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Study of Methods of Cooling used in the gas turbine industry and Fog/Overspray effect on turbine

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Abstract - Gas turbines are versatile power-producing machines but their performance is greatly degraded by adverse ambient conditions such as high air temperatures and humid or dusty environments. Being a constant volume-flow machine, the power of the gas turbine is directly proportional to the mass flow rate of the air passing through it, which is directly proportional to the air density. Since a high ambient temperature reduces the air-density, gas turbines designed to operate at standard conditions of 15.6°C (233K) lose significant portions of their generating capacity when installed in hot climates. A high inlet-air temperature also increases the compressor work and lowers the thermal efficiency. Therefore, gas turbines operating under hot climates do not only produce less power than their design capacity, but also consume more fuel. According to McCracken [1], gas turbines produce 25-35% less power in summer than in winter at an average increase of 6% in fuel consumption. While in temperate climates this problem is only faced during the hot summer days.

I. INTRODUCTION

Since the peak-load normally happens during the hot midday hours -when the gas turbines are least productive- this problem contributes to the noticeable shortage of electricity during summer time and causes big losses and considerable waste of resources to the whole country. Solving the problem by adopting power-augmentation methods does not only optimize the use of these resources, but also reduces the environmental impact of power generation. Many power- augmentation methods can be used to compensate for the effects of ambient conditions on the gas-turbine output, but the two most common methods are those of cooling the inlet-air and injecting water or steam into the combustion chamber.

II. METHODS OF COOLING

Traditional Evaporative Cooling

Traditional media based evaporative coolers have been widely used in the gas turbine industry especially in hot arid areas. The basic principle of evaporative cooling is that as water evaporates, it consumes 1,160 BTUs (2260 KJ/Kg)of heat (latent heat of vaporization) and in doing so reduces the ambient air temperature.

Inlet Fogging

Direct inlet fogging is a method of cooling where demineralized water is converted into a fog by means of special atomizing nozzles operating at 2000 psi(14 MPa) [3]. This fog provides cooling when it evaporates in the air inlet duct of the gas turbine. This technique allows 100% effectiveness in terms of attaining 100% relative humidity at the gas turbine inlet and thereby gives the lowest temperature possible without refrigeration (the wet bulb temperature). Direct high pressure inlet fogging can also be used to create a compressor intercooling effect by allowing excess fog into the compressor, thus boosting the power output considerably. In this paper, consideration is only made of evaporative fogging alone, with no discussion of fog intercooling being considered.

Cooling Coil Method

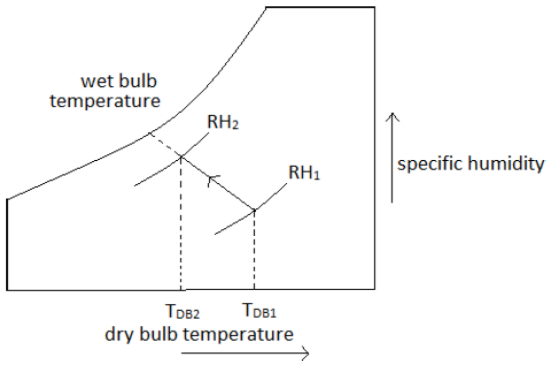
This air cooler operates in a different way than the water spray cooler; however, the temperature and relative humidity of fluid leaving the cooler depend on the coil temperature and relative humidity of ambient air. Ambient air enters the coil cooling at Ta and φa . Air passing over the outer surface of the coil experiences a drop in temperature and possibly a decrease in specific humidity, ω. The coil temperature can be adjusted to allow air to reach a certain desired temperature. In this case, the cooling load to be removed using cooling coil can be estimated; hence, the power input to the associated refrigeration system can also be evaluated.

Concept behind Fog Cooling

The main concept behind fog cooling is “Adiabatic Evaporative Cooling”. In adiabatic evaporative cooling, a large quantity of water is constantly circulated through the spray chamber. The air vapour mixture is passed through the spray and, in doing so evaporates some of the circulating water. The air may leave at a certain humidity ratio or in a saturated state. The increase in specific humidity is equal to the quantity of water evaporated per unit mass of dry air. No heat transfer takes place between the chamber and surroundings.

Therefore, the energy for evaporation is supplied by the air, and consequently the DBT is lowered. After the process has been in operation for a sufficient length of time, the circulating

water approaches the WBT of the air increases approximately 1-2%. With 2% of overspray, the net output power increases as high as 20%. As the ambient temperature increases, the net output power decreases; likewise increase of relative humidity lowers the net output power but with less impact than from the increased ambient temperature. Judging from the slopes of the curves in Figure,



Fog/Overspray effect on turbine

Figure shows that, the gross turbine power increases as the fog/overspray percentage increases. As overspray of 2% increases turbine power upto 4% for natural gas and 6% for LCV fuels. Figure also shows that turbine gross power increases upto 30% for using LCV-1 fuel and 15% for using LCV-2 fuel from the NG fueled output because fuel mass flow rate are significantly increased for using LCV fuels.

Figure also shows turbine gross power increases up to 30% for using LCV-1 fuel and up to 15% for using LCV-2 fuel from the NG fueled output because fuel mass flow rates are significantly increased for using LCV fuels. It is important to note that, the LCV fired GT size will be different from the NG-fired GT if the same operating condition (surge margin, total pressure loss, etc.) and component efficiencies are imposed. The gross turbine power also increases as the overspray percentage increases. For example, an overspray of 2% increases turbine power up to 4% for natural gas and 6% for using LCV fuels.

The net output power is calculated by deducting the air compressor power and fuel compressor power from the gross turbine power. Figure 6.5 shows that LCV fuels produce more net output power than natural gas even though LCV fuels significantly increases fuel compressor power 11 times for using LCV-1 and 6 times for using LCV-2 . When LCV fuels are burned, fog/overspray cooling seems as effective in achieving net power enhancement as when natural gas is burned. With saturated fogging, the net output power

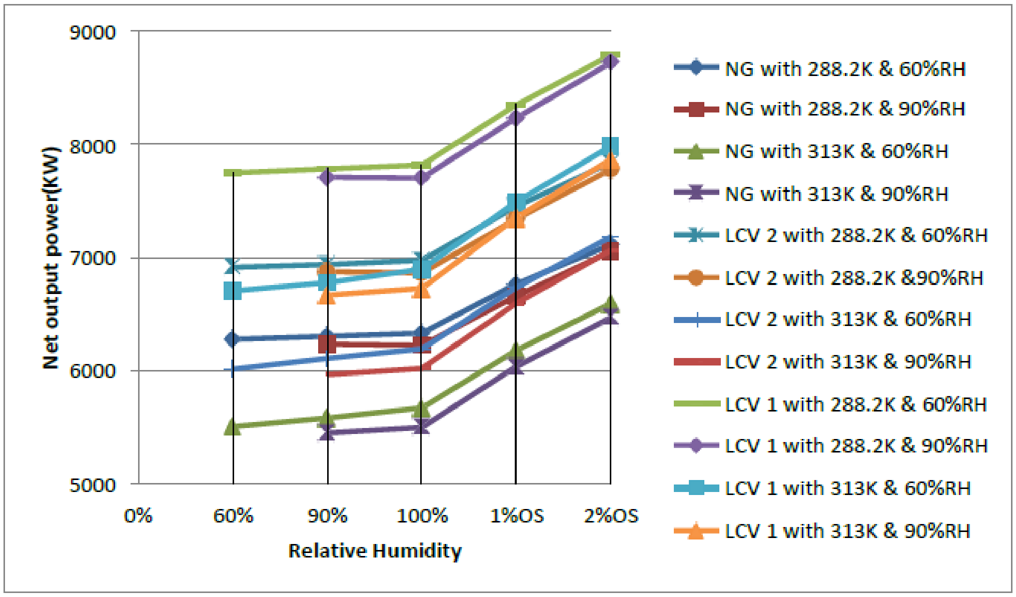


Figure Net output power under different conditions

III. CONCLUSION

Fog cooling is an evaporative cooling method that is becoming increasingly popular for airconditioning applications in general and gas-turbine power augmentation in particular . A series of stainless steel-tubing arrays distribute demineralised water under high pressure (14 – 25 MPa) to specially designed nozzles which, in turn, atomize the water into fine droplets in the form of fog. Due to its small size (5-10 µm) and distribution over a large area, the water droplets evaporate quickly and effectively cool the air. While pressurizing the liquid water requires a minimal amount of work input, it significantly improves the vaporisation and cooling processes. Unlike conventional media-type evaporative cooling, which can only achieve about 90% saturation, fogging can achieve full saturation of the inlet air and can cool it down to the wet bulb temperature.

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