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Performance Evaluation of a Simple Gas Turbine Power Plant Using Vapour Absorption Chiller

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ABSTRACT: *The performance of gas turbines in whichever way is operated; either as a simple cycle or a combined cycle is critically constrained by the prevailing ambient temperature, predominantly in arid or tropical climates Sub-Sahara Africa countries like Nigeria. In this present work, performance evaluation of a simple gas turbine power plant using vapour absorption chiller was carried out. A retrofitted power plant is modeled using IPSEpro software that utilizes waste heat from exhaust gas of the base power plant to generate steam in a heat exchanger. Part of the steam generated is used to power lithium bromide single-effect vapour absorption chillers which in turn cool the incoming air to the compressor. The results obtained show that the vapour absorption cooling system reduces the inlet temperature to the compressor from 25.7^{0}C to 15.065^{0}C. Also, the mass of air increased by 13.23kg/s, thereby boosting the power output with an increment of 3.5MW and thermal efficiency of 1.12%. Moreover, the specific fuel consumption reduces by 0.0079Kg/KWh and the net station heat rate reduces by 369KJ/KWh. This signified that less energy is consumed to generate higher power output and the retrofitted power plant will be more efficient than the existing power plant. Furthermore, greenhouse gas emission saving was analyzed. The result showed a net savings of 276.654kg greenhouse gases.*

Keywords: *Gas turbine; Vapour Absorption Chiller; Cooling; Thermal Efficiency; Power Output*.

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I Introduction

A gas turbine (GT), also known as combustion turbine is a rotary engine that removes energy from a flow of combustion of gas. It has an upstream compressor merged to a downstream turbine, and a combustion chamber in between. Energy is released when the air is mixed with fuel and ignited in the combustor. The resulting gases are absorbed over the turbine's blades spinning the turbine and powering the compressor. Gas turbines are considered as constant volume machines; as a result, the same volume of air moves into the compressor at a given speed. The combustion air of gas turbine is taken directly from the environment, and the weather conditions of the environment affect their performance. Generally, gas turbine power output and efficiency are adversely affected by environmental conditions such as high ambient temperature and relative humidity (RH). The recommended operation condition of gas turbines by International Organization for Standardization (ISO) is temperature of 15^{0}C and relative humidity of 60% (Ibrahim, et al., 2010; Orhorhoro, et al., 2017; Zunaid, et al., 2017). The average ambient temperate of the study gas turbine power plant is 25.7^{0}C, which is higher than the ISO condition. Due to this high temperature, the power output and thermal efficiency is low. However, cooling the intake air to compressor by incorporating vapour absorption chiller is a cooling techniques proposed here to mitigate the effect of ambient temperature on this gas turbine power plant.

Gas turbine performance is sensitive to the ambient air temperature. As the ambient air temperature increases, less air is compressed by the compressor. Thus, the gas turbine output rating is reduced. Besides, the compression work increases as a result of increase in the specific volume of the air which directly increases the intake air temperature (Büche, 2003; Mahmood, et al., 2009; Abam, et al., 2011; Ana, et al., 2012). The gas turbine is designed to operate with a constant air volume flow in the compressor. Nevertheless, when the ambient air temperature increases, its specific mass is reduced, so that the mass flow rate entering the turbine is accordingly decreased. Consequently, this decreases the power output and the efficiency of the gas turbine. The performance of the plant decreases as the ambient temperature increases, due to the inverse relationship between air density and temperature (Nasser and EL-kalay, 1991; Siadi-Mehrabad, 1996; Barzegar, et al., 2011; Kaviri, et al., 2012; Nami, et al., 2016). Improving the performance of gas turbine can be successful carried out through raising the turbine inlet temperature (TIT) and the compressor pressure ratio (Ibrahim, et al., 2011). It is a known fact that ambient temperature, humidity and pressure are crucial factors that determine the performance of a gas turbine plant (Kim, et al., 2011). Also, thermodynamic analysis revealed that thermal efficiency decreases with an increase humidity and ambient temperature (Meher-Homji, and Mee, 1995; Shi, et al., 2010; Sanaye, et al., 2010).

In tropical humid and hot arid zones like Nigeria, the ambient high air temperature restricts the air mass intake and consequently reduces the gas turbine power output and its efficiency. But, cooling the turbine inlet air back to the ISO condition (temperature of 15^0C and humidity of 60%) can restore the design point performance (Al-Tobi, 2009; Farzaneh-Gord and Deymi-Dashtebayaz, 2011). One of the ways to achieve this is the adoption of vapour absorption chiller. Vapour absorption chillers utilize the waste heat from the turbine exhaust to achieve cooling for the intake air. The chilled water produced from the absorption chillers can cool the incoming air to the recommended ISO conditions (Grossman, et al., 1994; Firdaus, et al., 2011). In this present work, the vapour absorption chiller is expected to cool the intake air down to 15°C without taking into account the effect of air humidity. Various parametric variations are considered to determine the impact of weather conditions on the performance of the study turbine. Aside from investigating the technical aspects, the present work briefly assesses the economic benefits of its implementation.

II Research Methodology

In this present work, IPSEpro software was used to modelled the gas turbine using vapour absorption chiller. IPSEpro is a set of software modules that create, analyse and utilize models of a new process plant or existing process plant. The core of IPSEpro is an exceedingly flexible modeling system for calculating heat balances and simulating processes. It has the capability to represent any problem as a network of collected and connected components. The IPSEpro design suite consists of a number of modules; however, only two of them were used in this present study. The gas power plant parameters and operating conditions used in the modeling are as shown in Table 1.

Table 1. Gas Turbine Power Plant Specifications

Specifications	Description/code
Manufacturer	GE
Model	GE9E
Fuel	Natural Gas
Frequency	50 Hz
Year	2006
Compressor	Axial
No. of compressor stages	16
No. of turbine stages	2
Compression ratio	9.7
Design capacity	508WM(ISO)
Generating Capacity	112.5MWe each
Turbine isentropic efficiency	0.894
Compressor isentropic efficiency	0.878
Turbine efficiency	0.97
Compressor efficiency	0.95
Average Inlet temperature	25.7^0C
Gas temperature	55^0C
Exhaust temperature	557.13^0C
Mass of air	376.72 Kg/s
Mass of fuel	6.7 Kg/s
Exhaust mass flow	383.42 Kg/s
Lower heat value (LHV)	46670 KJ/Kg
Design ambient barometric pressure	1.013 bar
Gas pressure	22.8 bar

Figure 1 shows the gas turbine power plant compressor inlet cooling arrangement. The gas turbine power plant comprises of the base gas turbine, two heat exchangers and a single effect vapour absorption chiller. A single-effect vapour absorption chiller was adopted for this research work. Also, LiBr- H_20 was chosen over NH_3-H_20. This is because of the non-toxicity of LiBr- H_20, low volatility of LiBr, and absence of rectifier. It equally possesses lower installation, low maintenance and operating costs. Furthermore, the refrigeration process considered is based on single effect LiBr- H_20 vapour absorption system fired by steam, which is generated by waste heat recuperated from gas turbine exhaust gases.

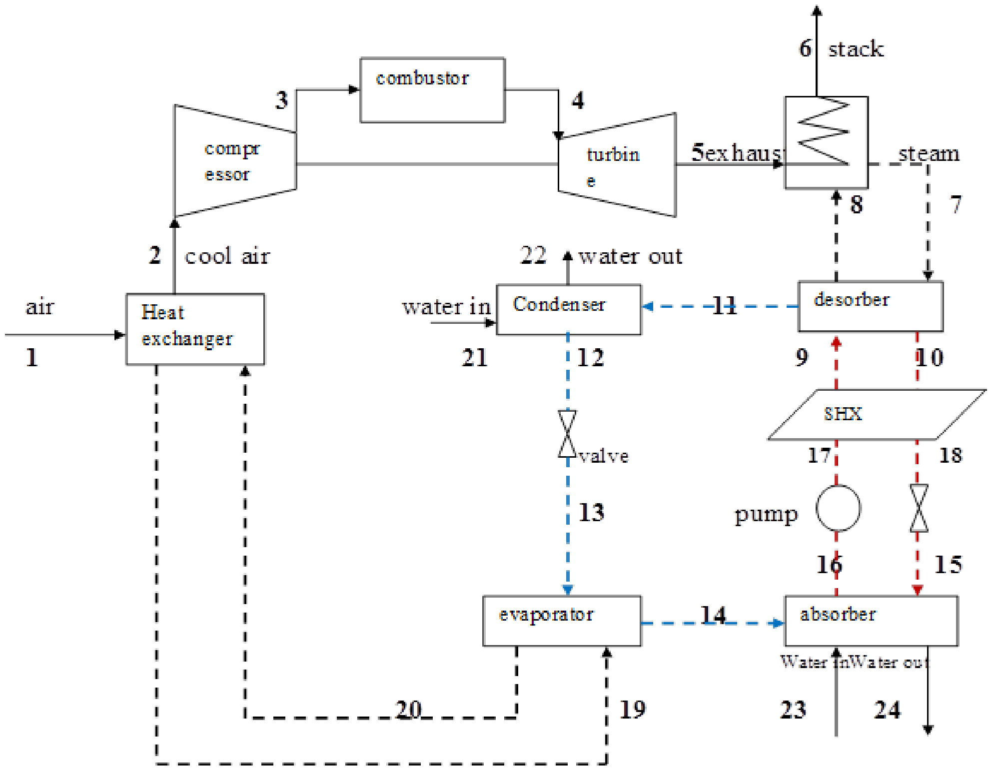

Figure 1. Gas Turbine Compressor Inlet Cooling Arrangement

Air come in to the compressor at state 2 and is compressed isentropically to a higher pressure, P_3. The pressurized air at state 3 experiences constant pressure heat accumulation in the combustion chamber where it supplies hot gases to the turbine at state 4. After isentropic expansion process, waste energy from the turbine exhaust gases at state 5 is recovered in the heat exchanger and stack gases at a temperature of 206.87^{0}C before it is dissipated to the environment at state 6. Moreover, the condensed steam at state 8 is compressed isentropically in a pump where it is returned as feed water to the exchanger. The exhaust gases obtained at state 5 heats the feed water to produce steam at state7. The steam produced at state 7 flows through a tube in the desorbed to heat the weak solution of LiBr-H_20 which is immersed in the tube. The LiBr-H_20 solution in the process absorbs heat from the steam. This causes the refrigerant to vapourized and separate from the absorbent solution. As the refrigerants vapourized away, the absorbent solution becomes more concentrated.

III Results And Discussion

The performance of the gas turbine power plant was determined using IPSEpro software. The software was used to evaluate compressor work, turbine work, net-power, thermal efficiency, specific fuel consumption and heat rate. Sensitive analysis of the gas turbine power plant was carried out using IPSEpro software. Variation in input variable such as temperature to the net power output, thermal efficiency, and specific fuel consumption were closely monitored. The results obtained are show in Table 2.

Table 2. Results obtained without Vapour Absorption Chiller and with Vapour Absorption Chiller

Item	Without Vapour Absorption Chiller	With Vapour Absorption Chiller	Units
Exhaust temperature	799.79	479.87	K
Compressor power	123800	123700	MW
Turbine power	225300	228700	MW
Net power	101500	105000	MW
Thermal efficiency	32.46	33.58	%
Specific fuel consumption	0.2376	0.2297	kg/kWh
Total mass flow rate	376.72	389.95	Kg/s

Figure 2 and Figure 3 highlighted the gas turbine performance in relation to ambient temperature with and without absorption chiller. As presented, an increase in temperature results in reduced power output and efficiency of the gas turbine without absorption chiller. This is due to the fact that at higher temperature, the air entering the compressor is less dense. As a result, a higher compressor work and lower turbine output are obtained. However, there was an improvement in net power output and thermal efficiency when vapour absorption chiller was incorporated. The power output and thermal efficiency increases as a result of reduction in ambient air temperature which lower the compressor power. A lower ambient temperature leads to higher air density and lower compressor power. This in turn gives a higher net power out and higher thermal efficiency. These results are in line with the work of previous researchers (Kakaras, et al., 2004; Saravanamuttoo, et al., 2009; Hosseini, et al, 2007; Ibrahim, et al., 2011).

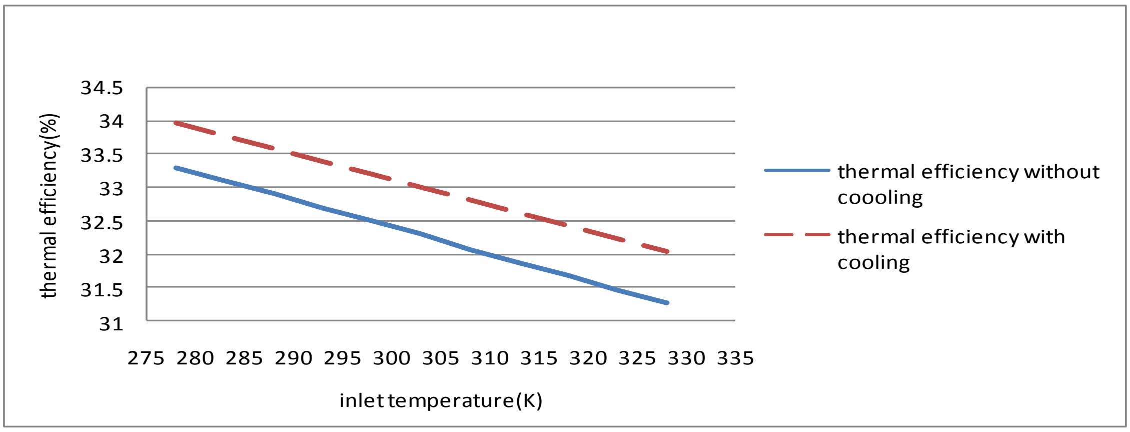

Figure 2. Effect of Ambient Temperature on Thermal Efficiency of Gas Turbine Power Plant

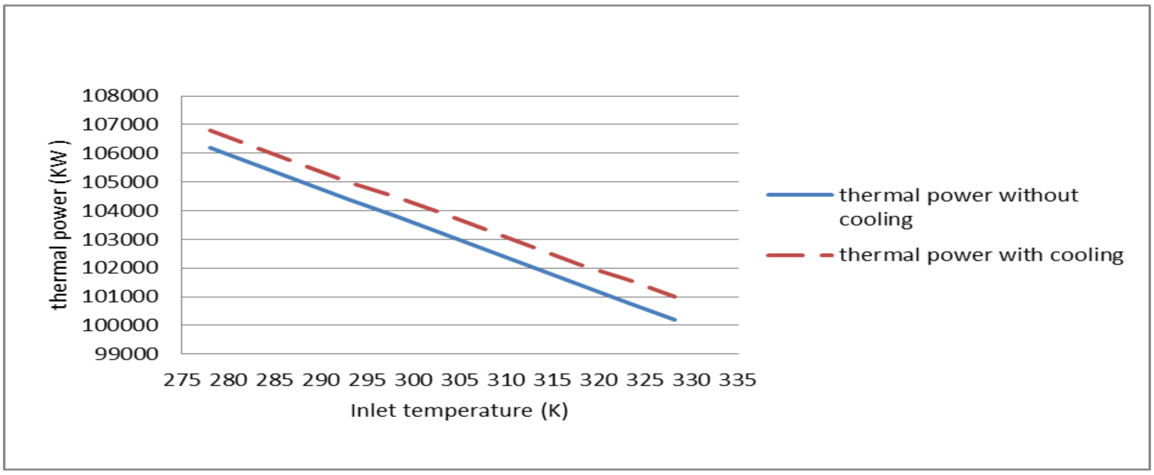

Figure 3. Effect of Ambient Temperature on Thermal Power Output of Gas Turbine Power Plant

Figure 4 shows that ambient air temperatures have a significant effect on specific fuel consumption on a gas turbine power plant. Increased in ambient air temperature resulted to increase in specific fuel consumption. This is due to increase in compressor power as a result of higher intake ambient air temperature. However, the specific fuel consumption reduces when cooling air intake is incorporated due to lower ambient air intake temperature.

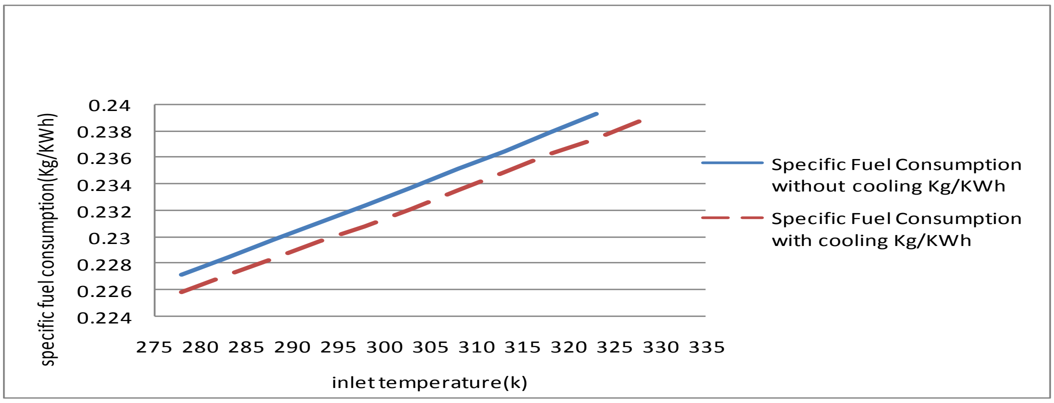

Figure 4. Effect of ambient temperature on specific fuel consumption

Therefore, the thermal efficiency, net-power output decreases and specific fuel consumption increases with increasing in the ambient air temperature**.** However, incorporating vapour absorption chiller improved the performance of gas turbine power plant as the thermal efficiency and net-power output obtained are high than that gotten from simple gas turbine plant without cooling. The incorporation of air intake cooling (vapour absorption chiller) will reduce environmental pollution as the specific fuel consumption is less than that of simple gas turbine plant.

Moreover, as the gas turbine power plant works at off-rated standard ambient air temperature, its specific fuel consumption and heat rate increases. These increase lead to emission of greenhouse gas (GHG) through turbine exhaust to the atmosphere which causes climate change. Equation 1 was used to calculate the greenhouse gas emission of the fuel of the gas turbine plant.

$GHG = FC \times EF_{CO2}$ (1) [24]

But,

Specific fuel consumption without vapour absorption chiller = 0.2376kg/kWh

Emission factor of natural CO_2 gas = 34260.008kWh

Thus, without vapour absorption chiller, the emission of GHG fuel was obtained as;

Emission of GHC Fuel = 0.2376 x 34260.00 = 8140.176kg

Also,

Specific fuel consumption with vapour absorption chiller = 0.2297kg/kWh

Emission of GHC Fuel = 0.2297 x 34260.00 = 7869.522kg

Thus, GHG fuel was save using vapour absorption chiller and the amount of fuel save was;

Emission GHG saving = 8140.176kg-7869.522kg = 276.654kg

IV Conclusion

The application of waste heat powered vapour absorption chiller for gas turbine compressor inlet air cooling was thermodynamically evaluated for performance. In the projected arrangement, the waste heat is recovered from gas turbine exhaust gases to generate steam in a waste heat recovery steam generator. This was driven by a single-effect lithium-bromide-water ($LiBr-H_20$) absorption refrigeration system (ARS) which generate cooling to the inlet air temperature entering the compressor. The thermodynamic performance of this arrangement was compared with a gas turbine power plant without vapour absorption chiller. The results obtained show that the inlet air cooling improves the net-power output and thermal efficiency by 3.45% and 1.12% respectively. The results also shown that the projected arrangement has a lower specific fuel consumption which confirm that the gas turbine power plant with vapour absorption chiller utilizes lesser fuel to produced higher power. Thus, this present work indicates that the implementation of vapour absorption chiller for gas turbine compressor inlet air cooling was clearly justified on the basis of thermo-economic feasibility. Also, the present work shows that vapour absorption chiller is an alternative solution to enhance electrical power generation in Sub-Sahara countries like Nigeria. This approach would also reduce plant natural gas consumption for power generation, likewise production costs and emissions.

V. Recommendation

Having carried out the research work on the performance evaluation of a simple gas turbine power plant using vapour absorption chiller, the following are recommended**:**

1. Gas turbine power plants design should be based on the weather data of the country where they are to be installed.
2. For the existing gas turbine power plant in Sub-Sahara Africa countries like Nigeria, the power plant should be retrofitted with vapour absorption chiller to enhance their performance.
3. Future research work should be carry out on optimizing the gas turbine power plant using other operating parameter like the relative humidity.

References

[1]. Abam, F. I., Ugot, I.U., and Igbong, D.I. (2011). Thermodynamic assessment of grid- based gasturbine power plants in Nigeria. J. Emerg. Trends Eng. Applied Sci., 2, 1026-1033

[2]. Al-Tobi, I. (2009). Performance Enhancement of Gas Turbines by inlet Air Cooling.

[3]. International Conference on Communication, Computer and Power (ICCCP'09) Muscat, 15(18), 165 – 170

[4]. Ana, P.S., Claudia, R.A., Edson, L.Z. (2012). Comparison of Different Gas Turbine Inlet Air Cooling Methods, World Academy of Science. Engineering and Technology 61, 40-45

[5]. Barzegar, A.H, Ahmadi, I.P., Ghaffarizadeh, A.R., Saidi, M.N. (2011). Thermo- economic-environmental multiobjective optimization of gas turbine power plant with preheater using evolutionary algorithm. Int. J. Energy Res, 35, 389-403

[6]. Büche, D. (2003). Multi-Objective Evolutionary Optimization of Gas Turbine Components. Unpublished PhD Thesis, Swiss Federal Institute of Technology, Zürich Farzaneh-Gord, M., Deymi-Dashtebayaz, M. (2011). Effect of various inlet air cooling methods on gas turbine performance, Energy, 36, 1196–1205

[7]. Firdaus, B.,Takanobu Y., Kimio N., Soe N. (2011). Effect of ambient temperature on the performance of micro gas turbine with cogeneration system in cold region. Applied Thermal Engineering, 31, 1058– 1067

[8]. Grossman, G., Wilk, M., DeVault, R.C. (1994). Simulation and performance analysis of triple-effect absorption cycles. ASHRAE Transactions, 100(2), 452–462

[9]. Hosseini, R., Beshkani A., Soltani, M. (2007). Performance improvement of gas turbines of Fars (Iran) combined cycle power plant by intake-air cooling using a media evaporative cooler. Energy Conversion and Management, 48 (4), 1055-1064.

[10]. Ibrahim, T.K., Rahman, M.M., Abdalla, A.N. (2010). Study on the effective parameter of gas turbine model with intercooled compression process. Scientific Research and Essays, 5(23), 3760-3770

[11]. Ibrahim, T.K., Rahman, M.M., Abdalla, A.N. (2011). Improvement of gas turbine performance based on inlet air cooling systems: A technical review. International Journal of Physical Sciences, 6 (4), 620-627

[12]. Kakaras, E. Doukelis, A. and Karellas, S. (2004). Compressor intake-air cooling in gas turbine plants. Energy, 29 (1215), 2347-2358

[13]. Kaviri, A.G., Jaafar, M.N., Mat Lazim, T. (2012). Modeling and multi-objective exergy based optimization of a combined cycle power plant using a genetic algorithm. Energy conversion management, 58, 94-103

[14]. Kim, Y.S., Lee, J.J., Kim, T.S., Sohn, J.L. (2011). Effects of syngas type on the operation and performance of a gas turbine in integrated gasification combined cycle. Energy Convers Manage, 52 (22), 62–71

[15]. Mahmood, F.G, Mahdi, D.D. (2009). A NewApproach for Enhancing Performance of a GasTurbine (Case Study:Khangiran Refinery). Appl., Energy, 86, 2750- 2759

[16]. Meher-Homji, C.B., Mee,T.R. (1995). Gas Turbine Augmentation by fogging of inlet Air. Proceeding of the 28thTurbomachinery Symposium, Houston Texas September

[17]. Nami,H., Mohammadkhani, F., Ranjbar, F. (2016). Thermodynamic Analysis and Optimization of a Novel Cogeneration System: Combination of a Gas Turbine with Supercritical CO_2 and Organic Rankine Cycles. International Journal of Engineering: IJE TRANSACTIONS C: Aspetcs, 29(12), 1765-1774

[18]. Nasser, A.E., EL-kalay, M.A. (1991). A heat-recovery cooling system to conserve energy in gas – turbine power stations in the Arabian Gulf. Applied Energy, 38 (2), 133-142

[19]. Orhorhoro, E.K., Achimnole, E.N., Onogbotsere, M.O., and Oghoghorie, O. (2017).

[20]. Simulation of Gas Turbine Power Plant using High Pressure Fogging Air Intake Cooling System. European Journal of Advances in Engineering and Technology, 2017, 4(9): 691-696

[21]. Sanaye,S, Tahani, M. (2010). Analysis of gas turbine operating parameters with inlet fogging and wet compression processes. Appl. Thermal Engineering, 30, 234-244

[22]. Saravanamuttoo, H., Straznicky, P., Rogers, C., Cohen, H. (2009). Gas turbine theory. 6th ed. Parson Education Limited

[23]. Shi, X., Agnew, B., Che, D., Gao, J. (2010). Performance enhancement of conventional combined cycle power plant by inlet air cooling, inter-Cooling and LNG cold energy utilization. Applied Thermal Engineering, 30, 2003 – 2010

[24]. Siadi-Mehrabad (1996). Turbine blade Investment casting cost estimating model.

[25]. International Journal of Engineering, 9(2), 53-59

[26]. Zunaid, M., Murtazab, Q., Samshera. (2017).Energy and Second Law of Thermodynamics Analysis of Shower Cooling Tower with Variation in Inlet Air Temperature. Interational Journal of Engineering: IJE TRANSACTIONS, 30(7), 1090-1097

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