A Review of Effect of Inlet Air Temperature on Gas Turbine Power Output and Methods of Inlet Air Cooling

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Abstract-- The inlet air temperature to the gas turbine mainly controls the power output and efficiency of the turbine. During the months of summer, when the temperature of ambient air increases and in certain regions where significant demand for power and high electricity occur, the inlet air cooling techniques are very useful for reducing the inlet air temperature and thus improving power output and efficiency. It is observed that an increment of 1°C in the compressor air inlet temperature decreases the gas turbine power output by 1%.Methods of cooling such as Evaporative Cooling (EC), Absorption Chillers (AC), Ceramic Tube Membrane Technology reduce the inlet air temperature by about 6°C.Evaporative Cooling method uses evaporation of water to reduce the inlet air temperature to the compressor or the turbine. These methods are highly advantageous and useful when specifically applied in hot and dry climates or conditions. The second method is the absorption chiller system in which a typical vapor absorption cycle is used with a refrigerant solution. Another technology for the humidification is ceramic tubes membrane technique. A section is built with a uniform cross section followed by a test section consisting of a matrix of ceramic tubes. These ceramic tubes are of porous design to achieve air cooling by humidification. Thus an overall look on the different techniques for the humidification of the inlet air is carried out in the paper.

Key words-- *Gas turbine ambient air, evaporative cooling method, absorption chillers, ceramic tubes membrane technology.*

I. INTRODUCTION

Gas turbines are used for electric power generation in several industrial applications [1]. The gas turbine engine unit consists of a compressor which takes up the atmospheric air to compress the air, a combustion chamber in which the fuel /air mixture is burned or the heat addition take place, and a turbine through which expansion of gases take place and a shaft coupled to it generates the electric power in the generator unit [1]. These cycles work on the Brayton's thermodynamic cycle and are referred as combustion turbines.

Usually, the combustion turbine rated capacity is based on standard condition of ambient air, and zero or no inlet and exhaust pressure drops, as specified by the International Organization for Standardization (ISO).Therefore according to ISO, the inlet air conditions are: temperature 15°C, relative humidity 60%, absolute pressure of 1.01325 bar at the mean sea level.

Combustion turbines are constant volume systems and their power output is directly proportional and limited by the mass flow rate of air flowing through the turbine. As the compressor has the fixed volumetric capacity of air for a given particular rotational speed, their volumetric efficiency remains constant and the mass flow rate of air or gas entering into the gas turbine varies with the ambient temperature and relative humidity [2]. Thermodynamic analyses show that thermal efficiency and power output of gas turbine decreases with the increase of ambient temperature and humidity, but the ambient temperature is the main parameter that controls the gas turbine performance significantly [1].

The rise in the ambient temperature results in decrease in air density, and thus, a mass flow rate entering through the turbine is reduced as the mass flow rate is directly proportional to the density. Thereby less air passes through the turbine and the power output and efficiency is reduced, at a given turbine entry temperature.

Gas turbines are used for power generation at several places in the world and each region has different climatic conditions. For example, in India, the average ambient temperature in the regions of Rajasthan during summer days is about 43°C and this factor causes a large drop in power output during the summer.

Due to these severe ambient conditions, the turbine inlet air cooling is one of many available technologies to improve the performance of the gas turbine power plants by cooling the air at the compressor entry [1], [6]. Thus, due to the increasing requirement for power to a low specific investment cost, new interests in the intake air cooling has been introduced in the recent years.

Two different methods are frequently employed for the turbine inlet air cooling: the evaporative cooling and the Absorption Chilling systems [7], [8]. [1] presented a comparison or difference between two common inlet air cooling methods, evaporative coolers and mechanical chiller in which vapor compression cycle is used to cool the inlet air, and one new technique that uses ceramic tubes to improve performance of a gas turbine. [3] Performed a review of inlet air cooling methods that can be used for improving the power output of Saudi Arabian industry's gas turbine during summer days. His results showed that the evaporative cooling system require a large amount of water. This puts a limitation on its use in the desert climates. The absorption chiller is an expensive system and its cost of investment is too high. Air humidification is normally carried out by spraying water in the ambient air flow upstream of the compressor inlet. This method requires a good quality water to avoid corrosion and erosion of the compressor blades. Also, the droplet drift may increase the amount of water for the humidification process.

II. GAS TURBINE UNIT

Let, P0 = Atmospheric pressure,
P1 = Inlet pressure to compressor,
P2 = Compressor exit pressure,
P3 = Combustor exit pressure,
P4 = Turbine exit pressure = P0,
T0 = Ambient temperature,
T1 = Compressor inlet temperature,
T2 = Compressor exit temperature,

T3 = Combustor exit temperature,
T4 = Turbine exit temperature = T0,
r = Compression ratio of compressor = P2/P1,
nc = Isentropic efficiency of compressor,
Y = Adiabatic index for the compression,

Assumptions of the Brayton's cycle:

1. The working fluid is air which behaves like an ideal gas.
2. All processes are reversible and there are no unintended heat losses.
3. Changes in K.E. and P.E. are negligible.
4. There are no pressure drops in ducting and in combustion chamber.
5. Specific heats do not change with temperature.
6. Mass of fuel is neglected.

Fig. 1 shows the single shaft gas turbine. The compressor inlet temperature is equal to ambient temperature. Furthermore, various parameters for determining the compressor and turbine work are calculated. First, the inlet pressure is given by:

$P0 = P1$ (1)

The air and combustion products are assumed to behave as an ideal gas.

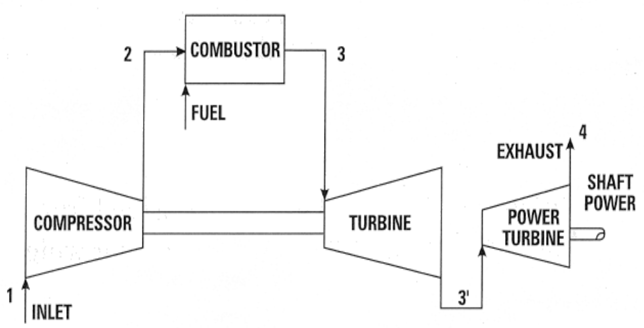

Figure 1: Schematic of the standard gas turbine cycle

The pressure of the air leaving the compressor can be calculated by the compression ratio which is known for the given compressor:

$P2 = r.P1$ (2)

Compressor work is calculated as :
$W_c = M_a \cdot C_{pa,avg}(T2 – T1)$ (3)
Similarly, turbine work is calculated as :
$W_T = M_t \cdot C_{pg,avg} \cdot (T3 – T4)$
Where, $M_t = M_a + M_f$,
$C_{pg,avg}$ = Average specific heat of gas, Thus the net power obtained from the gas turbine can be calculated by:

$W_{NET} = W_T – W_C$ (4)
This is the net power obtained from the gas turbine plant.

III. INLET AIR COOLING TECHNOLOGIES

A. Direct evaporative cooling

The direct evaporative cooling system is a simple and effective way of cooling the air stream in a direct evaporative cooler. In this case the air stream is directly in contact with a liquid water film and the cooling is accomplished by the adiabatic heat exchange between air and water film.

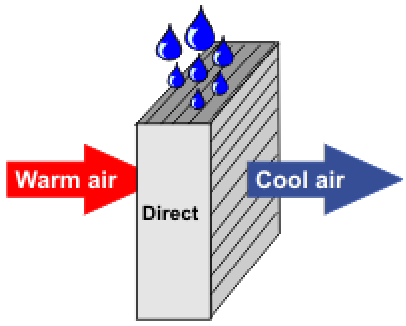

Figure 2: Direct type evaporative cooling

B. Indirect evaporative cooling

With indirect evaporative cooling, the temperature of a secondary air stream is cooled by water. The cooled secondary air stream passes through a heat exchanger, where it cools the primary air stream. The primary air stream which is cooled is circulated by a fan. This cooling method does not add moisture to the primary air stream. Both the dry bulb and wet bulb temperatures are reduced.

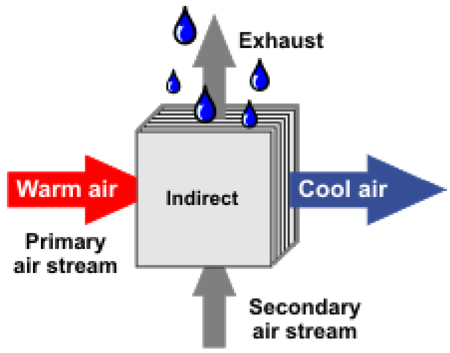

Figure 3: Indirect type evaporative cooling

a. Absorption chillers

It recovers the waste heat from turbine exhaust gases.The system consists of following main components:

1. Waste Heat Recovery Steam Generator (WHRSG)
2. Condenser to condense the steam
3. Expansion valve or throttle valve
4. Evaporator
5. Absorber
6. Solution pump

The exhaust from the gas turbine power plant is first passed to the WHRSG unit where the exhaust gases are made to pass over the tubes in which water flows.Exhaust gas heat converts this refrigerant into steam at a higher temperature and pressure and the leftover gases are exhausted to atmosphere.

Now, the steam is given to the condenser where condensation of refrigerant take place.(Refrigerant used is LiBr.) Refrigerant at saturated state at this point is then passed through a heat exchanger where it is cooled and the through an expansion valve or throttle valve where the two phase mixture is produced i.e. liquid + vapour form. The cold refrigerant is then passed through the evaporator where it is converted into pure vapour form. This low temperature vapour refrigerant (at 5°C) is passed to cool the inlet air of the compressor. The inlet air is cooled to about 10°C which increases the air density and thus a improves the efficiency. Fig.IV. shows the working of absorption chiller :

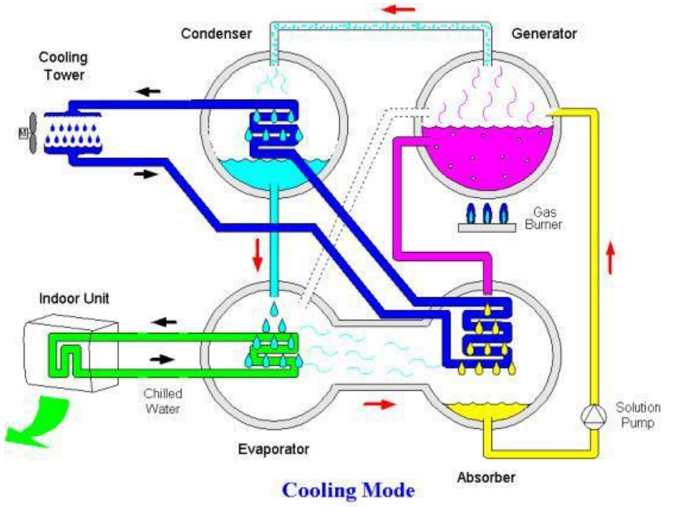

Figure 4: Absorption Chilling system

b. Ceramic Membrane Technology

The experimental apparatus consists of a blower and a matrix of ceramic tubes serving as a test section.The system has following sections/parts :

1. Conical adapter
2. Blower or fan
3. Settling or the straightener section
4. Honeycomb structure made of Al2O3

The ambient air is passed over the honeycomb structure made of aluminium oxide (Al2O3) from which it passes through the intake air duct having uniform cross section of 28×14cm and 356 cm long. The next section is the test section which consists of the ceramic tubes.There are two compartments for water inlet and outlet. The cold water from the tank is supplied by the pump to this test section and there take place the heat exchange between the ambient air and the cold water. Thus the cooled ambient air is passed through the conical adapter section which is blown by the blower to the compressor inlet. Velocity measurements are carried out using hot wire anemometer. Parameters like velocity, temperature, humidityof the air are measured at the inlet and exit sections. Temperatures are measured by the thermocouples located at both the sections and also one thermocouple measures the ambient air temperature.

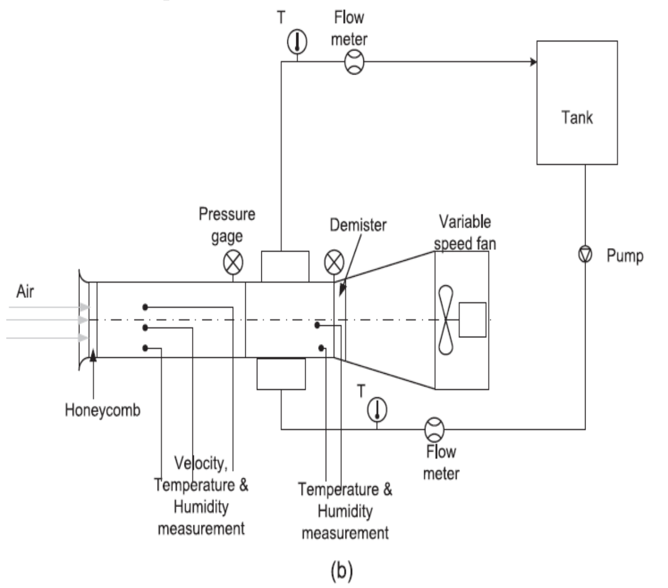

Figure 5: Ceramic membrane technology

IV. RESULTS AND DISCUSSIONS

Fig VI represents the effect of ambient air temperature on the gas turbine power output and thermal efficiency. As the ambient air temperature goes on increasing, the power output goes on decreasing when no inlet air cooling is applied. Next graph indicates that the temperature decreases when evaporative is implemented for the ambient intake temperature. Only evaporative cooling effect is shown in the graph and not all inlet air cooling methods.

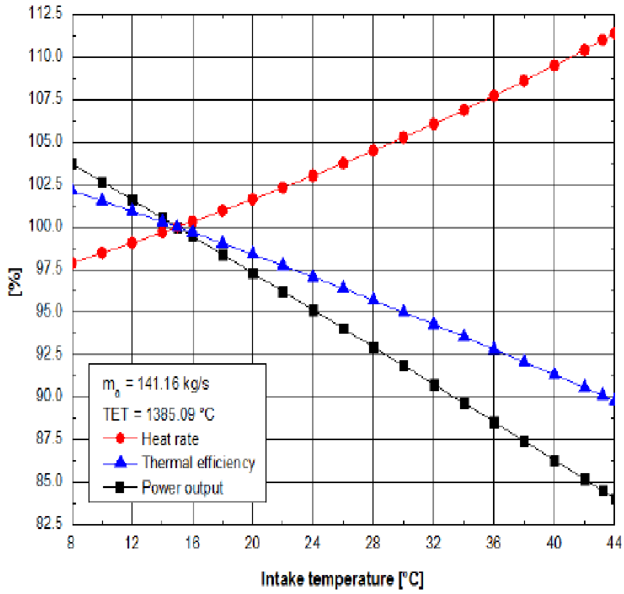

Figure 6: Effect of ambient air temperature on power output, efficiency and heat rate

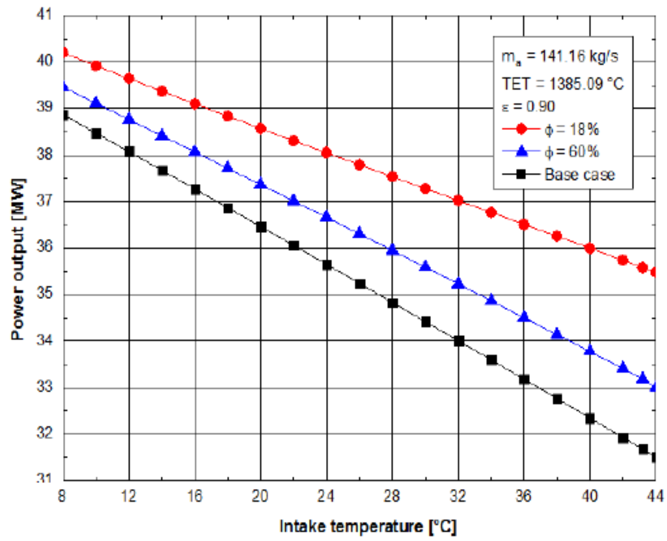

Figure 7: Effect of ambient air temperature on power output, with evaporative cooling

CONCLUSION

Results indicate that all the methods used for cooling the compressor inlet air or the turbine improves the power output and thermal efficiency. Nevertheless, the evaporative cooling method is limited by the ambient wet bulb temperature. On the other hand, absorption chilling method decreases the inlet air temperature to a greater extent. Therefore, exhaust gasses can be conveniently utilized where the inlet air is to be cooled to a less temperature.

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