.
- A cleanable air filter should be placed at the air entrance of the cooling coil in order to prevent blocking in a short period of time. The extraction and remounting of filters should be easily done.

- The pressure losses in the water side of the coil should be low, as in the air side. For general purposes the 100-150 Kpa range is not exceeded.
- A drop eliminator should be placed after the cooler in order to ensure droplets do not travel to the turbine.

CONSTRUCTION AND MATERIAL PROPERTIES:

- The cooling coil should be manufactured in accordance with industrial specifications.
- Modules should be easy to control and intervention in one should not require halting the entire system.
- The materials should be selected and used such that they will resist the ambient air conditions.
- Stainless steel is the main element preferred for the load bearing structure of the construction.
- Aluminum fins should have the proper coating for corrosion and UV resistance. In aggressive environments, epoxy coating and sometimes the epoxy-polyurethane coating options should be used.
- The fins should be thick and not be deformed for their entire useful life. 0.25 mm is used as almost a standard for fin thickness.
- Galvanized material should not be used for the system.
- The coil construction should be capable of bearing its own weight; in its connection to the cell 100% passage of air should be ensured and the air should not short-circuit.

CONCLUSION AND SOME UNDERLINED ISSUES:

The efficiency brought on by combustion turbine inlet air cooling is apparent beyond doubt. This offers charming advantages for turbines without prior application of CTIAC. Application is possible for all filters vertical or horizontal, by providing some additional volume. Since the application is made on the existing system, the required measurement, design and project development can be made on site. It seems prudent that the system be meticulously designed in a way that will provide the highest benefit for the producer, and that some miracle “economical” solutions be avoided.

It will be beneficial for selecting an energy storage or direct cooling system, which will provide inlet air cooling for all applied systems.

REFERENCES:

[1] Combustion Turbine inlet air cooling systems William E. Stewart, Jr. ASHRAE Publications
[2] ASHRAE HANDBOOK 2000 SYSTEMS AND EQUIPMENT

AUTHOR BIOGRAPHY

Naci ŞAHİN was born in Hekimhan, Malatya in 1958. He graduated from Mechanical Engineer Department of Istanbul Technical University in 1981. He worked in Termko Termik Cih. San. ve Tic. A.Ş. as a mechanical engineer between 1983-1985 and managed Production, Construction and Technical Service Departments in Friterm A.Ş. between 1985-1996. He has been Managing Director of Friterm A.Ş since 1996. Naci Şahin has been working actively in different industrial organizations and associations. He is the president of the University-Industry Cooperation Committee of İSKİD (Turkish Heating Refrigeration Air Conditioning Manufacturer Association). Naci Şahin has married and has two children.