EFFECT OF COMBUSTION TURBINE INLET AIR COOLING ON ENERGY EFFICIENCY

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ABSTRACT

For countries in the mild temperate zone such as Turkey, the efficiency offered by cooling turbine inlet air is beyond doubt. Increasing efficiency, maximizing production, thus reducing cost per unit is the crucial edge in today’s competitive environment. Detailed evaluation of the materials, performance and construction properties of turbine air coolers, which self-finance its installation and operation costs in the short term with the increase in efficiency they provide; shunning applications with short life terms and relatively high risks of malfunction that are not in compliance with the criteria specified in the following (article) is quite important for investors of the energy sector.

SUMMARY

Increasing efficiency and reaching maximum power output capacity with minimized expenses is a very important point in our era for energy manufacturers. 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 is no doubt that cooling inlet air provides more power output and efficiency in hot climate countries, like Turkey, than in cooler location countries. There are many designs such as wetted media, fogging, ovespraying/wet compression, mechanical chiller systems, absorption cooling systems, etc. available for combustion turbine inlet air cooling. This paper is intended to provide detailed information on economic benefits and comparison of different type Combustion Turbine Inlet Air Cooling system and material specifications, design criteria, performance and constructive features of Combustion Turbine Inlet Air Cooling Units using cooling coils.

1. INTRODUCTION

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 combustion turbine 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% with the deduction of the parasitic load in the system particularly in summer months.

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

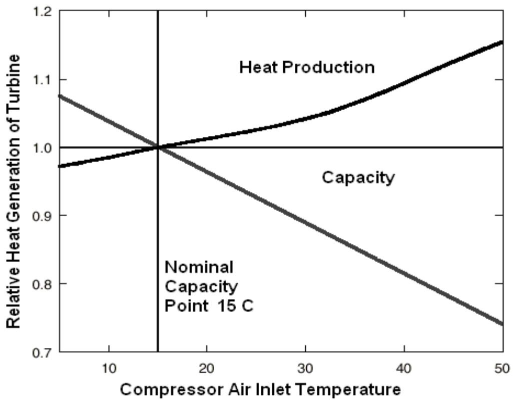
When systems where energy is stored as ice/water is used in combination with another cooling coil, they offer significant advantages in terms of providing compensation in the system.

Toward meeting the demands of the energy sector, FRITERM A.Ş. has been manufacturing the cooling coils of the combustion turbine inlet air cooling system as part of a complete package including the air filter and drop eliminator since 2001. The Cooling Coils are high efficiency exchangers designed with the EUROVENT accredited “FRİTERM COILS 5.5 FRT1” specialized software and testes at international laboratories. Offering cooling units in the form of complete packages, 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 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.

For a typical gas combustion turbine, an increase in inlet air from 15°C to 38° causes the capacity determined in the standard to drop to 73%. This drop may cause power producers to miss the chance to supply the increasing power demand appearing on days when temperatures increase as well as the need for cooling devices-units, and consequently the chance to increase their sales. From a contrary standpoint, cooling the inlet air from 38 °C to 15 °C prevents the 27% loss in standard capacity. If the inlet air is cooled to 6°C, the power generation capacity of the gas combustion turbine will rise to 110% of itself, consequently if the inlet air is cooled from 38°C to 6°C the power yield of the gas combustion turbine will rise from 73% to 110% of the specified power outlet, which can be construed as a power increase of around 40-50%.



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

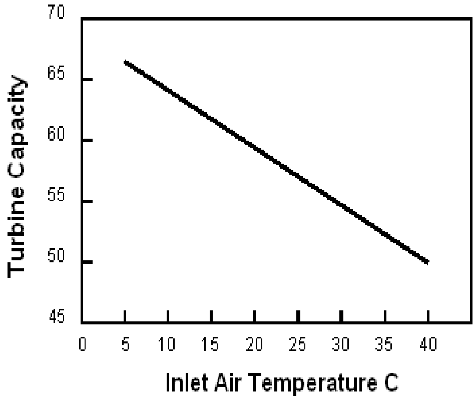


FIGURE:2 Effect of Air Inlet Temperature on Capacity for the 7B Combustion Turbine, *NEBRASKA*

The gas turbine capacities have been given for the +15°C temperature, 60% relative humidity and 14.7 psi 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

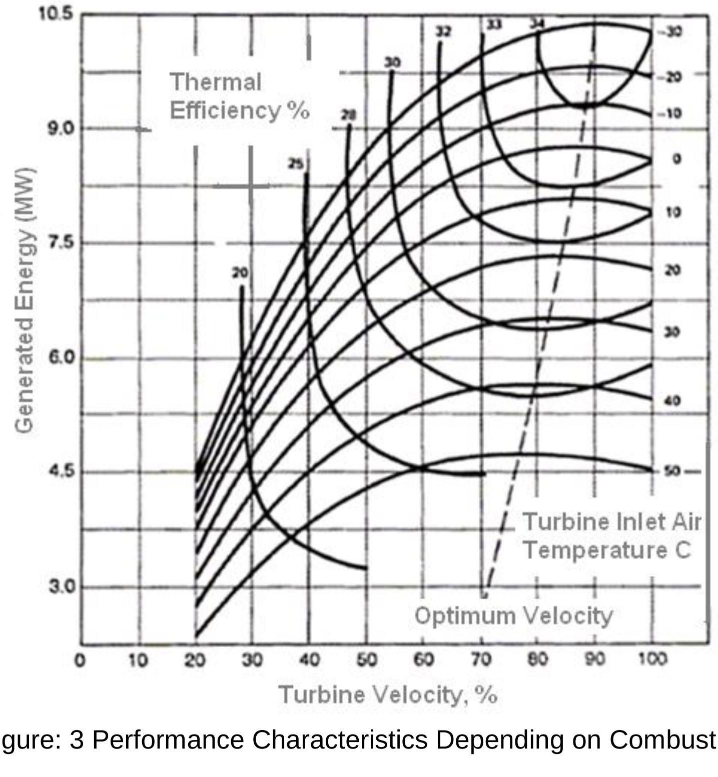
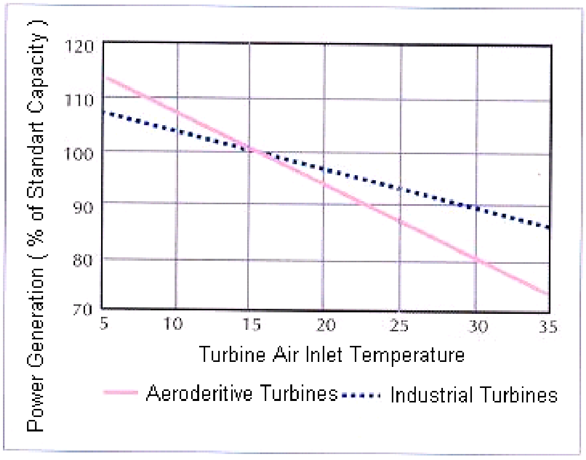


Figure: 3 Performance Characteristics Depending on Combustion Turbine Inlet Air Temperature

ADVANTAGES OF THE COMBUSTION INLET AIR COOLING SYSTEM:

1. Increase in capacity:

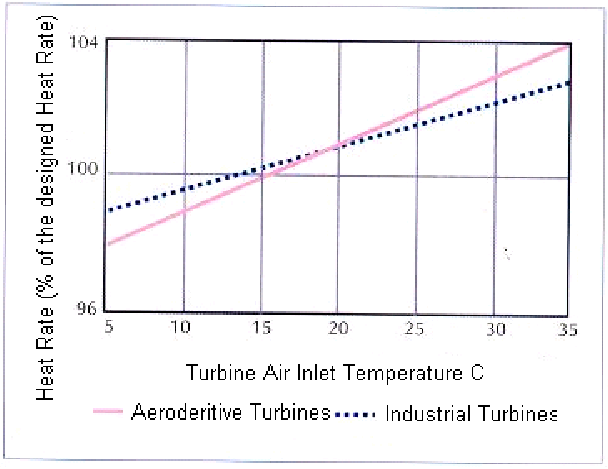


When compared to standard capacities in conditions where ambient temperature is above 15°C, the prevention or reduction in gas turbine power losses can be viewed as the primary benefit of Turbine inlet air cooling. Cooling the combustion turbine inlet air below 15°C also enables power plant owners to obtain a power yield above the standard generation capacity of the gas turbine.

Figure: 4 The Effect of variation in ambient air on power generation of the Gas Turbine.

2. Increase in fuel efficiency:

When compared to the efficiency and heat rate declared in the design in conditions where ambient temperature is above 15°C, the prevention of reduction in fuel efficiency is the most important benefit of combustion turbine inlet air cooling (Heat rate: the amount of heat required for one unit of electrical energy.)



An increase in air inlet temperature of 15°C to 38°C increases the heat ratio. This leads to an approximate 4% drop in fuel efficiency. The drop in fuel efficiency can be prevented by cooling the combustion turbine inlet air. For a typical gas combustion turbine, cooling the inlet air from 15°C to 6°C lowers the heat ratio and increases fuel efficiency by approximately 2%.

Figure 5 shows the effect of inlet air temperature on the heat ratio for Industrial and Aeroderitive combustion turbines.

3.Reduction of Main Investment Cost Depending on Capacity Yield of Power Generation Units:

If combustion turbine inlet air cooling is not applied on the power generation system, yet it is desired to make up for the capacity loss resulting from the rise in ambient temperature, the only applicable option is to use another gas turbine in the system or to assign a generator of another type. These alternatives are generally much costlier than combustion turbine inlet air cooling. (This has been demonstrated in the following pages by graphs.) Furthermore the capacity increase (the additional capacity that is gained) resulting from the cooling system application enables the delay of the necessary future investments.

4.Increasing the power output of the steam and steam turbine and raising the combined cycle efficiency:

In conditions where ambient temperature exceeds 15°C, combustion turbine inlet air cooling prevents loss of steam generated within the cogeneration system and power generation losses in the steam turbines within the combined cycle. As previously stated, the power generation of a gas turbine varies inversely with air temperature. This is due to the reduction in the mass flow rate of inlet air. A low mass flow rate leads to a decrease in the total energy of the gas turbine exhaust and consequently a reduction in the amount of steam generated in the heat recovery steam generators within the cycle. Low steam generation in heat recovery steam generators causes low generation in turbines within the combined cycle.

5.Improves the predictability of the quantity of power generation:

Some combustion turbine inlet air cooling technologies enable operation at the desired temperature which can potentially be as low as 6°C, independently of air conditions. Systems utilizing this technology make the prediction of the power output easier, and eliminate one of the variables –air- required for predicting the production in power generation plants utilising gas turbines.

6.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 achieved through combustion turbine inlet air cooling cuts NOx emissions by reducing combustion air temperature, thus eliminating the need for spraying water/steam for NOx control. The combustion turbine inlet air cooling system 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.

7.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.

8.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.

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
The air inlet temperature can be matched to the required turbine capacity. In this way, 100% open inlet guide vanes eliminate inlet guide vane pressure loss penalties

DISADVANTAGES OF THE COMBUSTION INLET AIR COOLING SYSTEM:

1. They require additional space and initial investment cost.
2. The system requires additional maintenance.
3. Heat exchanger coil (cooling coil) or evaporative media placed on the air entrance, cause pressure loss.

FACTORS THAT NEED TO BE CONSIDERED WHILE DECIDING TO INSTALL A COMBUSTION TURBINE INLET AIR COOLING 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 pr evaporative media (This is very important)
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

COMBUSTION INLET AIR COOLING TECHNOLOGIES:

Many technologies can be commercially used for the cooling of combustion turbine inlet air. These technologies have been classified in main categories below. Each system has its own advantages and disadvantages.

- The evaporative system: Wetted media (Evaporative cooling), Fogging (Pulverized spraying) and wet compression / spraying.
- Chillers: Mechanical and absorption chillers (With or without thermal energy storage.)
- LNG Vaporization
- Hybrid systems

1. Wetted media (Evaporative cooling):

The wet cooler method, which is the first technological system to be used for turbine inlet air cooling is the evaporative cooling technology. In this system, the cooling is achieved by phase variation of the water added to the inlet air of the gas turbine.
In this technology, the inlet air is subjected to the water film effect in the cooler. The cooler with the honeycomb formation is the one that is used the most. The softening process must be applied depending on the properties of the water and wetting equipment used. In the system the temperature can be brought closer to wet-bulb temperature by 85%-95% of the difference between the ambient dry-bulb temperature and wet-bulb temperature. This method is the option with the lowest investment and operation cost.

The basic disadvantage of this system is the fact that the cooling is limited to wet-bulb temperature. This means that cooling is dependant on weather conditions. In addition to this, the system quality should be continuously and carefully monitored for contamination of the circulating water and for drops in the operation efficiency.

This system reaches peak efficiency in dry and hot weather and efficiency decreases with high humidity in the environment. This is the most commonly used technology in spite of its high water expenditure.

2. Fogging (Pulvarized spraying) :

Fogging is a form of the evaporative cooling technology and its working principle involves adding tiny water droplets to the inlet air. These systems may be designed so that they will produce droplets of various sizes according to the time of evaporation and ambient temperature. The size of water droplets is usually less than 40 microns, and for the most part less than 20 microns. The water used in this system needs to be demineralized.

In this system, the temperature can be brought closer to wet-bulb temperature by 95%-98% of the difference between the ambient dry-bulb temperature and wet-bulb temperature. Consequently, the fogging system is somewhat more efficient than evaporative-wet cooling. The main investment cost is the same as in evaporative cooling, with similar limits and disadvantages. However, since fogging reduces the operating efficiency of the compressor and since the application of this system leads to various malfunctions, some gas turbine manufacturers do not want this system to be applied to their equipment. For this reason, the system is the second most popular in use.

3. Overspraying/wet compression:

In this method which is another evaporative cooling technology, more fog droplets are added to the inlet air which can evaporate under ambient conditions. The flow of air carries the excess fog to the compressor section of the gas turbine. Excess fog results in increased evaporation and cooling of the compressed air in this section as well as increased mass flow rate, creating results beyond the increase in power generation that can be achieved through other evaporative cooling technologies. On the other hand, this system has higher maintenance cost due the high character and quality of the water introduced into the environment.

4. Mechanical chiller systems:

Mechanical chiller systems can cool the inlet air to levels much lower than with evaporative cooling systems independently of wet-bulb temperature and preserve the desired inlet air temperature down to a minimum of 6°C.

Systems in which mechanical chillers are used, are operated by electrical motors or steam turbines. The inlet air is cooled to the desired temperature by passing it through coils in which refrigerant or water circulates. The cooled water is supplied directly from a chiller or from a thermal energy storage (TES) tank storing ice or chilled water. The heat storage system is typically used in places requiring inlet air cooling only for limited periods. When the TES system is compared to capacity requirements in periods where the cooling demand suddenly peaks, it can be seen to reduce total cost of the system. The TES system is charged (storing) on the previous night when energy expenditure comes at a low price, thus less or no electrical energy is required to operate chillers, which increases the net capacity of the power plant. In addition to all these compensating benefits, a large space is required for TES tanks.

In summary, the advantage of the mechanical cooling system is that it enables better cooling than can be achieved with other cooling systems, independently of ambient air conditions. The primary disadvantage of these systems is the high main investment price. Also, when the system is compared to evaporative cooling technologies it works with a high heat rate due to high parasitic load costs (0.70-0.81 kW/RT), so the efficiency can seem low.

5. Cooling systems with absorption:

The only difference in this system is the use of absorption chillers instead of mechanical ones. Absorption chillers require thermal energy (steam or hot water) as their main energy source. For this reason, they require much less energy than mechanical chillers. Absorption cooling systems can be used to cool the inlet air down to roughly 10°C. These systems may be installed with or without chilled water TES systems. Absorption chillers may be single effect or double effect chillers. Single effect chillers use hot water at 100 kpa vapor pressure. Double effect chillers on the other hand require less steam, but need steam at higher pressure (800 kpa).

The advantage of this system is that it has much lower cost from parasitic load and the main disadvantage is that the main investment cost is even higher than with mechanical cooling systems. The most successful application of these systems occurs in power plants where there is an excess of thermal energy. The conversion of this energy to electricity at a high value is profitable for the user (manufacturer).

5.1 Application alternatives for the use of the chiller system:

5.1.1 Direct Expansion 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.

5.1.2 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 fluid tubing is scarce, that it is limited to the packaged 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, 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 6.

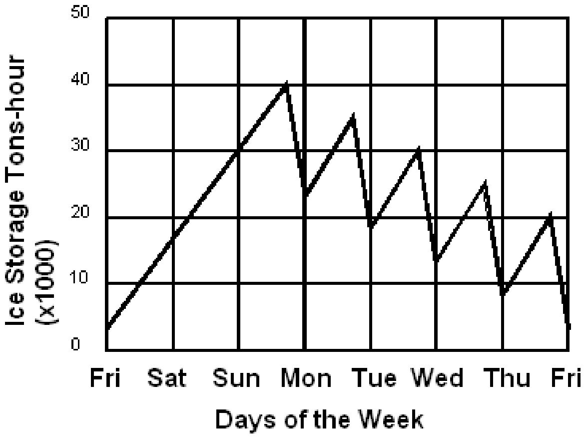


Figure: 6 Week Ice Storage Scenario, the Gilroy GT Plant

6. LNG Vaporization systems:

Liquefied natural gas (LNG) vaporization systems are appropriate for power plants round LNG centers. In case the natural gas is supplied for the power plant or other applications, the LNG must be vaporized by a heat source. It can be used as inlet air heat source for combustion turbine inlet air cooling applications.

7. Hybrid systems:

Hybrid systems include several cooling technologies like mechanical and absorption chillers. These kinds of systems are used in special plants where the price of electricity and availability of thermal energy is the main concern.

ECONOMIC EVALUATION:

2 hypothetical cogeneration plants in Los Angeles, California have been examined in order to evaluate the economic aspects of turbine inlet air cooling. One of the plants is an 83.5 MW capacity industrial gas turbine and the other a 42 MW capacity aeroderivative gas turbine. When the ambient dry-bulb temperature is 31°C and the wet-bulb temperature is 18°C, the production capacities of turbines without inlet air cooling drop to 75.3 MW and 32.1 MW respectively. According to the specified capacities, this equals a drop in capacity of roughly 10% and 24% respectively.

3 cooling applications can be considered for these two plants.
1)Wetted media (Evaporative cooling)
2)Fogging
3)Electrical chiller systems.

The evaluation of the economic feasibility of these systems also depends on the weather conditions of their region.

Increase in production output:

If we assume the difference for dry-bulb and wet-bulb temperatures for wetted media (evaporative cooling) and fogging systems is 90-98%, these technologies will be capable of cooling the inlet air to 19°C and 18°C respectively. If the electrical chiller system is designed to cool the inlet air by 7°C, a system of this kind requires a total cooling capacity of 2330 RT for a 83.5 MW turbine and a total cooling capacity of 1200 RT for a 42 MW gas turbine. *(Refrigeration Ton (RT): The cooling effect of 1 ton of ice at 0°C over 24 hours.)*

If we were to take the power requirement of a typical electrical chiller as 0.65 kW/RT for chilled water, condenser water and cooling tower pumps, the chiller capacities required for total parasitic loads by large and small capacity gas turbines are 1.9MW and 0.96 MW respectively.

The results indicate that evaporative cooling and fogging systems can raise the capacity of the larger uncooled system in this example from 75.3 MW to 81,3 MW and 81,9 MW (Figure.7a). This means that these technologies can reduce the 10% loss in capacity to less than 3%.

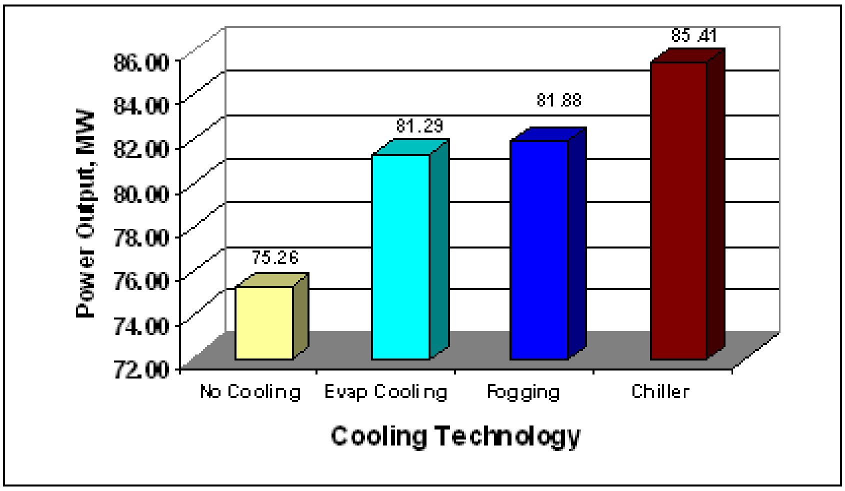


FIGURE.7 a) Effect of combustion turbine inlet air cooling on power generation for the 83.5 MW capacity gas turbine

While similar results are observed for aeroderivative and gas turbines, they are more striking than the results attained from industrial gas turbines (figure 7b). The capacity of the small system whose inlet air is cooled (for the first time) by evaporative cooling or fogging increases from 34.1 MW to 39.9 MW and 40.4 MW respectively, thus they reduce the 24% capacity loss to a percentage less than 4%.

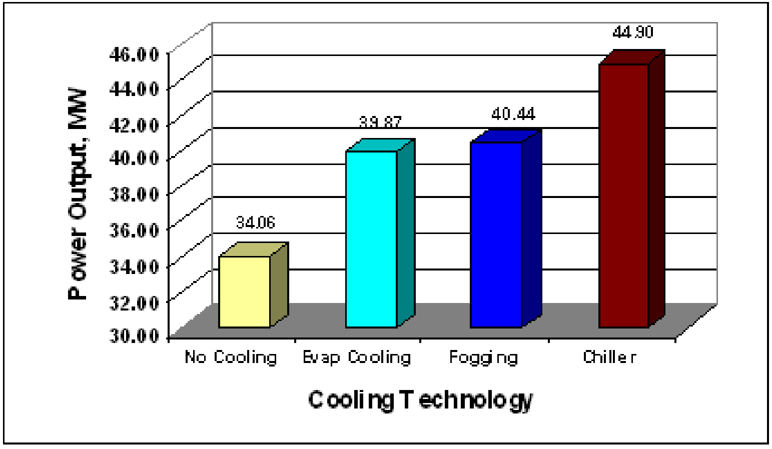


FIGURE.7 b) Effect of combustion turbine inlet air cooling on power generation for the 42 MW capacity gas turbine

Although the results delivered by the use of evaporative cooling and fogging, these methods are not adequate to fully match standard capacity. The increase in cooling that is achieved in these systems is dependant on the wet-bulb temperature of the region. If the wet-bulb temperature increases (outdoor humidity increases) their efficiency will drop. Consequently, the results of this technology in places of high humidity are not impressive.

The results indicate that electrical chiller systems are those providing the most increase in capacity even while they require large parasitic loads. The chiller system in this example has been designed to cool the inlet air by 7°C and can raise the power output above the declared capacity. Furthermore, the fact that the chiller system delivers stable power generation, independently of the ambient dry-bulb and wet-bulb temperature is another advantage of the system. On the other hand, the initial investment cost of chiller systems is high in comparison to evaporative cooling and fogging systems.

Economic Benefits:

The economic benefits of the 3 cooling technologies have been shown with graphs.

Basic data for installation costs:
-Cogeneration gas turbine plant (no cooling) 750,000$/MW
-Wetted Media (Evaporative cooling) 19000 $/ MW gas turbine capacity (at ISO)
-Fogging 19000$/MW gas turbine capacity (at ISO)
-Electrical chiller 800 $/RT

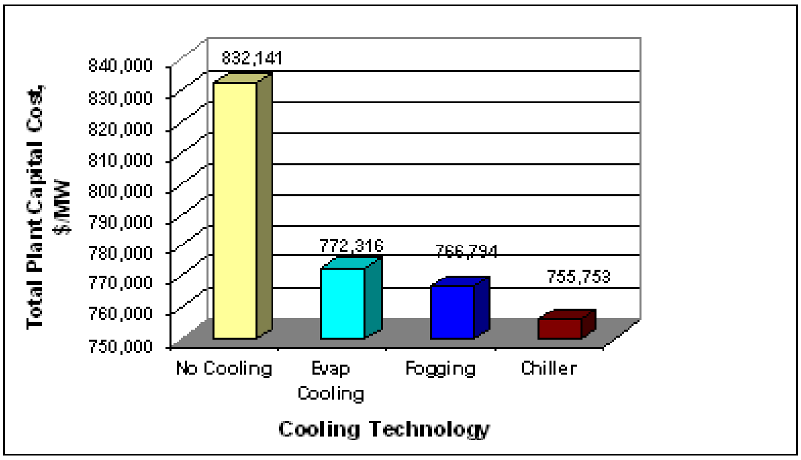


FIGURE.8 a) Effect of combustion turbine inlet air cooling on total plant cost for the 83.5 MW capacity gas turbine

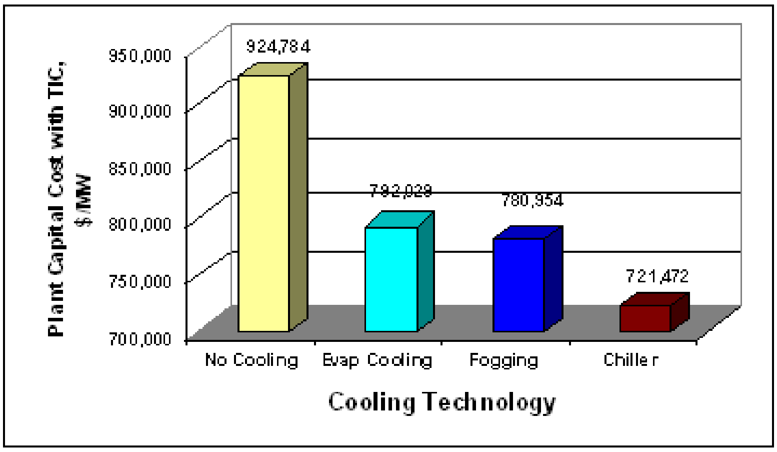


FIGURE.8 b) Effect of combustion turbine inlet air cooling on total plant cost for the 8 MW capacity gas turbine

The results given in terms of $/MW have shown that the main cost of the plant is less with systems with combustion turbine inlet air cooling than those without.

Plant owners can achieve increase in power output by two options: by adding another gas turbine to the system or by installing an inlet air cooling system on the gas turbine. As seen from Figure 6, when the increase in power output and basic costs are compared for each unit, the economic benefits of combustion turbine inlet air cooling is quite evident.

The results indicate that the main cost of the plant will rise in order to increase the plant capacity by 1 MW/Y, and that if a second plant is added to the system on which combustion turbine inlet air cooling is not applied, this increase in cost will be higher than the installation of the combustion turbine inlet air cooling system.

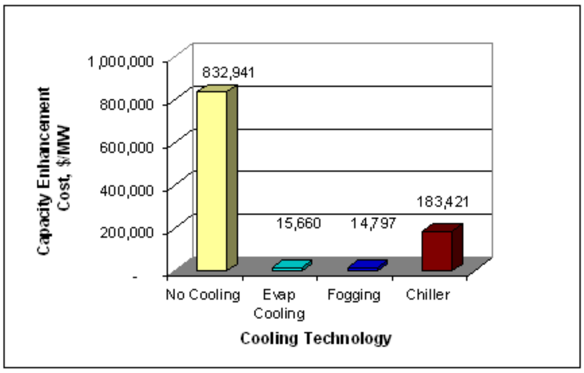


Figure 6a)
Effect of combustion turbine inlet air cooling on the cost of capacity enhancement for the 83.5 MW capacity gas turbine

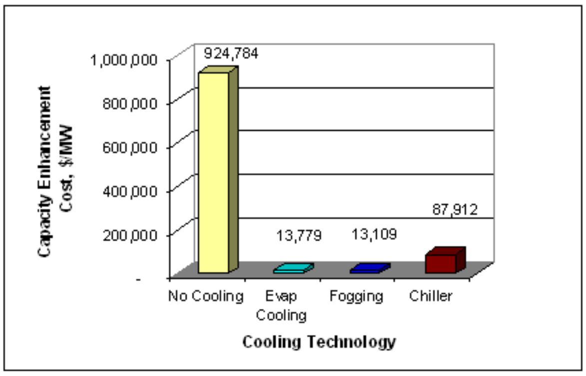


Figure 6b)
Effect of combustion turbine inlet air cooling on the cost of capacity enhancement for the 42 MW capacity gas turbine

The results of the combustion turbine inlet air cooling tec of the plant. For this reason, the economical benefits of technologies will vary from one region to the other.

Choosing the most efficient technology:

Our examples regarding combustion turbine inlet air cooling are for the environment where the dry-bulb temperature and wet-bulb temperature are 31°C and 18°C respectively. Still, this information is not sufficient to make a decision on the economic appeal on combustion turbine inlet air cooling nor on which cooling method is the most economical one. Such assumptions require knowledge of calculations made with detailed year-round weather information, fuel expenses, power demand profile and the market value of the generated power.

The most significant and commendable advantage of combustion turbine inlet air cooling is that it enables enhancement of the power output of the plant and that it ensures the stability of power generation even in conditions of high ambient temperature. The greatest advantage of this system is observed in instances where the ambient temperature is high and the humidity is low. The economical advantage of combustion turbine inlet air cooling can be said to be relatively lower in cold regions.

MATERIALS AND COSTRUCTION PROPERTIES, DESIGN AND PERFORMANCE CRITERIA OF INLET AIR COOLING UNITS

The materials, performance and construction properties of combustion turbine inlet air cooling systems with cooling coils used in Secondary Fluid Cooling systems and in combination with evaporative cooling and with Secondary Fluid Cooling systems must be known in detail by executives and technical staff employed in the energy sector.

Picture .1- Sample Application of a Combustion Turbine Inlet Air Cooling Unit

1. DESIGN AND PERFORMANCE CRITERIA OF INLET AIR COOLING UNITS

1.1 MAIN DESIGN CRITERIA:

The main design criteria for the design of combustion turbine inlet air cooling coils are: The desired dimensions of the coil, the total air flow through the coil, the inlet air temperature and relative humidity, the inlet and outlet cold water temperature, the water flow, the water-side and air-side pressure loss values of the system, the outlet air temperature and the desired cooling capacity.

By knowing the main design data specified above and the desired additional features, manufacturing firms may design and manufacture combustion turbine inlet air cooling coils in line with their own manufacturing techniques. The most important issue that must be considered, is that the manufacturing firm manufacture performance approved coils that are compliant with international standards. The manufacturing firm must comply with the measurement standard provisions of EUROVENT (Eurovent 7/C/005-97 Rating Standard for forced circulation air cooling and air heating coils) or the equivalent independent organizations in the design of combustion turbine inlet air cooling batteries. It is highly important for potential difficulties which would not be easily remedied; that the manufacturing firms possess a performance approved design software and design the coils by the help of this software/program.

1.2 PRESSURE LOSSES

For coil design, considering the negative impact of high pressure losses on capacity and costs, minimum values should be targeted for pressure losses; care must be taken that the total pressure loss in the air-side and the pressure losses –unless otherwise specified- in the air filter, coil and drop eliminator will not exceed (a maximum of) 254 Pascal (25.4 mmSS). Thus, the recommended pressure loss targeted for the cooling coil must be around 150-170 Pascal.

Low pressure losses should be targeted in the water side of the coil as well as the air side, and for general purposes –unless otherwise specified- it must be ensured that the water side pressure loss does not exceed a maximum value of 80-100 kPa.

1.3 AIR SPEED

The Cooling Coil should be designed such that the air speed will not exceed the preferred value of 2 m/s or the maximum value of 2.5 m/s.

1.4 REFRIGERTANT PROPERTIES

The use of glycol in the cooling coil is a necessity to prevent freezing. (A 20% glycol mixture by weight and a 30% glycol mixture by weight provide protection down to an average of –10°C and –16°C respectively.) (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.)

1.5 CIRCUITING

The circuiting and design of the coil should be such that the equal amount of refrigerant passes through all tubes, and all of the water and air in the coil can be purged.

2. MATERIALS AND CONCSTRUCTION PROPERTIES OF COOLING UNITS

The economic service life of gas turbines can be taken as 15-20 years. The useful economic life of the cooling system selected for cooling the inlet air of the combustion turbine should match that of the turbine. The economic life of the cooling unit depends on the selection of materials that are appropriate for the operating conditions. The cooling coil within the unit in particular must be manufactured in conformity with industrial specifications.

Picture.2- Sample Application of a Combustion Turbine Inlet Air Cooling Unit

2.1 PROPERTIES OF THE COOLING COIL

Cooling coils must be manufactured in conformance to the SEP (Sound Engineering Practice) defined under 97/23/EC PED (Pressure Equipment Directive). They must comply with the measurement standard provisions of EUROVENT (Eurovent 7/C/005-97 Rating Standard for forced circulation air cooling and air heating coils) or the equivalent independent organizations; the capacity, air-side pressure loss and refrigerant side pressure loss values must be based on clearly declared test results. Otherwise, the energy efficiency of the cooling unit will be low, which will have a negative impact on the overall efficiency of the system.

Cooling Coil design position:

For combustion turbine inlet air cooling systems, it is very important that the cooling coil is manufactured vertically rather than horizontally.

Purging the Water from the Coil and By-Pass: As outdoor temperatures drop toward winter, it becomes no longer necessary to operate the combustion turbine inlet air cooling system as in spring and summer. In this case, in winter months (when temperatures are low) the system must be completely purged against the risk of freezing of the system water. While it is not possible to purge the water completely in the horizontal position (construction), all the water can be purged in the cooling coil in the vertical position.

Performance and Pressure losses*:* A great majority of condensed droplets on the cooling coil move downward with gravity while a small number of droplets detach from the surface with the air flow and move toward the drop eliminator. In coils designed in the vertical position the tubes are vertical and fins are horizontal and vice versa in the coil in the horizontal position. In the horizontal design, the droplets flowing from top to bottom may converge and cover the gaps between fins toward the bottom. This leads to reduced cooling coil performance and increased pressure losses, hence decreased turbine efficiency. On the other hand, the fact that fins are horizontal for the vertical position of the coil enables the droplets to flow downward from the lowermost points of the fins without the risk of them merging at any point of the coil.

Tubing, Maintenance and air venting: The tubing of the water installation is much more practical and takes up less space in a system with batteries of vertical construction as opposed to horizontal construction. Thus, maintenance cost is relatively less in the vertical version. It is also much easier to vent the air collecting in the system with the vertical system.

2.1.1 Tubes:

In consideration of performance and cost-friendliness, the most appropriate tubing material for cooling coils is copper. For this reason, the copper tubes used must be manufactured per international standards. The most important parameter in applications is the wall thickness of the tube. The recommended tube and curve wall thickness is the range 0.635 mm – 1.00 mm

2.1.2 Fins:

The fin material widely used in cooling coils is Aluminum and it is important that the material be manufactured in conformity with international standards. Epoxy or in highly corrosive environments polyurethane over epoxy coated Aluminum fins should be used to increase the resistance of fins which will operate in outdoor environments to corrosion.

While the recommended thickness for fins is 0.25 mm, thicknesses between 0.15-0.25 can also be used depending on the application. The surface form of Aluminum fins should be flat (for minimum pressure drop), the fin spacing should be selected as a minimum of 3.2 mm or optimally as 4 mm for the purposes of contamination and the resistance effect. Lower values than 3.2 mm should not be used for fin spacing. Due to the constructive structure of the vertical unit, fins should be in the horizontal, and tubes should be in the vertical position.

2.1.3 The Collector

While copper tubes is the generally preferred material for inlet and outlet collector tubing material in applications, stainless steel material is also used. The collector tube diameters are determined in line with technical standards according to the capacity of the cooling coil. The wall thickness of the collector varies with the diameter.

In addition to inlet and outlet collection tubes, the system should also include a mechanism for venting the air collected in the coil and for purging all of the water, and the air vent and drainage outlet should be collected at a single point.

It must be ensured that the connections between the Inlet-Outlet Collector tubes and the main installation are detachable. In a vertically designed unit, the Inlet-Outlet connections are below the unit.

2.2 PROPERTIES OF THE COOLING UNIT CELL

Stainless steel is usually the material of choice for the casing material of the cell enclosing the cooling coil, drop eliminator, the air filters and drainage tray, thus combining all of the parts with various functions into a whole, that is the combustion turbine inlet air cooling unit. In environments of low corrosion, galvanised steel material coated with paint of high UV resistance can be used as a cheaper alternative to stainless steel material.

The cell design should not allow the air to create a short circuit by flowing from another point than the surface of the cooling coil. While it is advisable from a cost viewpoint to use special Aluminum profile and corner pieces, equivalent material with resistance to outdoor conditions can also be used. Aluminum materials should be rendered more resistant by coating with epoxy or polyester based electrostatic paint depending on ambient conditions.

Picture.3- Sample Application of a Combustion Turbine Inlet Air Cooling Unit

2.3 FILTER PROPERTIES

The dust, dirt etc. collecting on the cooling coil in time will lead to reduced coil efficiency. An air filter should be placed on the coil entry to prevent this. It is important that the filter used is not of the type to cause excessive pressure loss. The type EU2/EUROVENT 4/5 (G2/EN 779), 65%-80% efficient polyurethane air filter is usually preferred for applications. While the type E3 air filter can also be used in applications, it produces higher pressure losses as compared to the type EU2 filter.

2.4 THE DRAINAGE (CONDENSATION) TRAY PROPERTIES

For collection of the water condensing in the Cooling Coil and for its expulsion from the system, a drainage tray should be placed at the lowermost portion of the cooling coil cell, that is designed with adequate width to receive the water coming from the drop eliminators as well. The drainage tray must be made of stainless steel sheet, isolated against condensation and double walled

2.5 DROP ELIMINATOR PROPERTIES

Drop eliminators of Aluminum or PVC must be used in cooling coils to prevent water droplets travelling to the turbine due to the high air flow. Drop eliminators, by separating the droplets of water in ait help the droplets find their way (by flowing from the surface of the drop eliminator) to the condensation tray by the effect of gravity.

The drop eliminators used in the system must be of a design that will not lead to excessive pressure losses.

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