Adiabatic Air Cooling for Gas Turbine Power Plants

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The shortage of power generated by utility companies in most parts of India and its uncertain supply has compelled many industrial houses to install independent, captive power generating plants to take care of their own requirement. In remote areas of the country, far from the national electric distribution grid, power required for essential purposes such as for oil fields or for defence, can only be supplied by captive power plants. Recently some private companies are also installing medium capacity plants which feed power to the national grid. Such power plants are generally of the gas turbine type, since they are compact and gas is available.

ISO Ratings of Gas Turbines

The performance of a gas turbine is largely dependent on the environmental conditions under which it operates. International Standard Organization or ISO rating conditions for gas turbines capacity in MW is based on inlet air at 15°C, 60% RH at sea level or 14.7 psi absolute pressure, with a generator power factor of 0.9.

Improving the Performance of a Gas Turbine

With summer ambient conditions of 35°C to 45°C commonly prevailing in most parts of India, the turbine capacity, based as it is on 15°C ambient air, is reduced considerably, by as much as 20% for an inlet air temperature of 35°C. This is a large penalty to pay and hence several methods have been devised to reduce the temperature of the air intake to the turbine, thus improving its performance.

A gas turbine is a constant speed, constant volume machine and its output (electrical power generated) is directly proportional to the mass flow rate of the inlet air. Hence, if we can increase this mass flow rate by cost-effective means, we can optimize the output.

Intake air is used for combustion when it comes in contact with fuel and after combustion the mixture is expanded through the turbine

About the Author

Richie Mittal, is an engineering graduate from Birla Institute of Technology, Mesra and an M. Tech. in thermal engineering from Delhi College of Engineering. He is Director, Technical at Roots Air Systems Pvt. Ltd. for the past two decades and has a wealth of experience in industrial ventilation and evaporative cooling.

He is a member of both ISHRAE and ASHRAE and has been president, Delhi chapter, regional director- North, and treasurer - Head Quarters. He is presently the president of ASHRAE India Chapter.

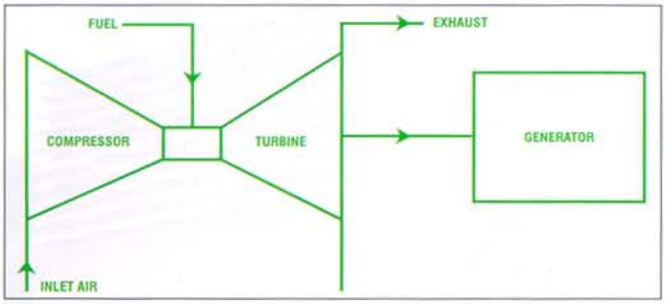

Figure 1 : General arrangement of combustion turbine.

section thereby producing power. Refer *Figure 1*. Hence, by either increasing the mass of intake air or the quantity of fuel, the turbine output can be increased. The optimum way to increase the mass of intake air is by increasing the density of air by adding moisture with the help of evaporative cooling.

Advantages of Inlet Air Cooling Systems

- Improvement in power output of the turbine due to increased mass flow of air at a lower temperature
- Better combustion efficiency since oxygen level increases due to increased air flow
- Increased turbine heat rate (efficiency)
- Increased turbine life due to exposure to colder (and cleaner) air
- Turbine generators have a waste heat recovery system that recovers and reuses the heat from exhaust air. With inlet air cooling, exhaust air has less heat and hence a smaller heat recovery system with lower capital cost can be used
- Increased overall efficiency results in reduced emissions and cleaner environment
- Shorter payback period

Evaporative Cooling Systems

Evaporative cooling is an adiabatic or a constant enthalpy process of reducing the temperature of an air stream by adding moisture to it. The process of converting water from liquid to vapor state requires energy. This energy is drawn from the air stream, sensible energy is converted to latent energy and the result is cooler and more humid air, which is also denser due to added moisture. An added advantage of this is that due to humidification, the air becomes considerably colder. It is the least complicated and most cost effective system where, in some cases, it is possible to obtain air outlet temperatures close to ISO levels.

These systems are most effective in dry climates where the scope for moisture addition into the dry air is very high. In humid weather, the air is anyway concentrated with moisture and this leaves very little scope for the evaporative cooler, whose operation is limited by ambient wet bulb temperature.

Vapor-compression Refrigeration System With or Without Thermal Energy Storage

Here, chilled water is used to cool the inlet air, either by circulating it through cooling coils. Such systems work well where the ambient humidity levels are very high. They are however very expensive, not only in terms of capital cost but also running cost and hence may not be cost-effective in many cases. Moreover, if such systems are used without thermal energy storage systems, the plant efficiency reduces drastically during reduced loads. Since the power consumption of these units is quite high, this can be a drawback during peak hours when the demand for electricity is the maximum. This disadvantage can be partly overcome by augmenting the system with a thermal energy storage system.

Vapor Absorption Chillers

This is a good choice when surplus/ waste steam is available. It however carries the disadvantage of a large capital cost and comparatively lower efficiency. Also, absorption chillers cannot provide water outlet temperature lower than 6-7°C. They can however adapt well to varying loads without causing drastic reduction in efficiency levels.

Design Details of Evaporative Cooling Systems

In an evaporative cooler, ambient air is filtered and passed over layers of wetted media at a certain velocity. This air-to-water contact decreases the air temperature and adds moisture to it, thereby increasing its density. This cold and humid air is then carried to the inlet of the gas turbine. The effectiveness of the system depends on the type of media, its surface area and the exposure time.

Construction

The evaporative cooling system is a compact unit made of stainless steel enclosure. It comprises a set of pre-filters and an evaporative cooling assembly made up of a tank, internal piping, FRP water distributors and cellulose cooling media. Catwalks with railings, ladders, marine lights and heavy duty access doors make up the maintenance portion of the plant. It is essential to note that since the entire unit is in contact with water, all parts are either stainless steel or FRP or such water-resistant material. *Figure 2* shows a section of a typical evaporative cooler and *Photo 1* shows a close-up of an actual installation.

Control philosophy

Controls play an important role in the efficient operation of the system. A control panel and suitable peripherals, which operate in unison, ensure that the plant is run at maximum efficiency.

- An RH sensor in the supply air path signals the pump to shut down when the supply air has almost

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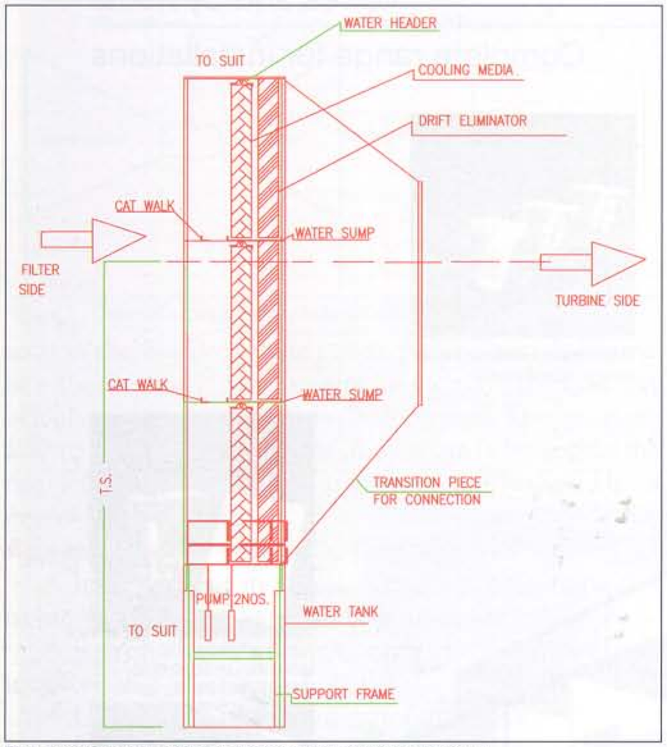

Figure 2: Section of intake evaporative cooling system.

reached saturation (say, 90% RH), since now the air is incapable of absorbing any more moisture and hence it is useless to keep the water circulating.

- A water flow switch is provided to ensure pump operation.
- A water conductivity sensor senses the water quality and notifies in case of any irregularity.
- A thermo-couple acts as a switch to shut off the pumps when the ambient air is very humid. This is sensed when the temperature difference between DB and WB of air is very low (less than 2-3°C).
- A thermostat is provided to stop the pump in case the ambient temperature is less than 15°C, since the

Photo 1: A typical inlet air evaporative cooling system

Designation	Lower	Upper	Unit
Conductivity	50	450	microSiemens/cm
Calcium Hardness (as CaC03)	45	170	ppm
Chlorides (as Cl)		<50	ppm
Total Alkalinity (as CaC03)	45	170	ppm
pH	7	8.5	-
Silica (as SiO)		<25	ppm
Iron (as Fe)		<0.2	ppm
Oil and grease		<2	ppm
Total dissolved solids		<550	ppm
Suspended solids		<5	ppm

Table 1: Recommended water quality for best performance of cooling media

turbine is anyway operating at I S O levels and no artificial measures are required to generate these conditions.

- Ball valves are provided at all necessary locations.

Design Criteria

Listed below are points to keep in mind while designing these systems:

- Maintain air velocity of less than or equal to 3m/sec across the media in order to avoid water carryover.
- Provide mist eliminators to further prevent water carryover. Mist eliminators however add to the pressure drop in the system and hence, one has to work out a balance between a lower air velocity and the depth/ area of the eliminators.
- Cooling media should give the best saturation efficiency with a low pressure drop. Water distribution over media should be even. Ensure height of the media is not more than 2400 mm.
- Water quality plays an important role in proper functioning of the cooling media. Salts in the water tend to form deposits and choke the air passages, thereby reducing efficiency. Other abrasive chemicals present in water can also reduce life of the cooling media. Please refer to *Table 1* which shows the ideal permissible percentages of various chemicals in the water. It is always advisable to ask your customer to get the water sample checked and take corrective measures, if the water quality is not up to the mark.
- Parts of the evaporative cooler that are in contact with water should be of stainless steel construction, for a long life.
- The piping carrying water to the media and back as well as the circulating pumps should be in SS.
- Shutting down a functioning power plant, even for routine maintenance can be very costly. Plant layouts and accessibility should be designed to facilitate fast work.
- The cooling media should be placed after the filtration systems so as to prevent dust collection on the media and also to avoid swelling of filter due to moist air. This

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swelling will increase the pressure drop across the filter.

- It is advisable to completely assemble the unit before dispatch so that minimum work is required to be done on site. However, since such power plants are usually located in remote and difficult terrains, it is important to assess the transportation facilities available before deciding to pre-fabricate the evaporative cooler at the factory.
- M. S. components, if used should all be epoxy coated. All nuts / bolts and accessories that will be in contact with water should be of stainless steel.
- While assembling the unit at site, it is advisable to take advice from structural/ civil experts and provide adequate strengthening of the supports, as recommended.

Case Study

The author has been part of a project in Rajasthan, where an evaporative cooling system was successfully installed to cool the inlet air in a gas turbine power plant. Studies and readings show impressive results.

The turbine, a Frame 6, capable of generating 39 MW at I S O conditions was installed at a remote location in Rajasthan, where inlet air was at 46°C with 15 % RH and generating only 30 MW, a de-rating of almost 23%.

After installing an evaporative cooling system at the turbine inlet, the inlet air temperature was reduced by 12°C. Empirical formulae show that the increase in output capacity of turbine with decrease in inlet air temperature is approximately 0.6 to 0.75% per 1°C reduction in air temperature. Accordingly, the increase in capacity of the turbine could be calculated as follows:

Increase in capacity = turbine capacity at ISO conditions (MW) x temperature difference in °C × 0.6%

= 39 (MW) × 12 (°C) × 0.6/ 100 = 2.808 MW

Cost-benefit analysis

The cost of installing a gas turbine at present is approximately Rs. 3 crores per MW while the installation cost of an inlet evaporative cooling system (based on experience) is approximately Rs. 2 lacs per MW.

In this case therefore, installing an evaporative cooling system for the inlet air to the turbine was definitely a very cost effective option.

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Conclusion

Evaporative cooling systems can be an excellent choice to adopt in gas turbine power plants located in dry areas. Higher the difference between ambient dry bulb and wet bulb temperatures, greater the efficiency of this system. While selecting cooling media, it is necessary to choose media with good saturation efficiencies. Also, for a good design, the air flow across the media should be as uniform as possible.

These systems are definitely a viable option when one's objective is "**P**ower **O**btained **W**ithout **E**xpensive **R**esources." It is a pleasant coincidence that this elaboration of the word *POWER* is so befitting in this case.

References

1. *ASHRAE Handbook- Fundamentals*
2. *Evaporative Cooling Handbook* by Robert E. Foster
3. Paper presented by Maurizio De Lucia and Carlo Lanfranchi at the *International Gas Turbine and Aero engine Congress and Exposition*, Houston, Texas- June 5-8 1995.
4. General Technical Brochures of Munters.
5. General Technical Brochures of Glacier Cor.
6. Article by Alexandra Giourof in the *Power Journal*, USA, May 1995.
7. Article by William E. Stewart in the *ASHRAE Journal*, September 1998.