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COMBUSTION TURBINE INLET AIR COOLING UNITS USED IN POWER PLANTS

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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 knowledge of the materials, performance and construction properties of turbine air coolers, which self-finance its installation and operation costs 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.

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.

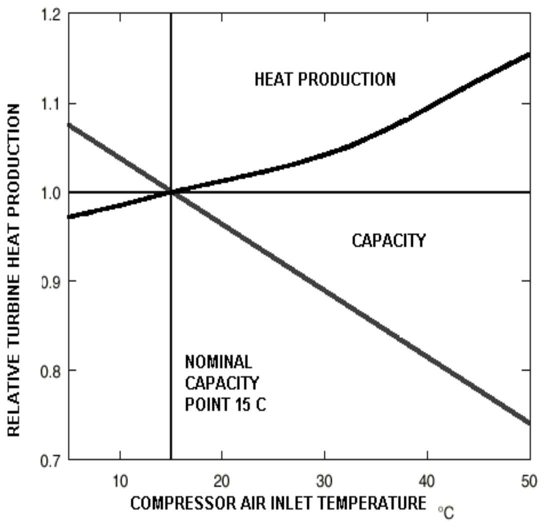
In applications made at a later date, it is possible to apply a combination of evaporative media, direct cooling with coolant or a chiller package with a cooling battery with secondary refrigerant. When systems where energy is stored as ice/water is used in combination with another cooling coil, they offer significant advantages in terms of providing compensation in the system.

Toward meeting the demands of the energy sector, FRITERM has been manufacturing the cooling coils of this package 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. For errors to be avoided in this relatively new style of application, the materials, performance and construction properties of combustion turbine inlet air coolers must be known in detail.

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 power losses spent on 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 values 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

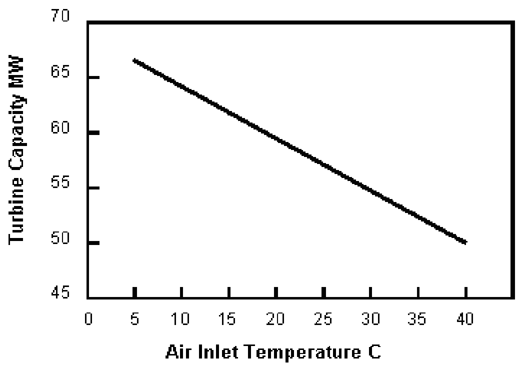


FIGURE:2 Effect of Air Inlet Temperature on Capacity for the 7B Combustion Turbine, *NEBRASKA*

The combustion turbine capacities have been given for the +15°C temperature, 60% relative humidity and sea level as specified by ISO. Connection factors for capacities under other conditions must be obtained from the manufacturer 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 generation by 3.5%.
- Each 1 kpa additional pressure loss in the filter, silencer and channels during entry, reduces power generation by 2%.
- Each 1 kpa additional pressure loss in the boiler, silencer and channels during exit, reduces power generation 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.

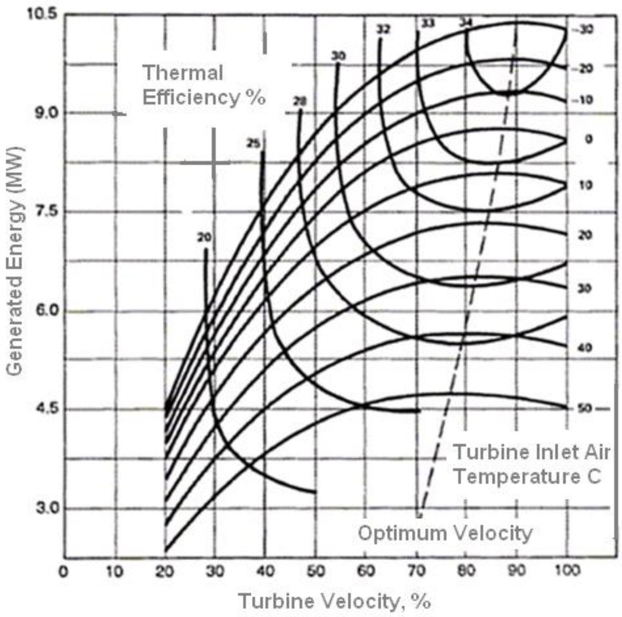
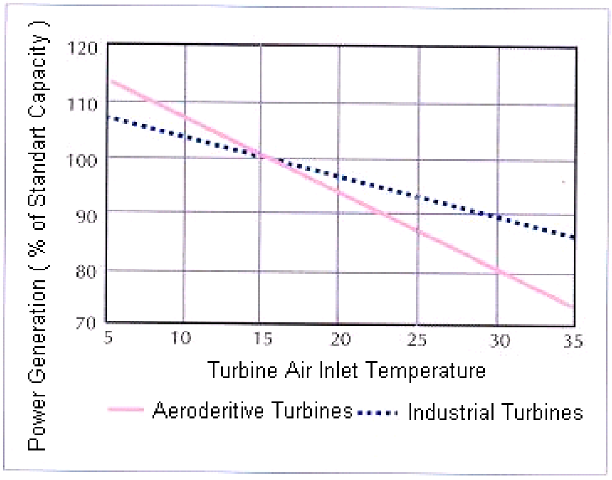


Figure:3 Performance Characteristics Depending on Combustion Turbine Inlet Air Temperature

ADVANTAGES OF THE COMBUSTION TURBINE INLET AIR COOLING SYSTEM:

Increase in capacity:

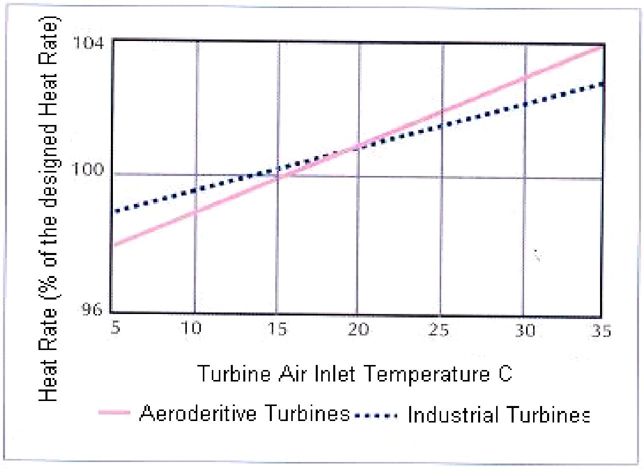


When compared to standard capacities in conditions where ambient temperature is above 15°C, the prevention or reduction in gas turbine power losses can be viewed as the primary benefit of Turbine inlet air cooling. Cooling the combustion turbine inlet air below 15°C also enables power plant owners to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

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 per 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.

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 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 to spray 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 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.

Improves the predictability 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.

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 guide valve eliminate inlet guide valve 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 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 or 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

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 fluid (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 energised 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 load loss excepting pumping losses during turbine operation. 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:

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.

The softening process must be applied depending on the properties of the water and wet equipment used. The wet cooler can cool the inlet air to 85%-95% of the difference between the ambient dry-bulb temperature and wet-bulb temperature.

The basic disadvantage of this system is the fact that the cooling is limited to wet-bulb temperature. This means that cooling depends on weather conditions. This system reaches peak efficiency in dry and hot weather and efficiency decreases with high humidity in the environment. Although this system has high water consumption, it is the most common technology due to low cost of operation.

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

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 chiller 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 good 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 in our country. Achieving efficiency and profitability in energy generation is sure to require greater sensibility.

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, manufacturers 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 VELOCITY

The Cooling Coil should be designed such that the air velocity 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.

Figure: 6.1
Figure: 6.2
A view from the manufacturing process of the combustion turbine inlet air cooling coil.

The coil construction must be such that the unit can carry its own weight and the material preferred for the load bearing structure must be stainless steel or galvanised steel coated with protective paint.

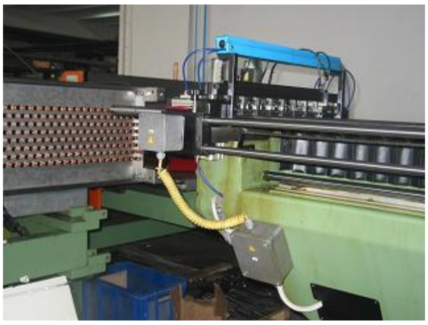
Cooling Coil design position: For combustion turbine inlet air cooling systems, it is very important that the cooling coil is manufactured vertically rather than horizontally.

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. (In cases where the combustion turbine inlet air cooling system is not operated, passing the inlet air from the cooling units will lead to pressure losses in the system, which in turn will cause a drop in the power generation of the turbine. In this case, the inlet air should be allowed inside from other parts of the system, thus “by-passing” the cooling coils. Air by-pass cavities should be of enough quantity and/or size to accommodate the air flow required by the turbine.)

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 at 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.

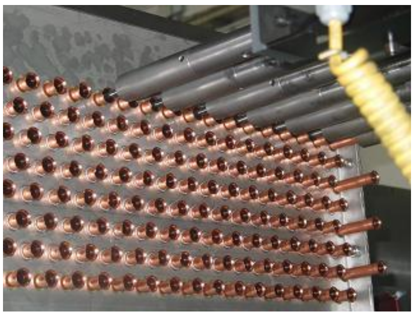
Tubing, Maintenance and Air venting: The piping of the water installation is much more practical and takes up less space in a system with coils of vertical construction as opposed to horizontal construction. Thus, maintenance cost is relatively less in the vertical version. It is also much easier to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

Figure: 7.1 View of the Tube Blowing Machine, the Blowing Process for Copper Tubes and of the Curves



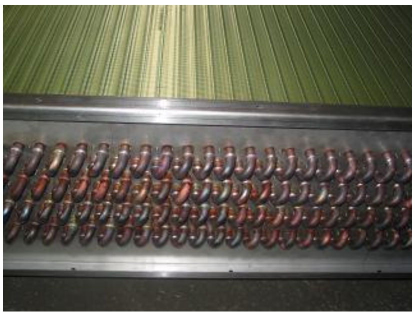


Figure: 7.2-3 View of the Tube Blowing Machine, the Blowing Process for Copper Tubes and of the Curves

In manufacture, after being processed in the Tube Cutting Machine tubes are arranged with Aluminum fins from the presses, making up the main body of the “Copper Tube-Aluminum finned” heat exchanger. An efficient exchange of heat between Tube and Fins requires excellent mechanical connection (firm contact between the Tube and fins). This process is handled hydro-mechanically in the Tube Blowing Machine.

2.1.2 Fins:

The fin material widely used in cooling coils is Aluminium 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.

Fin Press Lines and fins processes according to mould, form and spacing. Tight contact achieved between tubes with the Arrangement and Blowing process. Main finned block

Figure: 8.1 and Figure: 8.2

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.

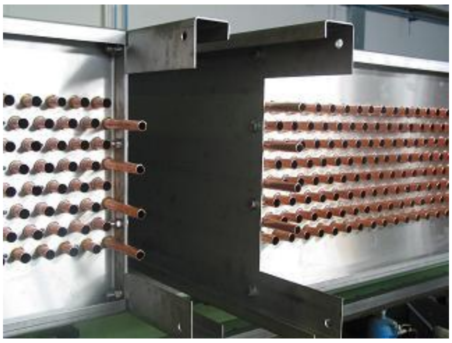
It must be ensured that the connections between the Inlet-Outlet Collector tubes and the main installation are demountable. In a vertically designed unit, the Inlet-Outlet connections are below the unit.

Figure:9.1 and Figure: 9.2
The Collector Processing Machine and Stainless Inlet-Outlet Collectors

2.1.4 Frame

Stainless steel sheet is the most appropriate choice for all casing materials used in the coil. Mirrors should also be manufactured from stainless steel sheet, and it should be ensured that stainless steel mirrors will not cut the copper tube. To this end, applications such as double wall mirrors should be made. This way, the mirrors will be prevented from grinding and cutting during thermal expansion or contraction.



In addition to stainless steel casing material, electro statically painted galvanised material is also used in environments of low surface corrosion.

As well as the stainless steel sheet material, the Aluminum material used should also be coated with protective surfaces like powdered paint etc.

Figure:10 Coil frames

2.1.5 Brazing:

All copper tube-curve, copper tube-collector connections, connections used in frames and all connections of fittings should be done with the "Brazing" method and the solder wires used for soldering should be silver alloy solder wires.

For operators making the connections to be well trained persons, is another factor which will have a positive impact on quality.

Figure 11 The Brazing application on the Cooling Coil

2.1.6 Pressure Test:

The Cooling Coil should be subjected to an imperviousness test under 20 kg/cm^2 of pressure.

Figure: 12.1 and Figure :12.2 The execution of the test process within the test pool by feeding pressurized air to the coil.

2.1.7 Cleaning

In order to remove residues like oil etc. from the cooling coil after the test, the coil should be washed with steam/scalding water containing chemicals and dries afterward.

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.

Figure: 13.1-2-3 View of the Cooling Unit Cell from the Drop Eliminator and the Filter sides
(Filter cartridges are installed on location).

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.

Cartridge type air filters must be washable and cleaned regularly. The use of stainless material or electro statically painted galvanised steel material for filter cartridges that should be manufactured in an easily mountable-dismountable design, is important for long-term resistance. To make sure filters are not subject to any deformation or contamination during manufacture or shipping, the filter cartridges must be installed after the unit is installed in its actual place within the facility.

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 should be manufactured from stainless steel sheet, isolated against condensation and double walled. The drainage tray must be designed such that it will prevent the collection of the condensed water and be capable of easy water expulsion by virtue of the drainage pipe whose size varies with the quantity of condensed water. A syphon must be present at the outlet of the drainage tray.

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 drain tray by the effect of gravity.

Figure: 14.1 Drop eliminator detail – from the left and right

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

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