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Influence of Turbine Inlet Temperature of The Performance of a Gas Turbine Power Plant Utilized for Electricity

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Abstract- The influence of turbine inlet temperature of the performance of a gas turbine power plant utilized for electricity has been done. The investigation which comprises of recorded turbine data that were used to compute the parameters of power output, power differential, compressor work, turbine work, heat supplied, net work, SFC, AFR, and thermal efficiency of the gas turbine power plant. Correlation of these parameters with the turbine inlet temperature showed close dependence on this temperature. The resulting equations are therefore useful in predicting any of the parameters with known values of turbine inlet temperature for the particular type of this turbine plant excepting that of the power output, air-fuel ratio and thermal efficiency which showed decreasing trends with increase of turbine inlet temperature.

Indexed Terms- Influence, Turbine inlet temperature, Plant parameters, Performance

I. INTRODUCTION

Gas turbines generate their power from burning a fuel-air mixture in a combustion chamber, whence the fast-flowing combustion gases are used to move the turbine[1].One of the most important advancements in gas turbine technology is the increase in turbine inlet temperature, achievable due to advances in turbine blade cooling techniques and metallurgical improvements[1][2]. Several other approaches had been proposed and applied, through research, to achieve improvements in performance of gas turbines; some of the established performance criteria of gas power plants being the thermal efficiency, specific fuel consumption, power output and work ratio. These criteria are affected by such parameters as compressor inlet temperature, compression ratio, combustion inlet temperature and turbine inlet temperature[4][5].

In an earlier study, the authors carried out an evaluation of the influence of ambient temperature on a gas turbine plant situated in the coastal region of Nigeria, with a characteristic warm and humid climate [6]. Results of that study showed improvements in plant performance with reduced ambient temperature, in consonance with results of other studies, albeit at varying levels of improvement [1][7][8]. The present study analyses the influence of the turbine inlet temperature (which derives from the exhaust temperature of the combustion chamber) on the performance of that gas turbine plant.

II. METHODOLOGY

The methodology involved the collection of operational data from logsheets of the turbine unit, generator and the plant auxiliaries of the 'MS5001 Nuovopignone' turbine plant of the Trans-Amadi Gas Turbine Station Phase II at Port Harcourt, Nigeria. Relevant plant parameters which were not in the available records were obtained using appropriate thermodynamic principles and equations [9][10]. Utilizing the provided nomenclature and referring to Fig. 1, the relevant equations are obtained as follows:
The plant network can be obtained as

$$\dot{W} = \dot{W}_T - \dot{W}_C \tag{1}$$

Where, Turbine Work

$$\dot{W}_T = \dot{m}_{\mathrm{g}} C_{\mathrm{pg}} (T_3 - T_4) \tag{2}$$

Compressor Work

$$\dot{W}_C = \dot{m}_{\mathrm{a}} C_{\mathrm{pa}} (T_2 - T_1) \tag{3}$$

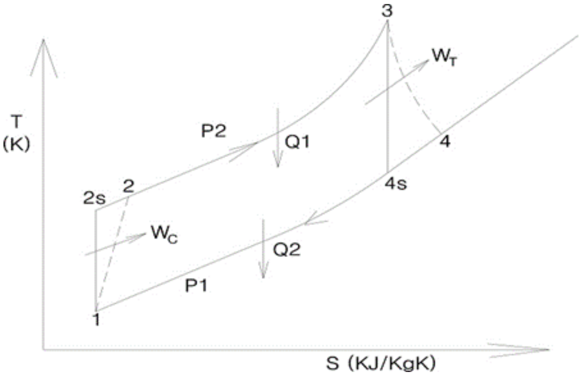

Figure: T – S Diagram for the Simple Gas Turbine Operation [9][10][12][15]

The energy balance in the combustion chamber is given as [8].

$$\dot{m}_a C_{pa} T_2 + \dot{m}_f \times LHV + \dot{m}_f C_{pf} T_f = (\dot{m}_a + \dot{m}_f) C_{pg} \times T_3 \qquad (4)$$

Where LHV = 47541.6KJ/Kg [11]

Considering that the term $\dot{m}_f C_{pf} T_f$ is negligible in relation to $\dot{m}_a C_{pa} T_2$ [11] in Eqn. 4, the turbine inlet temperature T_3 is obtained as

$$T_3 = \frac{\dot{m}_a C_{pa} T_2 + \dot{m}_f LHV}{(\dot{m}_a + \dot{m}_f) C_{pg}} \qquad (5)$$

The heat added in the combustion chamber can be approximated as [13]

$$Q_{added} = \dot{m}_g C_{pg} (T_3 - T_2) \qquad (6)$$

The plant thermal efficiency can be expressed as

$$\eta_{th} = \frac{\text{Net Work}}{\text{Heat Supplied}} = \frac{W}{Q_{added}} \qquad (7)$$

Furthermore, the specific fuel consumption can be expressed as [14]

$$SFC = \frac{3600}{AFR \times \dot{W}} \qquad (8)$$

with the AFR given as

$$AFR = \frac{LHV}{Q_{added}}$$

III. RESULTS AND DISCUSSION

- Results

Table 1 shows the design parameters of the test 'MS5001 Nuovopignone' gas turbine while Table 2 shows operational data as obtained from the logsheets of the turbine unit, generator and plant auxiliaries. The calculated parameters(using a 'Matlab' software), namely turbine inlet temperature, compressor work, turbine work, network, heat supplied, specific fuel consumption, air – fuel ratio and thermal efficiency, utilizing the data in Table 2, are shown in Table 3. This table also shows values of the power differential, obtained as the difference between the design power of 25MW and the recorded power output shown in Table 2.

The influence of the turbine inlet temperature on the recorded power output, power differential, compressor work, turbine work, heat supplied, network, specific fuel consumption, air – fuel ratio and thermal efficiency are depicted in the respective graphs of Figures. 2 to 10, obtained using a 'Microsoft Excel' program.

- Discussion

The graphs show that for an increase in turbine inlet temperature from 1041^{o}C to 1165^{o}C the following respective changes in the parameters of power output, power differential, compressor work, turbine work, heat supplied, network, specific fuel consumption, air-fuel ratio and thermal efficiency occurred: 11.13MW to 11.05MW, 13.87MW to 13.95MW, 220KW to 230KW, 760KW to 910KW, 2130KW to 2710KW, 540KW to 680KW, 0.300Kg/KWh to 0.310Kg/KWh, 22.4 to 17.5 and 25.4% to 24.7%. With the exception of the graphs of Figures. 2, 9 and 10 (which, respectively, depict decreasing trends for power output, air-fuel ratio and thermal efficiency) all graphs show increasing trends for the various parameters. The least coefficient of determination R^2 for the graphs, obtained from the 'Excel' program, is 0.673 (for the parameter of specific fuel consumption). From statistical data (Lipson & Sheth, 2007), R^2 required for a 95% confidence level is 0.500. Since this is less than 0.673, there is 95% confidence that all the graphs can be utilized in obtaining the various values of parameters which they represent, with a knowledge of any turbine inlet temperature.

CONCLUSION

The influence of turbine inlet temperature on various plant parameters has been performed. The graphical results indicate good correlation of parameters with changing turbine inlet temperature and are, therefore, useful in predicting values of parameters for any given turbine inlet temperature of this plant.

Table: Design Values of MS5001 Nuovopignone Gas Turbine Plant

S/N	Parameters	Units	Design Data
1	Power Output	MW	25
2	Thermal Efficiency	%	26.6
3	Heat Rate	Kcal/W.h	2.833
4	Specific Fuel Consumption	kg/KW.h	0.308
5	Ambient Temperature	^{0}C	25.0-45.0
6	Specific Heat at Constant Pressure of gas	kJ/kgK	1.155
7	Specific Heat at Constant Pressure of Air	kJ/kgK	1.005
8	Isentropic Constants for air	None	1.40
9	Isentropic Constants for gas	None	1.33
10	Mass Flow Rate of air	kg/s	122.9

Table 2: Plant Operating Values from Direct Reading of Logsheets

S/N	Ambient Temperature $T_1{}^0C$	Compressor Exit Temperature $T_2{}^0C$	Exhaust Temperature $T_4{}^0C$	Fuel Supply $\dot{m}_f$ (kg/s)	Power Output (MW)
1	28	246	385	2.66	11.13
2	29	247	387	2.67	11.13
3	30	248	390	2.68	11.13
4	31	250	392	2.69	11.12
5	32	254	394	2.80	11.11
6	33	257	388	2.82	11.10
7	34	258	400	2.90	11.09
8	35	260	389	2.92	11.08
9	36	262	388	2.98	11.07
10	37	265	379	3.00	11.04

Table 3: Calculated Plant Parameters

S/N	Turbine Inlet Temperature $T_3{}^0C$	Compressor Work $\dot{W}_c$(KW)	Turbine Work $\dot{W}_T$(KW)	Heat Supplied Q_{added} (KW)	Net Work $\dot{W}_{net}$ (KW)	Air Fuel Ratio AFR	Thermal Efficiency η_{th} (%)	Specific Fuel Consumption SFC (kg/KWh)	Power Differential (MW)
1	1041	219	758	2125	539	22.37	25.37	0.299	13.87
2	1045	219	760	2141	541	22.21	25.27	0.300	13.87
3	1049	219	761	2157	542	22.04	25.13	0.301	13.87
4	1054	220	765	2174	545	21.87	25.07	0.302	13.88
5	1092	223	806	2358	583	20.16	24.72	0.306	13.89
6	1101	225	824	2392	599	19.88	25.04	0.302	13.90
7	1127	225	840	2533	615	18.77	24.28	0.312	13.91
8	1135	226	862	2568	635	18.51	24.72	0.306	13.92
9	1156	227	887	2677	660	17.76	24.65	0.307	13.93

10	1165	229	908	2714	679	17.52	25.02	0.303	13.96

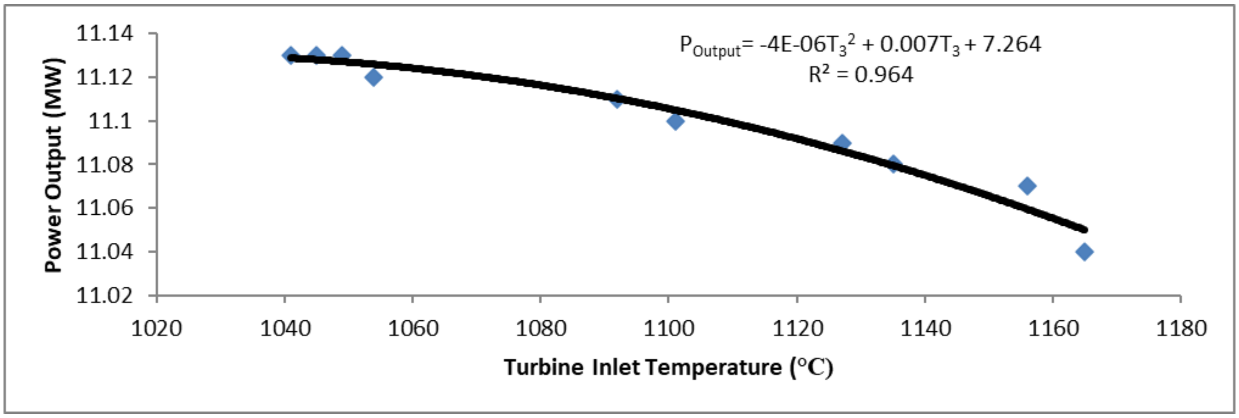

Figure 2 : Influence of Turbine Inlet Temperature on the Power Output

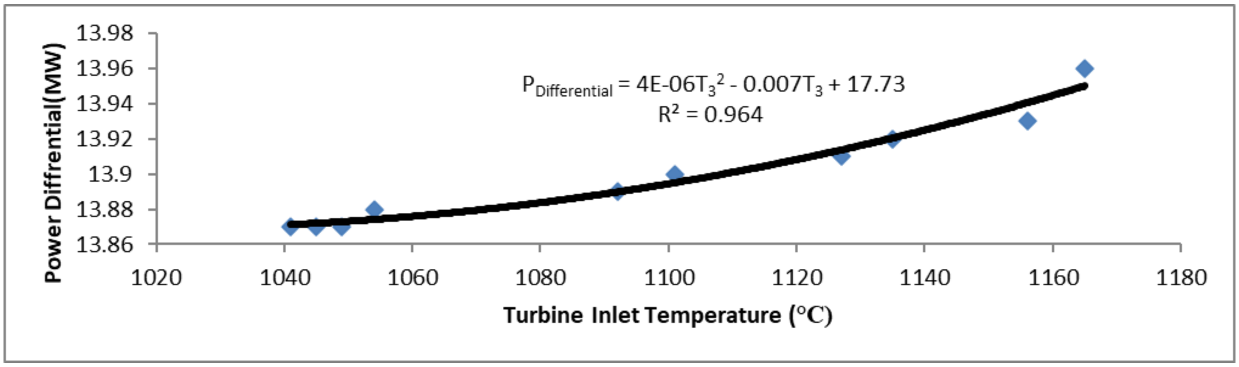

Figure 3: Influence of Turbine Inlet Temperature on the Power Differential

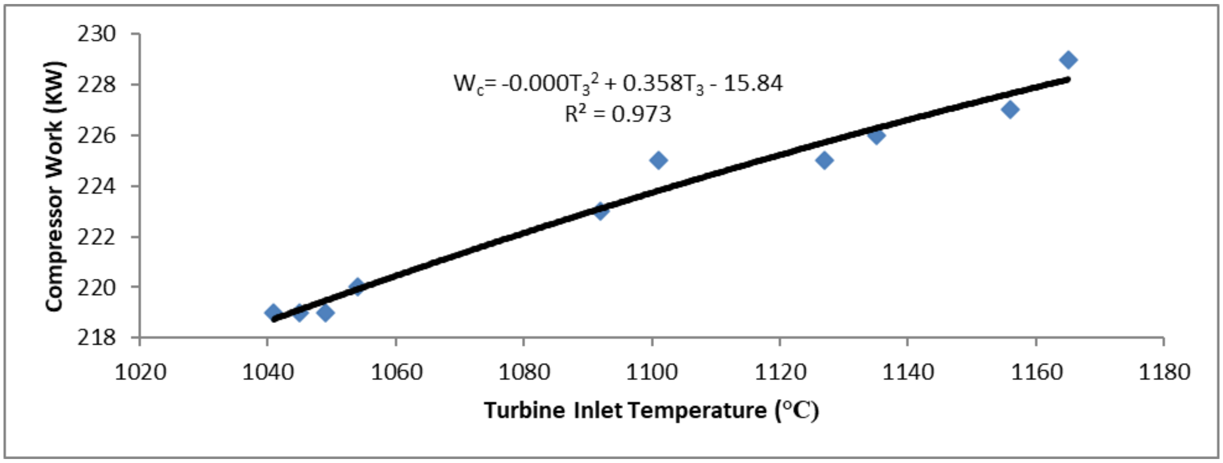

Figure 4: Influence of Turbine Inlet Temperature on the Compressor Work

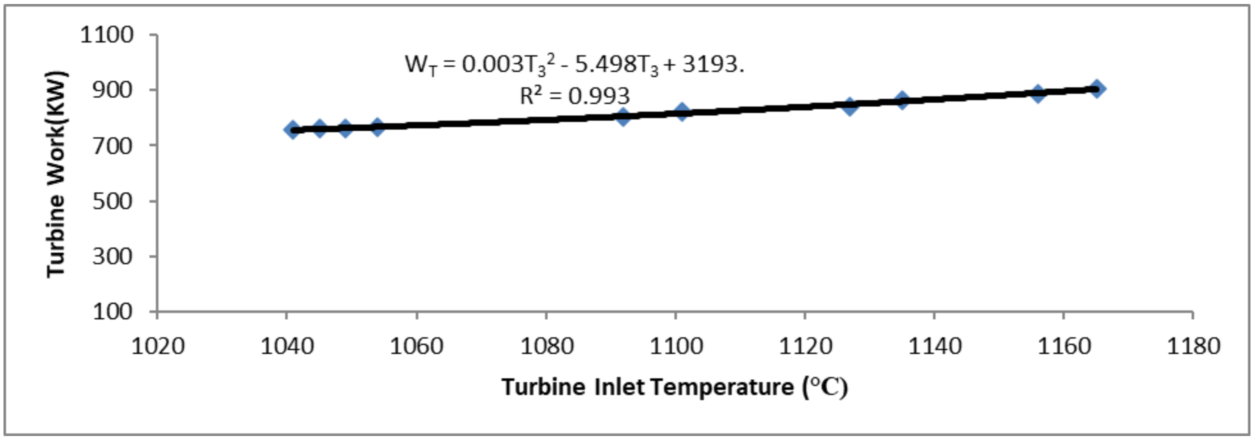

Figure 5: Influence of Turbine Inlet Temperature on the Turbine Work

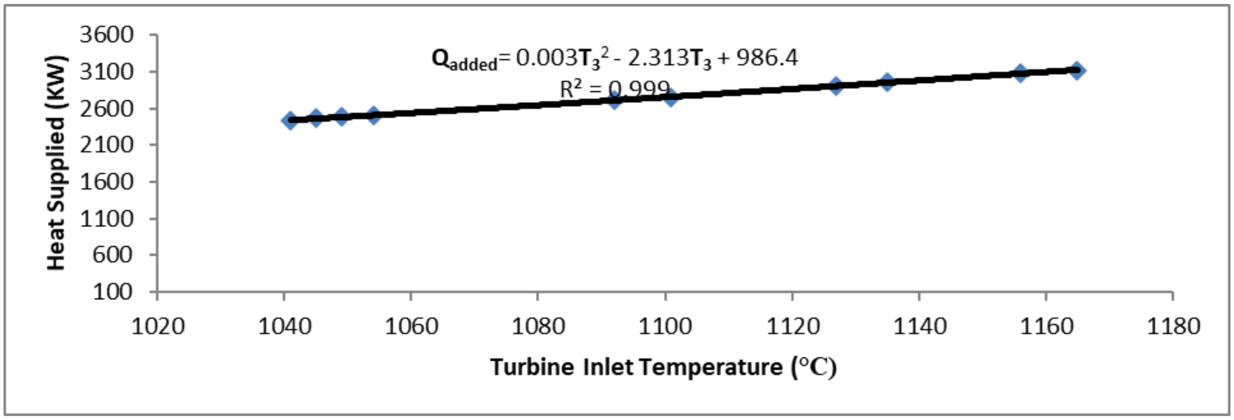

Figure 6: Influence of Turbine Inlet Temperature on the Heat Supplied

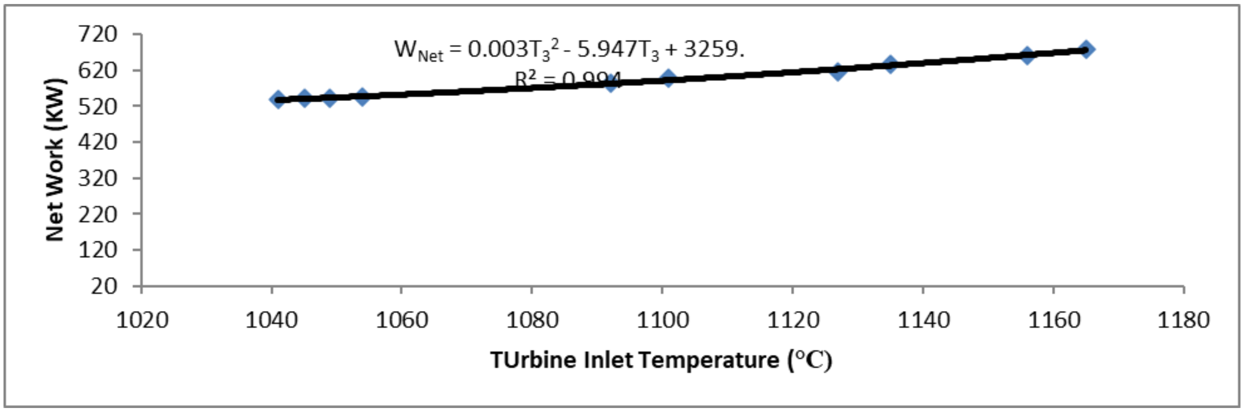

Figure 7: Influence of Turbine Inlet Temperature on the Net Work

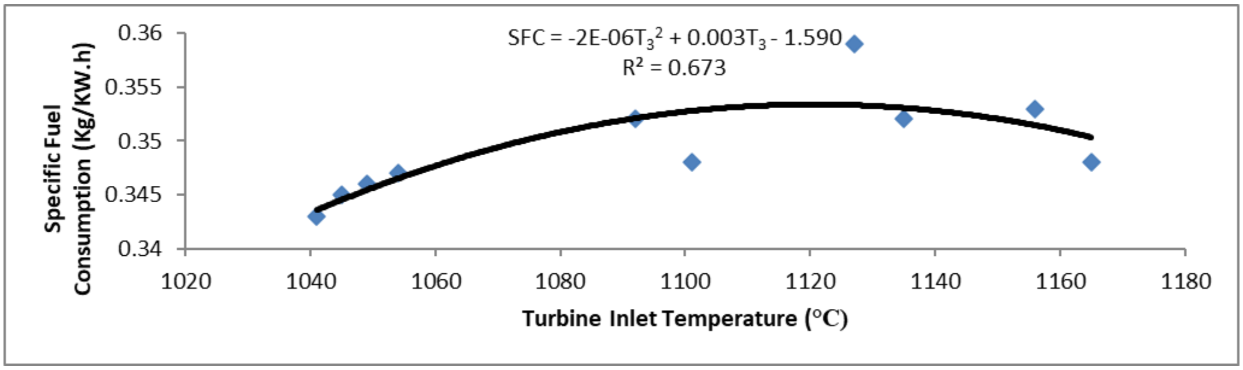

Figure 8: Influence of Turbine Inlet Temperature on the Specific Fuel Consumption

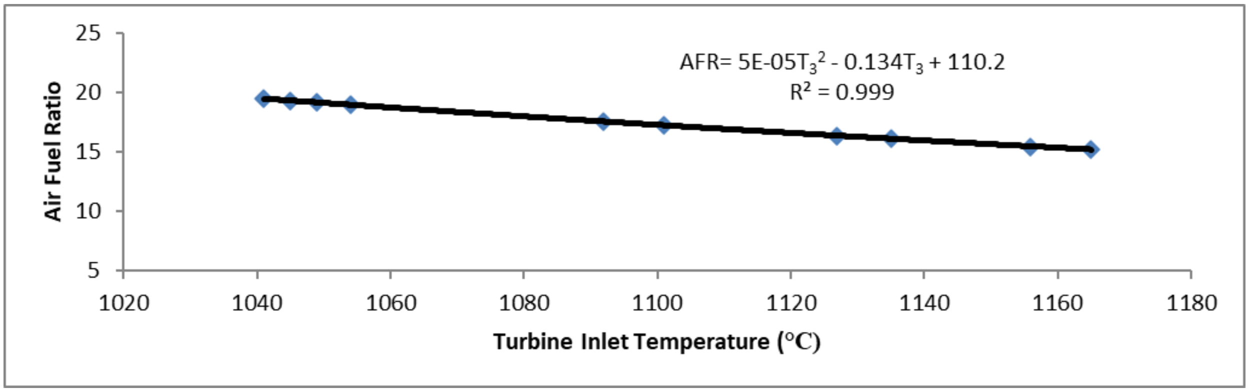

Figure 9: Influence of Turbine Inlet Temperature on the Air Fuel Ratio

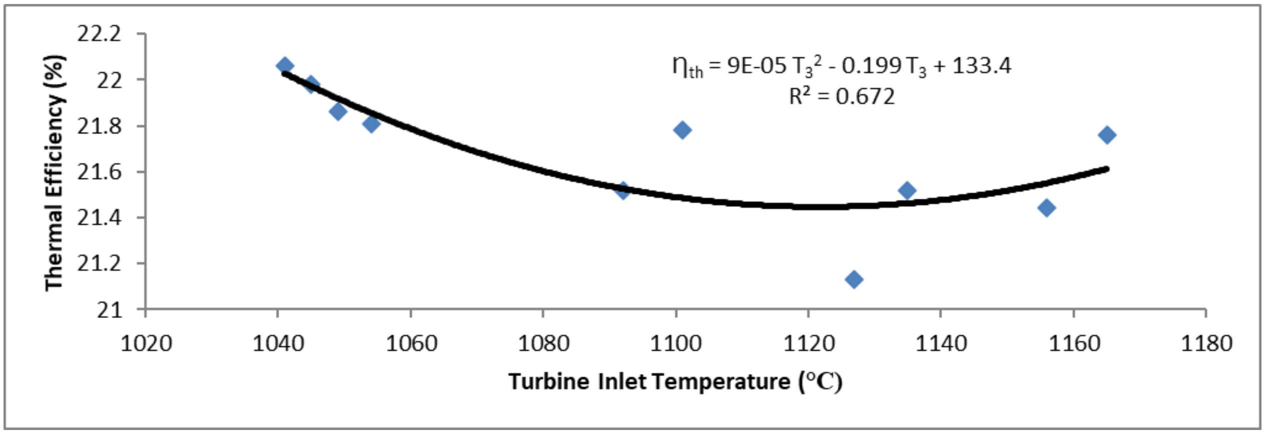

Figure 10: Influence of Turbine Inlet Temperature on the Thermal Efficiency

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