# SIMULATION OF A GAS TURBINE PLANT USING EVAPORATIVE COOLER

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**ABSTRACT:** This research work focus on the simulation of a gas turbine power plant using evaporative cooler. Aspen HYSYS software was used for the simulation of the gas turbine with and without cooling system using the actual operating data for performance evaluation. The results obtained on the simulation of the gas turbine at ambient air temperature of 29 $^0$C without the use of cooling system showed that ambient air temperature decreases the net power output, thermal efficiency and power output. However, when the gas turbine was incorporated with air intake cooling system, there was drop in ambient air temperature which resulted to an increase in net power output, thermal efficiency and power output.

## 1. INTRODUCTION

Gas turbines are used for electric power generation, operating airplanes and for several industrial applications. The gas turbine engine consist of a compressor to raise combustion air pressure, a combustion chamber where the fuel/air mixture is burned and a turbine that through expansion extracts energy from the combustion gases. The simple gas turbine plant operates according to the open Brayton thermodynamic cycle and present low thermal efficiency and are referred as combustion turbines.

The performance of a gas turbine power plant is commonly presented as a function of power output, specific fuel consumption and it is sensible to the ambient conditions [1]. Thermodynamic analyses from literature show that thermal efficiency and specific output decrease with the increase of humidity and ambient temperature, but the ambient temperature is the variable that has the greatest effect on gas turbine performance [2].

The ambient temperature rise results in decrease in air density, and consequently, in the reduction of the mass flow rate. Thereby, less air passes through the turbine and the power output is reduced, at a given turbine entry temperature. Moreover, the compression work increases due to the augmentation of the volume occupied by the air.

According to [1], the net power output produced by gas turbine is directly proportional to the air mass flow and decreases when ambient temperature increases. The work of Ibrahim [3] shows that an increment of 1 °C in the compressor air inlet temperature decreases the gas turbine power output by 1 %.

The aim of this research is to carry out a thermodynamic analysis of a gas turbine power plant (Niger Delta power plant Holding Company Omotosho Generation Station phase 2) using the evaporative cooler method.

Evaporative coolers, often called "swamp coolers", are cooling systems that use only water and a blower to circulate air. When warm, dry (unsaturated) air is pulled through a water soaked pad, water is evaporated and is absorbed as water vapor into the air. The air is cooled in the process and the humidity is increased [4].

Using evaporation media reduces $NO_X$ in the emission from combustion chambers; and therefore, positive effects of environmental consequences are introduced. Cooling the air as much as 10°C will increase approximately $6 - 10\%$ in electrical power generated [5].

 Status of application of evaporative inlet air cooling systems in three great power plant including Rajaei, Qom and Fars were studied. Comparing economic and technical aspects showed that using evaporation media system was more effective than fog system. Using wetted media type to cool the gas turbine inlet air in five PG6581 and three PG6551 type gas turbine showed that wetted media caused the inlet air temperature drop at $12 - 14$°C and increases 4MW for each of PG6581turbines and 3.5MW for each of PG6551gas turbines [6].

## 2. MATERIALS AND METHOD

Omotosho Generation Station (phase II) is a gas turbine plant owned by Niger Delta Power Holding Company (NDPHC). The power plant is located at Omotosho, Okitipupa Local Government area of Ondo State, Nigeria. It has four GE frame machines with the installed capacity of 125MW for each machine bringing its total installed capacity to 500MW.

### 2.1. Data Collections

The operating data for gas turbine unit from (2013 to 2016) of Omotosho Power Plant were collected from the daily turbine control log sheet. The daily average operating variables were statistically analyzed and mean values were collected for the period of January to December with an overall average.

Summary of operating parameter of a (GE Frame) gas turbine unit used for this study is presented in Table 1. The thermodynamic analysis of the plant and its performances was carried out without cooling and with cooling of the inlet air entering the compressor.

The basic gas turbine cycle is Brayton cycle; it consists mainly of compressor, combustion chamber and turbine. Air enters the compressor where it is compressed and heated after that its goes to the combustion chamber, where fuel is burned at constant pressure before it eventually raises the temperature of air to the firing temperature. The resulting high temperature gases enter the gas

turbine where they expand to generate the useful work. Figure 1 shows the flow chart of the system without cooling while figure 2 shows modelling of gas turbine unit by incorporating an evaporative cooler.

**Table 1.** Summary of operating data for the 125MW G.E simple cycle gas turbine power plant of Omotosho power plant (phase II).

| S/N | Operating Parameters | Valve | Unit |
|---|---|---|---|
| 1 | Mass flow rate of air through compressor (ma). | 361 | Kg/s |
| 2 | Temperature of inlet air to compressor ($T_1$) | 302 | K |
| 3 | Pressure of inlet air to compressor ($P_1$) | 101.3 | Kpa |
| 4 | Outlet temperature of air from compressor ($T_2$) | 611 | K |
| 5 | Outlet pressure of air from compressor ($P_2$) | 1066 | Kpa |
| 6 | Fuel gas (natural gas) mass flow rate (mf) | 6.5 | Kg/s |
| 7 | Fuel – air ratio at full load (on mass basis) | 56:1 | |
| 8 | Inlet pressure of fuel gas | 24 | Bar |
| 9 | Inlet temperature of gas turbine ($T_3$) | 1405 | K |
| 10 | Maximum exhaust temperature of T. outlet | 851 | K |
| 11 | Combustion efficiency $\cap_{ce}$ | 90 | % |
| 12 | Pressure drop in the combustion chamber | 10 | % |
| 13 | Installed capacity | 125 | MW |
| 14 | Isentropic eff. Of compressor | 89.20 | % |
| 15 | Isentropic eff. Of Turbine | 89.80 | % |
| 16 | Specific heat capacity of air 1 Cpa | 1.005 | KJ/kg K |
| 17 | Specific capacity of gas Cpg | 1.15 | KJ/kg K |
| 18 | Lower heating value (LHV) | 45880 | KJ/kg K |
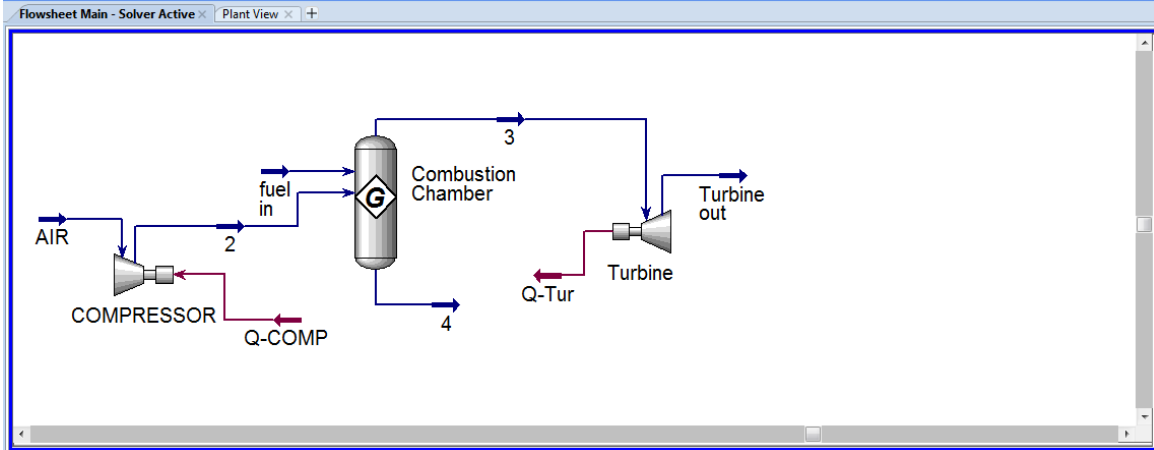


**Figure 1**. Simulated schematic of a simple gas turbine cycle without a cooling system.

The gas turbine power plant with inlet air cooling is modeled in the following assumptions. The following assumptions were made in the simulation of the gas turbine using the evaporative cooling system, compressor inlet temperature, the air and combustion products are assumed to behave as ideal gases.

I.   The process modeling uses a steady-state simulation, that is, all the operating conditions are constant.
II.  All component have adiabatic boundaries.
III. The ambient conditions of temperature and pressure are at $15^0$C and 101.3kpa.

IV.     The air and the combustion products are assumed to be ideal.
V.      Kinetic and potential components of energy are neglected.
VI.     The combustion process is assumed to be a conversion reaction during simulation using ASPEN HYSYS.
VII.    There is about 90% energy conversion in the reactor.
VIII.   The compressor and turbine has an adiabatic efficiency of 89.20% and 89.80% respectively.
IX.     The component of the natural gas is Methane and temperature at entering is 55°C.
X.      The natural gas inlet pressure is 24 bars.
XI.     The pressure drop across the combustion chamber was assumed to be 0.010%.
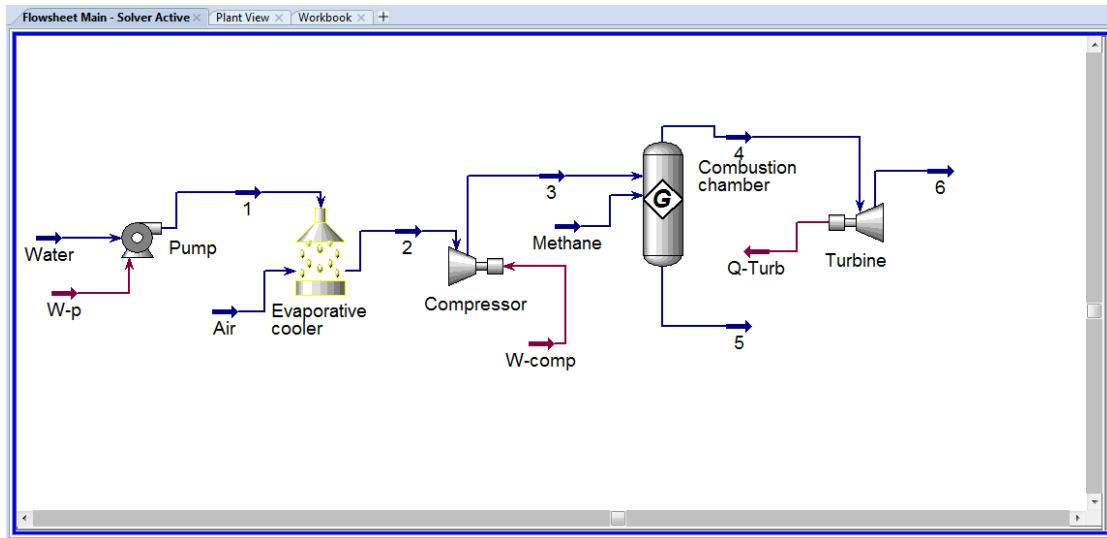


**Figure 2.** Simulated schematic layout of the gas turbine cycle with an evaporative cooler.

Aspen HYSYS was used to model the gas turbine without cooling and gas turbine with an evaporative cooler units. The first step in creating the model was the selection of a standard set of components and a thermodynamic basis to model the physical properties of these components.

When the component list was created, HYSYS created a new component list called Component List-1. The next step was the selection of a Fluid Package for it.

The Simulation Environment was entered to begin building the process model. The Pump, cooler unit, Compressor, Conversion Reactor, Turbine icons from the model palette were clicked and placed on the flow sheet in Figure 2. The combine unit of pump and evaporative cooler are used to simulate an evaporator unit: when the incoming air enters the evaporative unit, the intake air mixes with the cold water from the pump thereby reducing the temperature of the air entering the compressor.

## 3. RESULT AND DISCUSSION

Aspen HYSYS software was used to simulate the performance of the plant. The result obtained is shown in Table 2 and Table 3 to know the influence of a change in input variable such as temperature on the net power output, power generated thermal efficiency and heat rate. The results

were used to compare the performance of the plant when it is incorporated with air intake cooling system (evaporative cooler).

**Table 2**. Simulated result obtained by simple type gas turbine

| S/N | Result of Simulation | Output | Output |
|---|---|---|---|
| 1 | Compressor work $W_c$ | 116500kW | 116.5MW |
| 2 | Turbine work $W_t$ | 217900kW | 217.9MW |
| 3 | Power generated | 101400kW | 101.4MW |
| 4 | Thermal efficiency | 0.2985 | 29.85% |

**Table 3**. Simulated result obtained by adding an evaporative cooler

| S/N | Result of Simulation | Output | Output |
|---|---|---|---|
| 1 | Pump work $W_p$ | 0.0611kW | 0.0000611MW |
| 2 | Compressor work $W_c$ | 100400kW | 100.400MW |
| 3 | Turbine work $W_t$ | 214000kW | 214.000MW |
| 4 | Power generated | 112989kW | 112.989MW |
| 5 | Thermal efficiency | 0.3213 | 32.13% |

## 4. CONCLUSION

The power generated and thermal efficiency of a gas turbine power plant without an air inlet cooler are 101.4MW and 29.85% respectively. Power generated and thermal efficiency of a gas turbine power plant with an air inlet cooler are 112.989MW and 32.13% respectively.

As shown in table 2 and 3.2 the power generated and the thermal efficiency is higher when the power plant is incorporated with an evaporative cooler than a normal gas turbine without an inlet air cooler. An increase in power generated means more mega Watts of electricity is generated, more money is made and the running cost reduces.

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