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Thermodynamic Analysis of Wet Compression for Gas Turbine in Power Plant

Hasan Athari[1*], Sajjad Emami[2]

[1]Islamic Azad University-Khoy Branch, Khoy, Iran line Salmas, Iran
[2]Islamic Azad University-Khoy Branch, Khoy, Iran line Khoy, Iran

[*]Corresponding Author Email: Hasan.athari@gmail.com

Abstract: In order to achieve high efficiency and high specific work with lower emissions, the use of advanced gas turbine cycle in power systems is unavoidable. There are so many methods for this purpose. In this research, inlet air cooling has been analyzed thermodynamically. The utilize of inlet fogging for entrance of air in the compressor of gas turbine has these advantages such as easy installation, law primitive cost and maintaining cost also it causes to increase output power and improving the heat efficiency, special in during the peak loud, in power plant. In this study, the gas turbine cycle with steam injection and inlet fogging cooler has investigated because of second low of thermodynamic irreversibility in different parts of cycle has evaluated, and paying attention irreversibility in combustion chamber and wasting from outlet exhaust gas will be help full they obtained results are compared with normal injected gas. Also, our research data has analyzed in by EES software which is a computer program for modeling of gas turbine cycles. The obtained result in indicates that the output power in steam injected gas turbine cycle with inlet fogging cooler (FSTIG) is more outstanding them the simple steam injected gas turbine cycle (STIG).

Keywords: Gas turbine, Air cooling, Fogging cooler, Steam injection, Energy, Thermodynamic irreversibility.

Introduction

The performance of gas turbine cycle is influenced by ambient temperature. The output power and heat efficiency will be reduced, seriously. If the ambient temperature increased, the output power of gas turbine would decrease and also demand because of peak loud times increased during the summer days (Dawoud et al., 2004).

The recovery of wasted power by cooling of entrance air is one of advanced ways. In let cooling, Fogging specially, is one of the best ways in this method. The water morsels are sprayed on the entrance air (Lampugnano, 2000). And reduce the air temperature to reach to wet-bulb temperature. Sanayi and Tahani in (2009) studied the energy analysis of fogging for saturated state with 1% and 2% over spray, and they found that the entrance air fogging will increase the power of compressor to reach the maximum amount in saturated state, because decreasing of temperature causes the increasing density and mass rate.

In overspray, full spray water, state because of inter cooling effect, the water morsels evaporate in of compressor and approach the adiabatic process to isothermal process. So, the consumption power of compressor decreased (Cheng et al., 2009).

In gas power plants because at high temperature of exhaust gases from turbine stock, remarkable energy wastes. Steam injection method by recovery boiler in path of these gases, because of heat transfer between water and gases, saves the lost energy by producing the high pressure steam in superheated state this steam injected to combustion chamber. Therefore by increasing the mass rate and specific heat of combustions production, the turbines work increased.

Also, It is possible to utilize both techniques that we cold it FSTIG method. Using of fogging method in steam injection gas turbine causes to reduce the entrance-air's temperature (Chaker & Meher-Homji, 2002). So the amount of produced vapor is reduced in boiler because of low-temperature of exhaust gas from turbine stock.

The general discription of fsitg cycle

According to figure (1), entrance air with primitive pressure (P) and temperature (T_1) and relative humidity (W_4) enter the fogging cooler and because of spraying of water on the air the relative humidity of air raises to reach 100%, and air temperature reduces to reach to well-bulb temperature.

We assumed that the mixture process is adiabatic. Then, the saturated air enters in the compressor with polytropic efficiency $(\eta_{\infty,comp})$, and it is compressed until certain pressure rate. This air enters in the combustion chamber and causes the combustion process by the fuel which is at C_nH_m form in order to controlling the high-temperature of produced gasses (TIT), the air amount is elected more than (stocumetric) amount and it is identified with extra air factor (λ).

Then, the hot gases expended in turbine politropicly and produce the power. These gases enter the recovering boiler and produce the super heat vapor that is injected to the combustion chamber again.

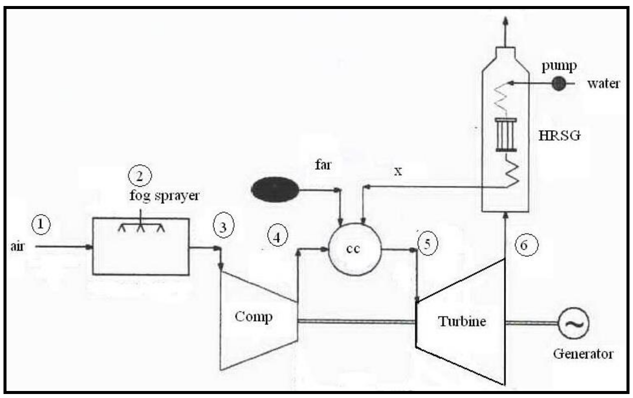

Figure1. Gas turbine cycle with steam injection and inlet fogging cooler.

Exergy analysis of different parts of cycle

The exergy balancing in fogging cooler is:

$$m_1\psi_1 + m_f\psi_f - m_3\psi_3 - m_w\psi_w - i_{fogcooler} = 0 \qquad (1)$$

That out let temperature and amount of consumption water in cooler is achieved by analyzing the energy.
The energy balancing in compressor is:

$$m_3\psi_3 + m_w\psi_w - W_{comp} - m_4\psi_4 - i_{comp} = 0 \qquad (2)$$

Utilizing of energy analysis, the out let air temperature from compressor and consumption power is achieved for 20kg entrance air.

The energy balancing in combustion chamber is:

$$m_4\psi_4 + m_{fuel}.\psi_{fuel} + m_s\psi_s - m_5\psi_5 - i_{cc} = 0 \qquad (3)$$

According to the energy analysis and defining entrance gases into the turbine temperature (TIT), the above equation is achieved.

The energy balancing in turbine is:

$$m_5\psi_5 - W_{turb} - m_6\psi_6 - i_{turb} = 0 \qquad (4)$$

By using the first law of thermodynamics, amount of recovery energy in boiler is achieved:

$$q_{HRSG} = ms(h_s - h_{w,hrsg}) \qquad (5)$$

The energy balancing in recovering boiler is:

$$m_6\psi_6 + m_s\psi_{w,HRSG} - m_6\psi_{stack} - m_s\psi_s - i_{HRSG} = 0$$

$$m_6 = m_3 + far.m_1 + m_s \qquad (6)$$

So the amount of recovered energy by boiler is:

$$Ex_{recovery} = m_s(\psi_s - \psi_{w,HRSG}) \qquad (7)$$

The wasted exergy from boiler's stock is:

$$Ex_{stack} = (m_3 + far.m_1 + m_s)\psi_{stack} \qquad (8)$$

Table 1. Nomenclature

Mg	Mass of sprayed water
ψ f	Exergy of sprayed water
m_w	Mass of unevaporated water (overspray)
ψ_w	Exergy of unevaporated water (overspray)
λ	Extra air factor
far	The ratio of fuel-mass to entrance air-mass
m_s	Mass of injection vapor to combustion chamber
ψ_s	Exergy of injection vapor to combustion chamber
ψ_{stock}	Exergy out let gasses from stock
$\psi_w, HRSG$	Exergy of water in pressure of combustion chamber

The total analysis of cycle based on second law of thermodynamics

According to above equations, the irreversibility of total cycle is achieved from sum of irreversibility in each part of cycle.

$$I_{cycle} = i_{fogcooler} + i_{comp} + i_{cc} + i_{turb} + i_{HRSG} \qquad (9)$$

The second law of thermodynamics efficiency is defined as follow: (Jobaidur & Wang, 2006)

$$\eta_{II,cycle} = \frac{W_{net}}{far \times \psi_{fuel}} \times 100$$

$$i_{rel,fogcooler} = \frac{i_{fogcooler}}{i_{cycle}} \qquad (10)$$

$$i_{rel,comp} = \frac{i_{comp}}{i_{cycle}}$$

$$i_{rel,turb} = \frac{i_{turb}}{i_{cycle}}$$

$$i_{rel,cc} = \frac{i_{cc}}{i_{cycle}}$$

$$i_{rel,hrsg} = \frac{i_{hrsg}}{i_{cycle}} \qquad (11)$$

$$i_{rel,fogcooler} + i_{rel,comp} + i_{rel,cc} + i_{rel,turb} + i_{rel,hrsg} = 1 \qquad (12)$$

The total assumptions for analysis of cycles

For approaching the results of the real cycles, we must enter following assumptions in equations.
The mass rate of entrance air is considerate 20 kg/s.
The polytropic efficiencies of compressor and turbine are 0.88.

The consumed fuel in combustion chamber is methane (CH_4) that its low heating value's amount is 50010 kg/kg.

The efficiency of boiler (ratio of observed heat by water to total heat of exhaust gases from turbine's stock) is 96%.

The efficiency of combustion chamber assumes to be 99% and drop pressure is 4%.

Difference of temperature at pinch point in boiler is 25 $^{\circ}C$ and final difference of temperature is 50 $^{\circ}C$ (Jobaidur & Wang, 2006).

Validation

In order to valid the achieved results from software analysis, we compared them by result of source for the GE917IE turbine (Sanaye & Tahani, 2009).

Table 2. Result of source for the GE917IE turbine.

	Reported	Computed	Difference%
$CIT[^{\circ}C]$	30	30.08	0.2
$CDT[^{\circ}C]$	293	286.9	2
W_{net}[Mw]	133	136	2.2
TOT$[^{\circ}C]$	553	577	4.3
Heat rate $[\frac{kj}{kwh}]$	10609	10653	0.4

Consideration of fstig cycle based on first law of thermodynamics

In FSTIG cycle, by increasing the ambient temperature in certain pressure ratio, the consumption power of compressor is increase but the mass of entering into turbine is almost constant. So, the produced power by turbine will be fixed, and out let power reduced. In the certain temperature, FSTIG'S power is more than the STIG'S one. By increasing the amount of overspray, total mass rate of turbine and produced power of turbine Increase and consumption power of compressor because of inter cooling effect reduce. So, the output power is increased.

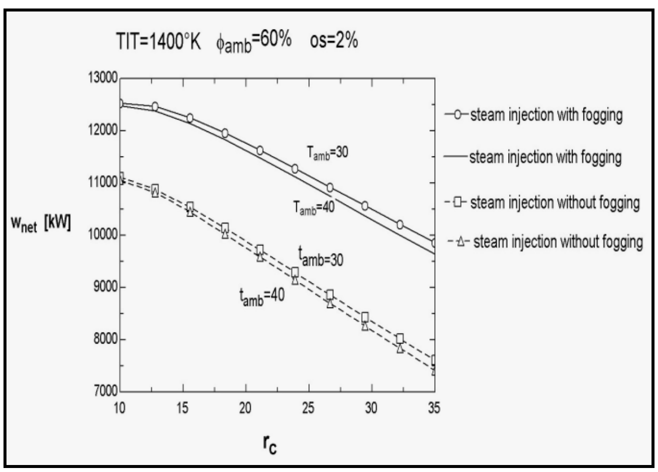

Figure2. The outlet power of FSTIG cycle to relative pressure in different ambient temperature.

Consinderation of sftig cycle based on second law of thermodynamics

Figures (3) and (4) indicate the irreversibility cures for compressor in different pressure ratio. By increasing the pressure ratio, because of increasing out let air temperature from compressor and its exergy, the irreversibility of compressor decrease. Over spraying the water, because of inter cooling effect, causes to irreversibility reduction. Also, the figures indicate that in high ambient temperature and high humidity ratio, the irreversibility of compressor in FSTIG cycle is reduced.

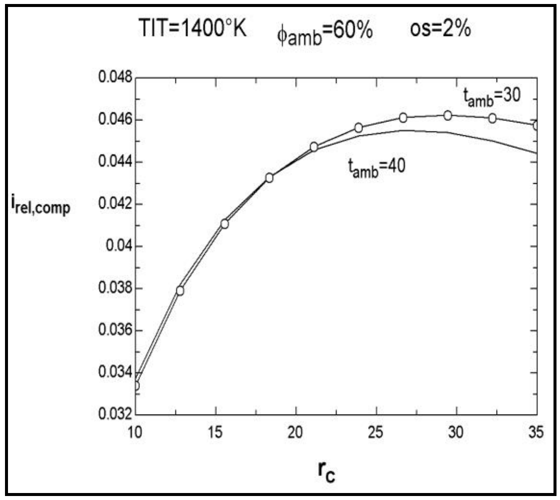

Figure 3. Compressor relative irreversibility in FSTIG cycle to pressure ratio in different ambient temperature.

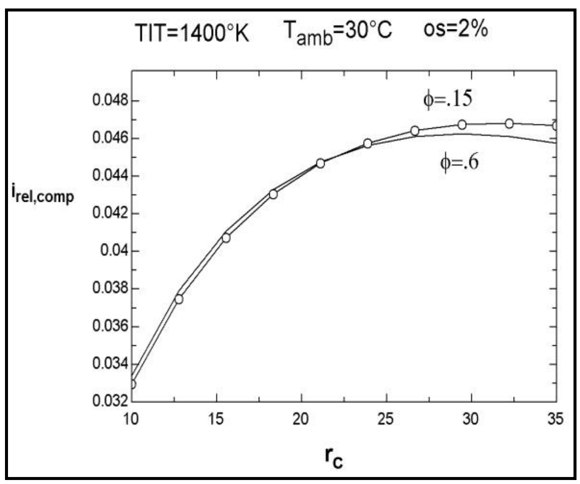

Figure 4. Compressor relative irreversibility in FSTIG cycle to pressure ratio in different ambient relative humidity.

Figure (5) investigates the irreversibility of combustion case in entrance variety condition. It's clear that by utilizing ambient temperature and pressure ratio, irreversibility is reduced because the outlet temperature of compressor and its energy is increased.

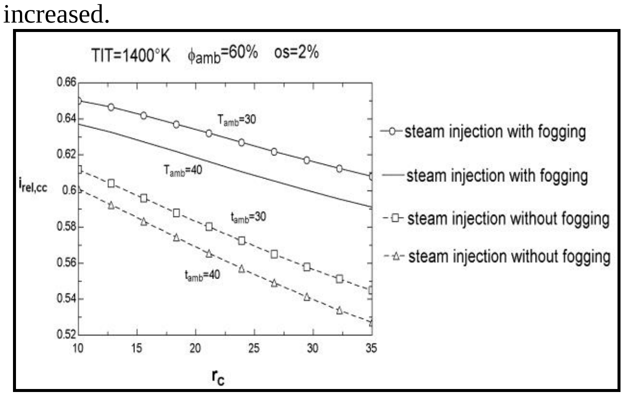

Figure 5. Combustion chamber relative irreversibility in FSTIG cycle to pressure ratio in different ambient temperature.

Results

According to the results, we found that the maximum amount of irreversibility in FSTIG cycle happen in the combustion figures (6) and (7) help us to compare the performance of different cycles in the maximum power and maximum conditions at 45ºC ambient temperature and 15% relative humidity.

Figures (6) and (7) indicate that second law of thermodynamic efficiency for STIG cycle is more than in both FSTIG'S efficiency and simple gas turbine cycle's (SGT).

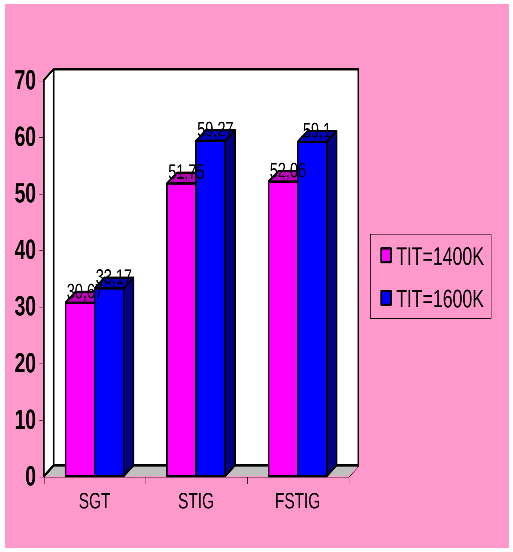

Figure7. 2nd law efficiency for different cycles in maximum outlet power at $T_{amb} = 45^{\circ}C \;\; \phi_{amb} = 15\%$ and OS=2%.

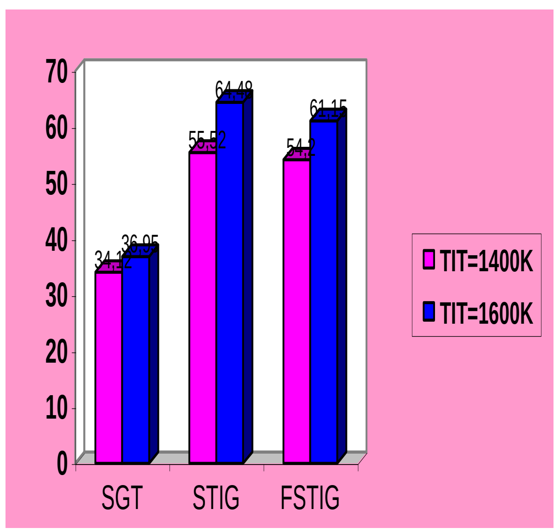

Figure 8. 2nd law efficiency for different cycles in maximum efficiency at $T_{amb} = 45^{\circ}C \;\; \phi_{amb} = 15\%$ and OS=2%.

Concern for irreversibility in combustion chamber and wasted energy by exhaust gases from turbine stock is more useful because. They contain the majority amount of wasted energy in the FSTIG'S cycle.

Figures (9) and (10) show that, the utilize of cooler in PTIG cycle causes to increase irreversibility in combustion chamber. By raising the TIT, the outlet temperature of turbine (TOT) increases. So, the temperature of produced vapor in boiler increases, Two. It causes to reduce the irreversibility combustion.

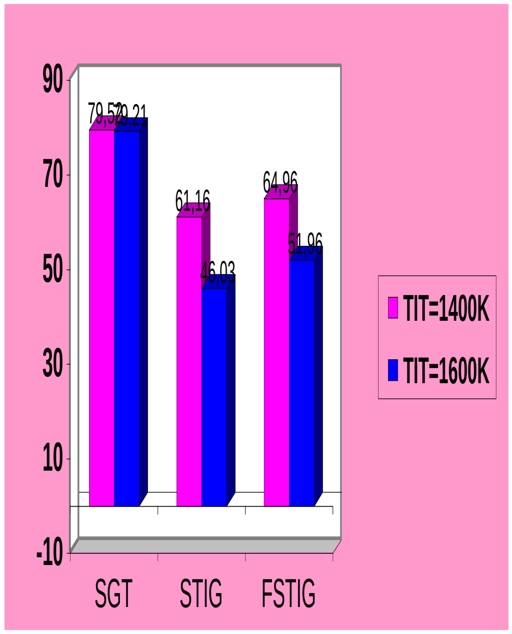

Figure 9. The relative irreversibility of combustion chamber for different cycles in maximum outlet power at $T_{amb} = 45^{\circ}C$ $\phi_{amb} = 15\%$ and OS=2%.

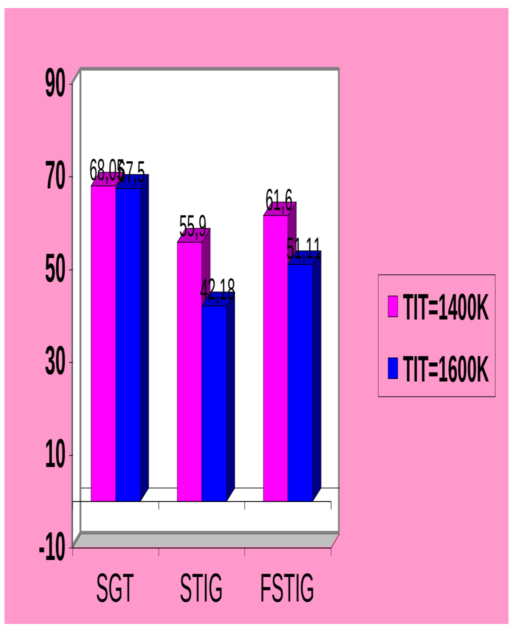

Figure 10. The relative irreversibility of combustion chamber for different cycles in maximum efficiency at $T_{amb} = 45^{o}C$ $\phi_{amb} = 15\%$ and OS=2%.

In figures (11) and (12) the wasted energy from turbine stock is indicated with numerical percent. In these figures, the remarkable reducing of wasted energy in STIC cycle is outstanding. Because of using this method, we recovery enormous amount of out let gasses that causes to increase the mass rate of turbine entrance.

$EL_{exit}[KW]$

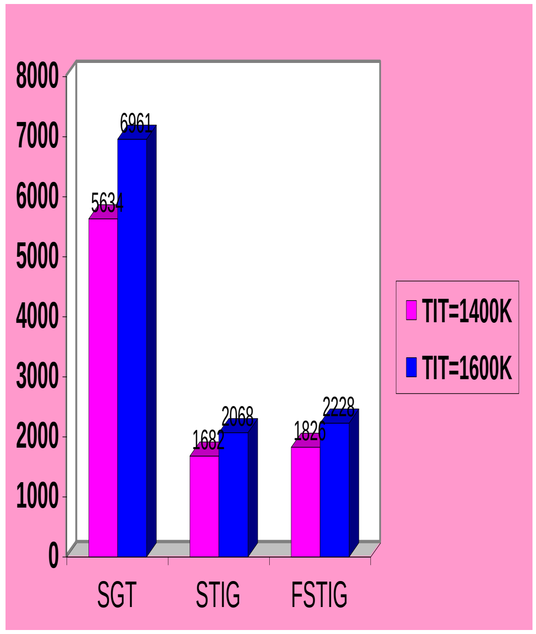

Figure 11. Energy losses by exhaust gasses from turbine stock for different cycles in maximum outlet power at $T_{amb} = 45^\circ C$, $\phi_{amb} = 15\%$, OS=2% and entrance flow 20kg.s $^{-1}$.

$EL_{exit}[KW]$

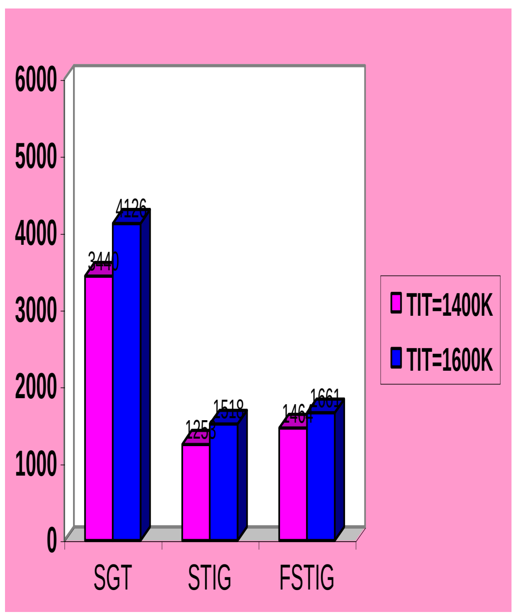

Figure 12 . Energy losses by exhaust gasses from turbine stock for different cycles in maximum efficiency at $T_{amb} = 45^\circ C$, $\phi_{amb} = 15\%$, OS=2% and entrance flow 20kg.s $^{-1}$ **.**

Conclusion

Considering the results, we can conclude that gas turbine cycle with steam injection and simultaneous cooling (FSTIG) is better than the other cycles in terms of outlet power, and in term of thermal efficiency, cooling cycles without steam injection (STIG) are better than others.

The simple gas turbine cycle by utilizing the fogging system (FST) can be improved in terms of performance and efficiency, BUT fogging system in (FSTG) cycle causes the decreasing of efficiency.

References

Chaker M, Meher-Homji C B, 2002. Inlet Fogging of Gas Turbine Engines:Climatic Analysis of Gasturbine Evaporative Cooling Potential Ofinternational Locations. Proceedings of ASME Turbo Expo. The Netherlands. [Google Scholar] [Publisher] https://doi.org/10.1115/1.1707034

Dawoud B, Zurigat Y H, Bortmany J, 2004. Thermodynamics assessment of power requirements and impact of different gas-turbine inlet air cooling techniques at two different locations in oman. Applied Thermal Engineering. [Google Scholar] [Publisher] https://doi.org/10.1016/j.applthermaleng.2004.11.007

Jobaidur R, Wang T, 2006. Fog and Overspray Cooling for Gas Turbine Systems with Low Calorific Value Fuels. Proceedings of GT2006ASME Turbo: Power for Land. Sea & AirMay 8-11, Barcelona, Spain. [Google Scholar] [Publisher] https://doi.org/10.1115/GT2006-90396

Lampugnano V, 2000. Various Turbine Inlet Air Cooling, Mechanical Refrigeration Systems, Comparison and Optimization. Proceedings of 2000 International Joint Power Generation Conf. [Google Scholar]

Sanaye S , Tahani M, 2009. Analysis of gas turbine operating parameters with inlet fogging and wet compression processes. Applied Thermal Engineering. [Google Scholar] [Publisher] https://doi.org/10.1016/j.applthermaleng.2009.08.011

Yang C , Yang Z , Ruixian C, 2009. Analytical method for evaluation of gas turbine inlet air cooling in combined cycle power plant. Applied Energy. 86: 848–856. [Google Scholar] [Publisher] https://doi.org/10.1016/j.apenergy.2008.08.019