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Influence of temperature on energy production performance at the Azito thermal power plant (southern part of Côte d'Ivoire)

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Abstract

Technological advances in plant design, cooling and materials are essential to optimise performance under variable conditions. These factors are even more critical under climate change, which may exacerbate these thermal challenges. In this study, the impact of temperature variations on the energy production efficiency of the Azito thermal power plant is investigated using the THERMOFLOW model.

The simulation results show that the variation of the atmospheric temperature is an important factor that affects the operation of the basic equipment and the auxiliary equipment of the power generation units. The characteristics of the gas turbine, an essential piece of equipment in the combined cycle system, fall short of the manufacturer's specifications. This will reduce the efficiency of the unit.

Keywords: Thermal power plant; Energy production; Combined cycle; Simulation; THERMOFLOW model; Azito

1. Introduction

Gas-fired combined cycle power plants are the most advantageous type of power generation due to their minimal environmental impact and significantly higher power generation efficiency compared to conventional power plants [Tsanev S. V., 2009] [Melnikov Y. V., 2009]. However, depending on the area of operation and climate conditions, these plants do not deliver the electrical power specified by the manufacturer [Arakeliane E.K., 2007]. The Azito thermal power plant, built in the southern part of Côte d'Ivoire and commissioned in 1999 with an installed capacity of 450 MW, is the most efficient natural gas-fired power plant in Côte d'Ivoire. It accounts for 35% of the 80% of energy produced by Ivorian thermal power plants [Esmel Guillaume, 2012].

In this study, we determined the power and efficiency of the Azito Thermal Power Plant as a function of ambient air temperature using the THERMOFLOW" model. In the following sections, we present the Azito Thermal Power Plant and describe the data and methodology used for the simulation. Then, we present the results of the simulation of the plant operation with THERMOFLOW, followed by an interpretation of the results. Finally, the paper ends with a short conclusion.

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2. Material and methods

2.1. Description of the study area

The Azito thermal power plant is one of Côte d'Ivoire's main electricity production facilities. It is located in the Azito region, some 25 km west of Abidjan, the country's economic capital. This strategic location enables the plant to meet the growing energy needs of the population and support the country's industrial development. The plant is managed by Azito Energie, a key player in Côte d'Ivoire's energy sector, and is equipped with several power generation units.

In operation since January 1999 with a 150 MW gas turbine, and in February 2000 with a second 150 MW turbine identical to the first, of the GT 13 E2 type designed by Alstom Power, the Azito thermal power plant reached its phase III in 2015 with its extension into a combined cycle, making it a mixed plant using both two (2) gas turbines and a steam turbine through the presence of two (2) heat recovery boilers. The mission of this phase is to provide customers with guaranteed power to meet the needs of the Ivorian grid, as well as the growing demand for energy in West Africa [Esmel Guillaume, 2012].

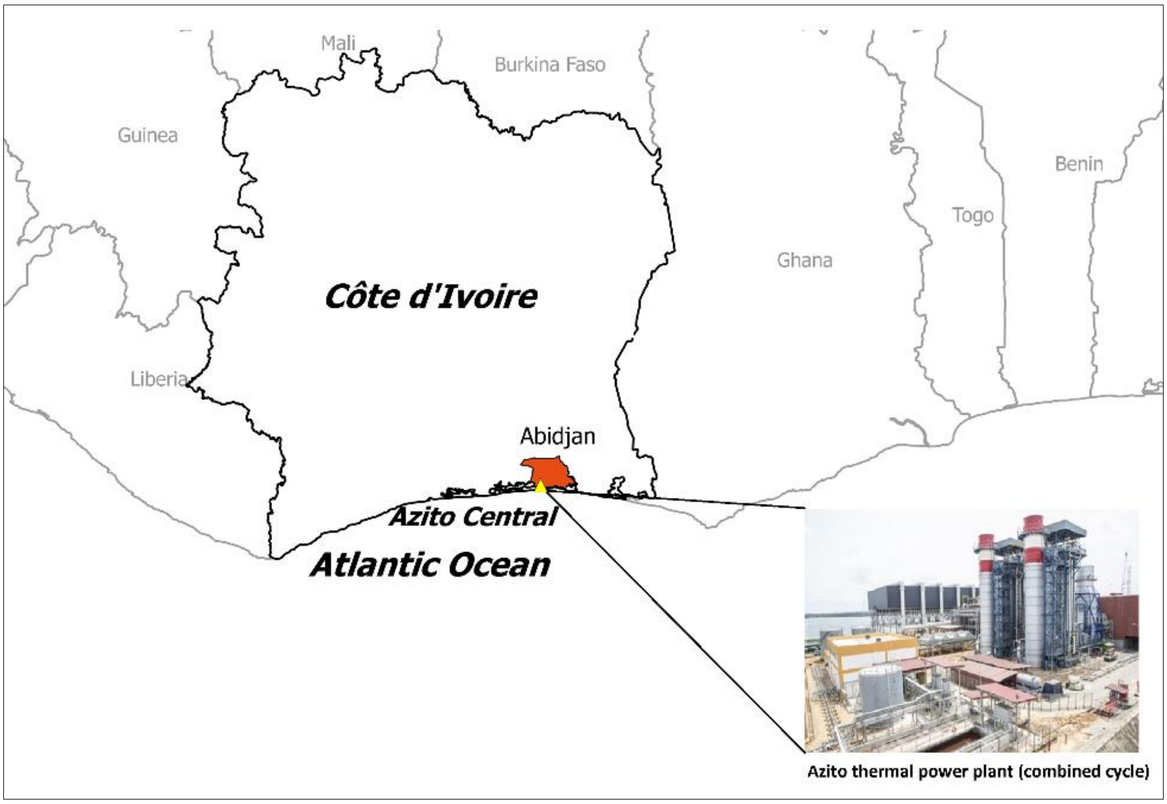

Figure 1 Study area location

2.2. Data

Table 1 shows the characteristics of the Azito Phase III thermal power plant, which consists of two gas turbines, one steam turbine and one heat recovery boiler.

Table 1 Plant characteristics

Type of installation	Energy used	Number of turbines	Turbine type	Installed power (MW)
Gas-thermal combined cycle	Natural Gas	3	2 turbines GT13 E2 1 steam turbine	450

2.3. THERMOFLOW model

THERMOFLOW is software for the engineering and development of power generation systems. Since 1988, engineers, developers and consultants have relied on Thermoflow for the design, conceptual engineering, cost estimation and economic analysis of a wide range of power generation systems.

Used in fields as varied as the energy industry, energy management and thermal system design, it enables engineers to make informed decisions, improve energy efficiency and reduce costs, while taking complex variables into account. Its ability to dynamically simulate thermal systems and deliver reliable results makes it an essential choice for any organization seeking to improve the thermal and energy management of its facilities. THERMOFLOW has already been used in several works in the description of its performance and in simulation [Jasiński, P. B.2024; Al-Obaidi, et al., 2022; Meet Shah et al., 2022].

This study is based on the facilities of the Azito Thermal Power Plant, a combined cycle plant commissioned in several phases, the latest of which is Phase III, which consists of the extension of the existing gas-fired facilities with the installation of two heat recovery boilers and one steam turbine, in order to increase electricity production from 300 MW to 450 MW and to meet the increasing demand of consumers.

2.4. Method

Simulations with THERMOFLOW, considering the Azito thermal power plant, were carried out at different temperatures and full loads, based on a humidity level of 60%:

- Air temperature +25 °C and 100% load.
- Air temperature +30 °C and 100% load.
- Air temperature +35 °C and 100% load.

The nominal load was chosen as we do not take into account the weekly and annual load graph which depends on the demand on the power grid. The three remarkable temperatures were chosen namely 25 °C, 30 °C and 35 °C as they represent specific average temperatures in the climatic conditions of Cote d'Ivoire.

3. Results of simulation

3.1. Simulation for air temperature +25 °C and 100% load

For an ambient air temperature of +25 °C and 100% load, we have the following results:

- Steam turbine electrical power: 158.67 MW;
- Gas turbine electrical power: 152.09 MW;
- Net block power: 450.03 MW;
- Gas turbine inlet temperature: 1118 °C;
- Gas temperature at gas turbine outlet: 535 °C;
- Gas temperature at heat recovery boiler inlet: 533 °C;
- Gas temperature at heat recovery boiler outlet: 106 °C.

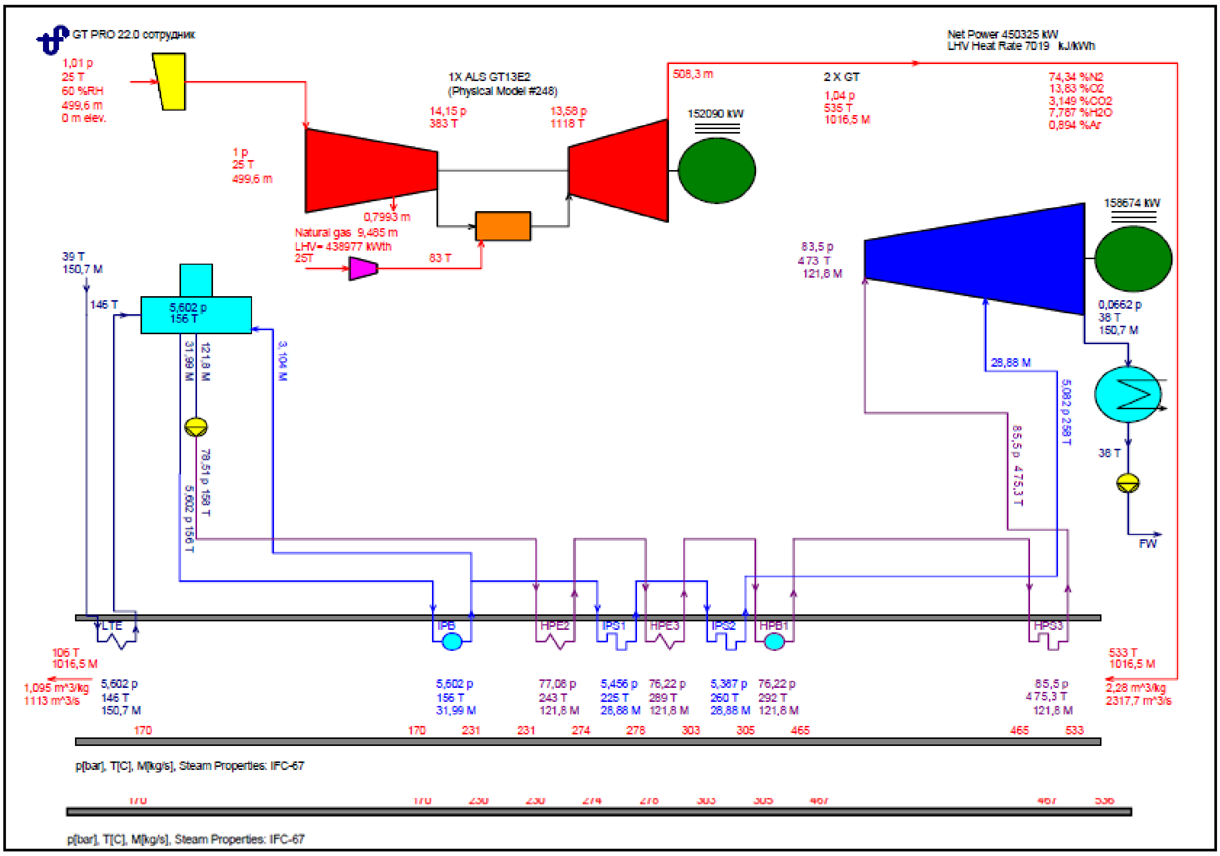

Figure 2 Results of the thermal calculation of the mixed block based on GT13E2 (Alstom) for air temperature +25 °C and 100% load

3.2. Simulation for air temperature +30 °C and 100% load

For an ambient air temperature of +30 °C and 100% load, we have the following results:

- Steam turbine electrical power: 154.31 MW;
- Gas turbine electrical power: 147.06 MW;
- Net block power : 436.06 MW ;
- Gas turbine inlet temperature: 1116 °C;
- Gas temperature at gas turbine outlet: 538 °C;
- Gas temperature at heat recovery boiler inlet: 536 °C;
- Gas temperature at heat recovery boiler outlet: 108 °C.

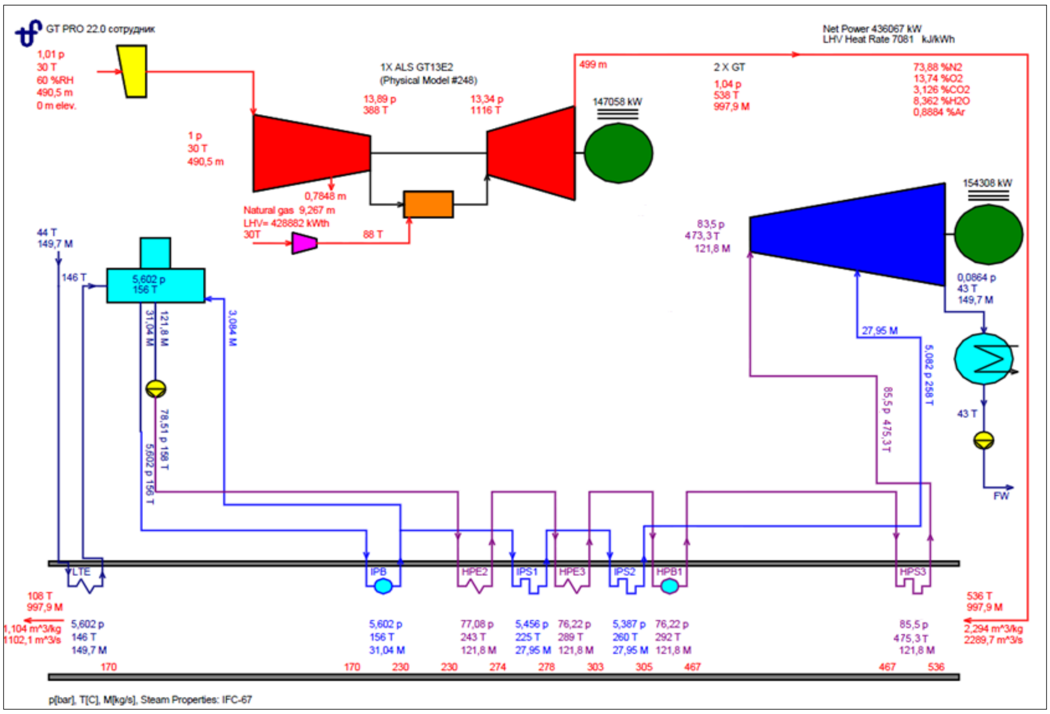

Figure 3 The results of the thermal calculation of the mixed block based on GT13E2 (Alstom) for air temperature +30 °C and 100% load

3.3. Simulation for air temperature +35 °C and 100% load

For an ambient air temperature of +35 °C and 100% load, we have the following results:

- Steam turbine electrical power: 150.04 MW;
- Gas turbine electrical power: 142.10 MW;
- Net block power: 422.02 MW;
- Gas turbine inlet temperature: 1114 °C;
- Gas temperature at gas turbine outlet: 542 °C;
- Gas temperature at heat recovery boiler inlet: 540 °C;
- Gas temperature at heat recovery boiler outlet: 111 °C

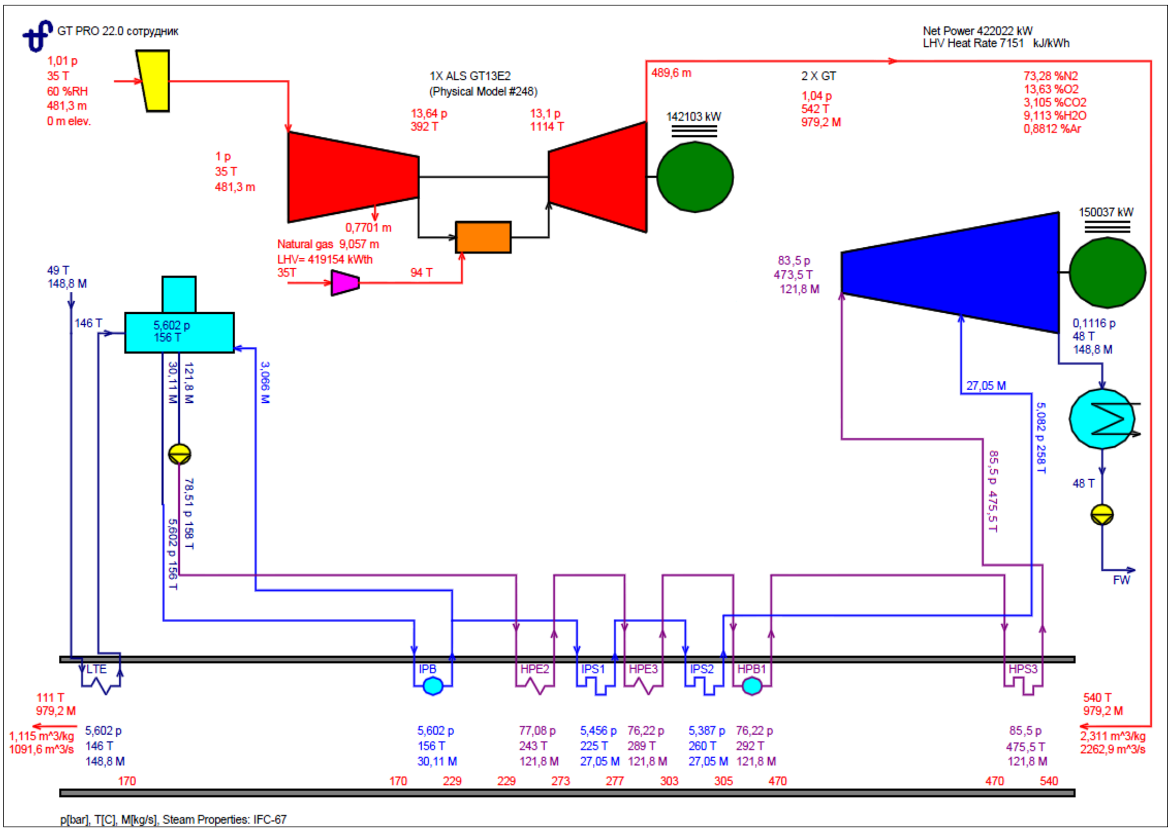

Figure 4 Results of the thermal calculation of the mixed block based on GT13E2 (Alstom) for air temperature +35 °C and 100% load

3.4. Summary of results

The summary of parameter calculations for a combined-cycle power plant comprising two Alstom GT 13 E2 gas turbines (TG), two heat recovery steam generators (HRSG) and a steam turbine (TAV) are shown in the tables below.

Table 2 Gas turbine (TG)

Ambient air temperature (°C)	**25**	**30**	**35**
Electrical power, gross (MW)	152.09	147.05	142.10
Efficiency, gross (%)	34.65	34.29	33.9
Gas flow rate (kg/s,)	9.49	9.267	9.057
Hot gas temperature at TAG outlet (°C)	549.2	538.4	489.6
Hot gas flow at TAG outlet (kg/s)	1016.5	997.9	979.2

Table 3 Heat recovery boiler

High-pressure circuit (HP)			
Steam flow (kg/s)	122.2	121.5	121
Steam pressure (MPa)	8.5	8.5	8.5
Steam temperature (°C)	495.1	475.3	455.2
Low-pressure circuit (LP)			

Steam flow (kg/s)	27.82	26.9	26
Steam pressure (MPa)	0.508	0.508	0.508
Steam temperature (°C)	258.3	258.3	258.3
Outlet gas temperature (°C)	118.4	115.9	113.5

Table 4 Steam turbine (TAV)

High-pressure circuit parameters at the high-pressure vessel outlet			
High-pressure steam pressure (MPa)	8.3	8.3	8.3
High-pressure steam temperature (°C)	494	473.3	454.1
High-pressure steam flow rate (t/h)	336.88	337.7	338.6
Low-pressure circuit parameters at low-pressure storage outlet			
Steam pressure (MPa)	0.508	0.508	0.508
Steam temperature (°C)	258.3	258.3	258.3
Steam flow rate (t/h)	77.27	74.72	72.2
TAV electrical power (MW)	151.29	146.88	142.69
Nominal steam pressure at condenser (MPa)	0.0109	0.013	0.017

Table 5 Plant data

Gross electrical power of block (MW)	454.473	440.98	426.89
TAG power (MW)	304.18	294.11	284.2
TAV power (MW)	151.29	146.88	142.69
Block net electrical power (MW)	439.194	424.90	411.02
Gas flow (kg/s)	18.98	18.55	18.134
Internal electrical power (MW)	11.47	10.98	9.39
Gross efficiency (%)	50.42	50.32	50.21
Net efficiency (%)	49.32	49.22	49.15

4. Interpretation of results

On the basis of the calculations carried out, we have constructed the dependents of variation of electrical power (gross and net) figure 5 and 6, of block efficiency (gross and net) figure 7 and 8 as a function of ambient air temperature for nominal loads.

4.1. Variation of electrical power (gross) as a function of ambient temperature at base load (100%)

For a 100% operating load, this variation in gross electrical power as a function of temperature

($P_g = f(T)$) is summarized as follows:

- For T=25 °C, $P_g = 443\ MW$
- For T=30 °C, $P_g = 430\ MW$
- For T=35 °C, $P_g = 417.5\ MW$

For an increase in ambient air temperature of 5 °C, we observe a drop in electrical power of around 3%.

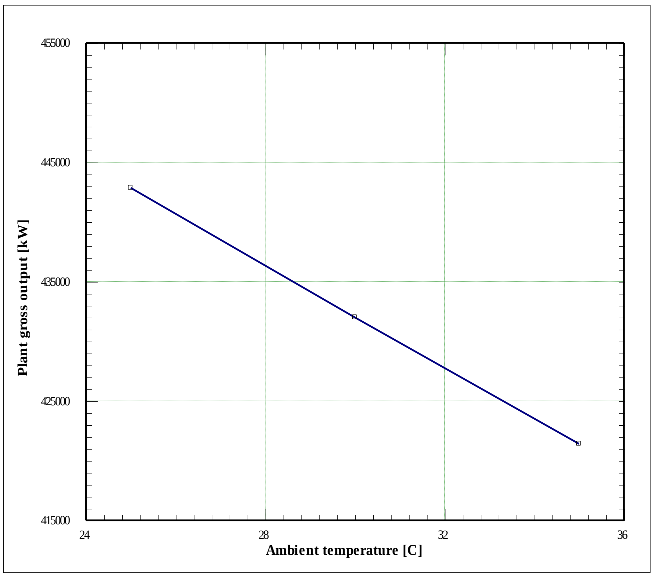

Figure 5 Diagram showing variation in electrical power (gross) as a function of ambient temperature at base load (100%)

4.2. Variation of net electrical power with ambient temperature at base load (100%)

For a 100% operating load, the variation in net electrical power as a function of temperature ($P_n = f(T)$) is summarized as follows:

- For T=25 °C, $P_n = 431.5\ MW$
- For T=30 °C, $P_n = 420\ MW$
- For T=35 °C, $P_n = 414\ MW$

For an increase in air temperature from 25 °C to 30°C, net electrical power drops by 2.6% and from 30 °C to 35 °C we have a 1.5% drop in electrical power.

The variation in net electrical power as a function of ambient temperature at base load (100%) is illustrated in the diagram below.

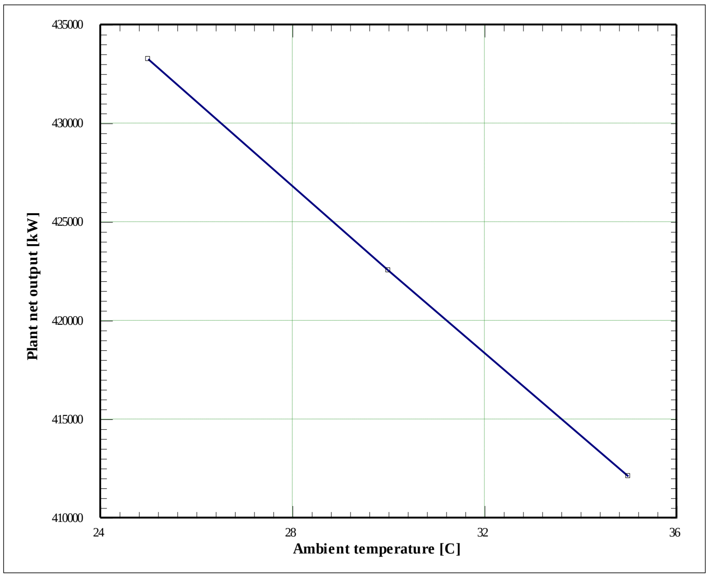

Figure 6 Diagram showing variation in net electrical power as a function of ambient temperature at base load (100%)

4.3. Variation of gross efficiency as a function of ambient temperature at base load (100%)

For a 100% operating load, the variation of gross efficiency as a function of temperature ($\eta_g = f(T)$) is summarized as follows:

- For T=25 °C, $\eta_g = 50.42$
- For T=30 °C, $\eta_g = 50.32$
- For T=35 °C, $\eta_g = 50.2$

For an increase in ambient temperature from 25 °C to 30 °C, gross efficiency drops by 0.1% and from 30 °C to 35 °C, we see a 0.12% drop in gross efficiency. The variation in yield as a function of ambient temperature is shown in the diagram below.

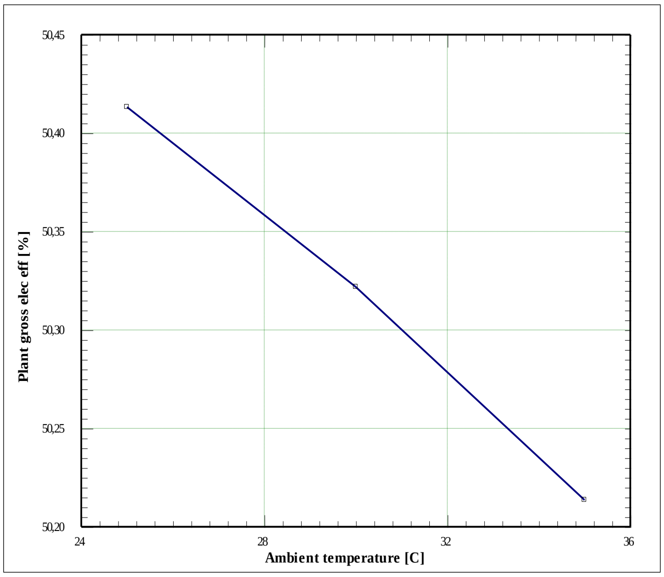

Figure 7 Diagram showing variation in gross efficiency as a function of ambient temperature at base load (100%)

4.4. Variation of net efficiency as a function of ambient temperature at base load (100%)

For a 100% operating load, the variation of net efficiency as a function of temperature ($\eta_n = f(T)$) is summarized as follows:

- For T=25 °C, $\eta_n = 49.32$
- For T=30 °C, $\eta_n = 49.22$
- For T=35 °C, $\eta_n = 49.15$

For an increase in ambient temperature from 25 °C to 30 °C, net efficiency drops by 0.1% and from 30 °C to 35°C, we see a 0.07% drop in net efficiency. The variation in net efficiency as a function of ambient temperature is shown in the diagram below.

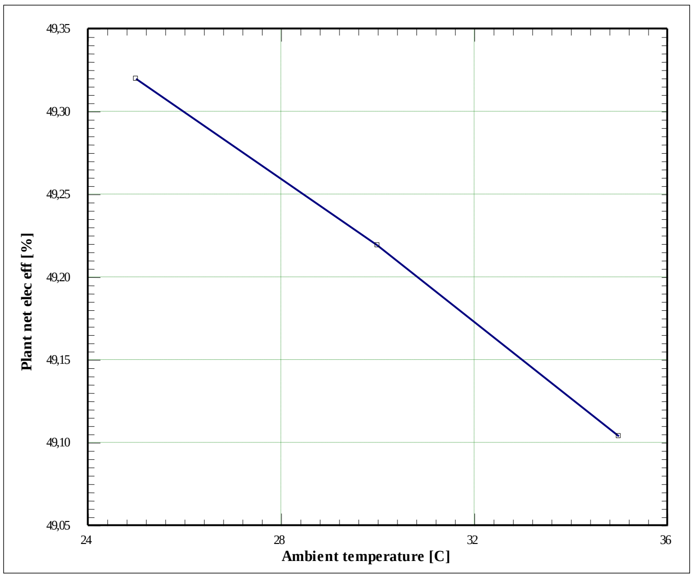

Figure 8 Diagram showing variation in net efficiency as a function of ambient temperature at base load (100%)

From the results, we note that, for nominal loads with an increase in ambient air, the electrical power and efficiency of the block decrease. This variation in efficiency from 49.32% to 49.15% is not significant because the air variation in Côte d'Ivoire is not remarkable unlike the temperature variation in Russia where the temperature varies from -45 °C to+45 °C. Melnikov Y. V., in his 2009 publication in the journal "Energy Economics and Water Treatment", showed that the efficiency of thermal power plants with heat recovery boilers in Russia varied from 50.5% to 52% [Melnikov Y. V., 2009]. This temperature factor must be taken into account when operating production units, and also when regulating the weekly, monthly and annual electrical load graph.

5. Conclusion

This study highlighted the influence of ambient temperature on the energy production efficiency of the Azito thermal power plant. Temperature is a key factor that directly influences the efficiency of thermal power plants. Temperatures around 15 °C are favorable to the energy characteristics of the plants, but temperatures that are too high or too low can reduce system efficiency. Our study showed for an ambient temperature of 25 °C we have an efficiency of 49.32%. At 35 °C the system efficiency is 49.15%. Hence, for a difference of 10°C, we notice a 0.17% drop in the efficiency of the power generation unit. Technological advances in plant design, cooling and materials are essential for optimizing efficiency under varying conditions, and taking these factors into account is even more critical in the context of climate change, which can exacerbate these thermal challenges.

However, to optimize the efficiency of our installation, it would be necessary to install an air cooler at the compressor inlet to control the temperature. It should be noted that this study does not take into account the upgrading to MXL2 of the gas turbines in 2019 and 2020 to increase their power.

Compliance with ethical standards

Authors contribution

Esmel GUILLAUME: conceptualization, Formal analysis, Funding acquisition, Methodology, Writing - original draft. **Sacre Regis DIDI; Désiré C. MELEDJE** and **Alexandre T. KEUKEU**: Conceptualization, Methodology, Writing - review & editing.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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