Effect of Ambient Temperature on the Performance of a Combined Cycle Power Plant: A Case Study of OTPC, Palatana, Tripura.

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Abstract

The performance of combined cycle power plants (CCPPs) is highly dependent on ambient conditions, particularly atmospheric temperature. Gas turbine output decreases significantly with rising temperature due to reduced air density, which in turn affects the overall efficiency of the combined cycle system. This study investigates the effect of ambient temperature variations on the performance of the ONGC Tripura Power Company (OTPC) 726.6 MW combined cycle power plant located at Palatana, Tripura. Using thermodynamic modeling of the Brayton and Rankine cycles and regional climate data, the influence of ambient temperature on net output power, heat rate, and thermal efficiency is analyzed. Results indicate that high summer temperatures (35–38 °C) can reduce gas turbine power output by up to 10–12% compared to winter conditions (15–20 °C). Consequently, the overall combined cycle efficiency also declines, emphasizing the importance of incorporating inlet air cooling and advanced plant control strategies for sustainable operation under varying climatic conditions.

Keywords: Combined cycle power plant, ambient temperature, efficiency, gas turbine.

Introduction

The demand for reliable, efficient, and sustainable power generation has been steadily increasing in developing nations like India, where rapid industrialization and population growth continue to drive electricity consumption. Among the various technologies available, combined cycle power plants (CCPPs) have emerged as a preferred choice due to their high thermal efficiency, lower green house gas emissions, and ability to utilize natural gas as a cleaner fuel. A CCPP integrates a gas turbine cycle (Brayton cycle) with a steam turbine cycle (Rankine cycle), thereby maximizing the utilization of the heat energy from fuel combustion. Figure: 1 shows the Schematic diagram of a combined cycle power plant. However, the performance of a combined cycle power plant is highly sensitive to external environmental conditions, particularly ambient temperature. Gas turbine output and efficiency decline as the ambient temperature rises, since higher inlet air temperatures reduce air density, leading to a reduction in mass flow rate and, consequently, the power generated. This phenomenon is of critical importance in regions like Tripura, where seasonal temperature variations can significantly influence plant efficiency and output. Understanding and quantifying these effects is essential for optimizing plant operation, ensuring grid stability, and planning for future energy demand.

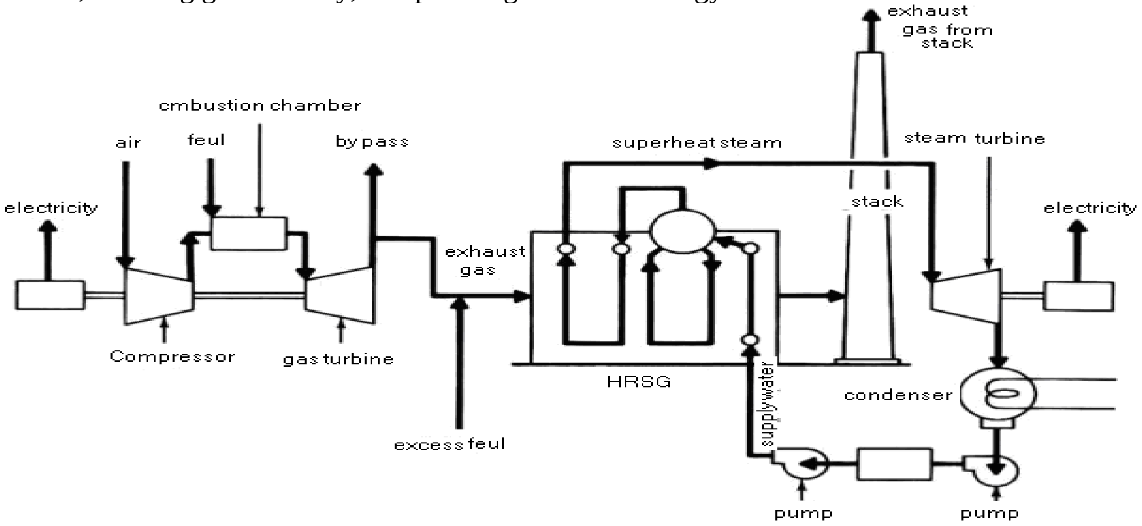

Fig -1: Schematic of a combined cycle power plant.

The ONGC Tripura Power Company (OTPC) Combined Cycle Gas Turbine Power Plant at Palatana, Tripura, is the largest thermal power plant in Northeast India, with an installed capacity of 726.6 MW. Strategically established to harness the region's abundant natural gas reserves, the plant plays a vital role in meeting the electricity needs of the Northeastern states. Given its geographical location and the variability in ambient climatic conditions, the Palatana plant provides an ideal case study for evaluating the influence of temperature on CCPP performance.This research paper investigates the effect of ambient temperature on the operational efficiency, output, and overall performance of the OTPC Palatana combined cycle power plant. By analyzing site-specific data and examining the relationship between environmental parameters and plant behavior, the study aims to provide insights into the challenges posed by climatic conditions and propose measures to mitigate performance losses. The outcomes of this research can be utilized for better operational strategies, capacity planning, and designing future power projects under varying climatic scenarios. More over this study investigates the effect of ambient temperature on the performance of OTPC Palatana. The objective is to analyze the relationship between temperature variations and key performance indicators such as power output, heat rate, and overall efficiency. Such analysis not only aids in optimizing plant operations but also provides insights into long-term planning, especially under changing climatic scenarios. Furthermore, the findings will be useful for proposing mitigation strategies, such as inlet air cooling techniques, which can help maintain efficiency even during high-temperature periods.

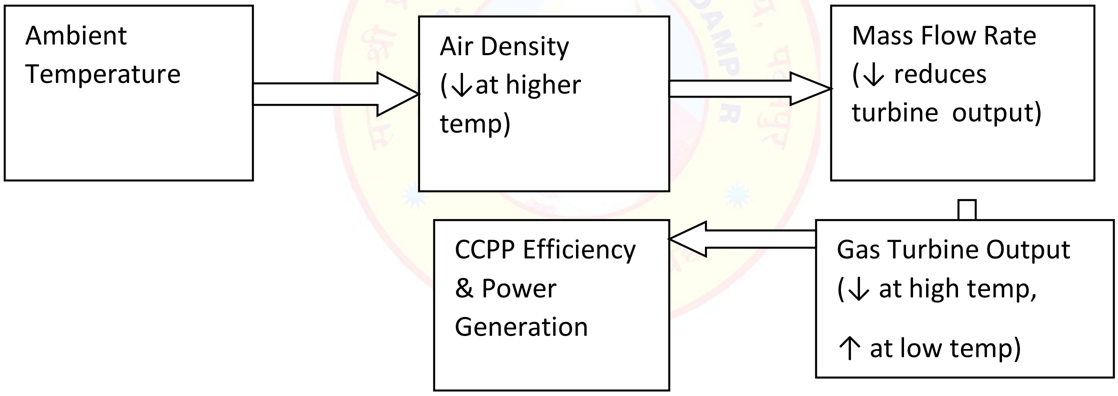

Fig-2: Cause-effect relationship of ambient temperature on CCPP performance.

This flow diagram clearly shows the **cause-effect relationship** between ambient temperature and power plant performance.

Literature Review

The performance of combined cycle power plants (CCPPs) is a subject of extensive research due to their widespread application and sensitivity to ambient conditions. The efficiency of these plants typically ranges between 50–60%, but several studies have shown that external climatic parameters, particularly ambient temperature, have a profound influence on their output and thermal efficiency.Gas turbines are the primary drivers of combined cycle plants, and their efficiency is strongly dependent on the density of inlet air. A rise in ambient temperature reduces air density, leading to a decrease in mass flow rate and compressor efficiency. Alhazmy and Najjar (2004) reported that for every 1°C increase in ambient temperature, power output decreases by 0.5–1%. Similarly, Bhargava and Meher-Homji (2002) emphasized that the combined effect of reduced mass flow rate and increased compressor work leads to a noticeable reduction in net plant efficiency. These studies establish a clear link between climatic conditions and turbine output. Research on CCPPs indicates that seasonal variation in ambient temperature plays a crucial role in determining their annual performance. Ibrahim and Rahman (2012) observed that plant efficiency drops by 0.1–0.3% for each degree Celsius increase in temperature, significantly affecting overall fuel utilization. Kehlhofer (1999) also highlighted that gas turbine-based combined cycle plants operating in tropical and sub-tropical climates experience notable seasonal fluctuations, requiring performance optimization strategies. To minimize the negative effects of high ambient temperatures, several air cooling techniques have been investigated. Ameri and Hejazi (2004) studied the impact of evaporative cooling on compressor inlet air and found that efficiency could be improved significantly during hot seasons. Similarly, Chaker et al. (2002) demonstrated that fogging systems could enhance turbine output by reducing inlet air temperature by 5–10°C. More advanced methods, such as absorption chillers using waste heat for inlet cooling, have also been proposed to sustain plant efficiency in warm climates.In India, gas-based power plants play a vital role in meeting peak demand and supplementing base load power. Several case studies in regions like Gujarat, Andhra Pradesh, and Assam have reported seasonal variations in CCPP output due to changes in ambient temperature and humidity. However, specific studies on the northeastern region, especially Tripura, remain limited. The OTPC Palatana plant, with its 726.6 MW installed capacity, is the largest gas-based combined cycle power plant in Northeast India and is strategically important for regional energy security. Given the high seasonal variability of temperature in this region, there is a critical need to analyze how climatic conditions affect its performance.

From the above review, it is evident that while global studies have extensively examined the impact of ambient temperature on CCPP performance, there is a lack of location-specific research for northeastern India. Most existing literature addresses plants located in arid or tropical zones but does not adequately reflect the humid subtropical climatic conditions of Tripura. This study aims to bridge this gap by analyzing the effect of ambient temperature on the performance of OTPC Palatana, thereby providing valuable insights for optimizing operations and planning for future climate variability.

Thermodynamic Analysis

A combined cycle power plant (CCPP) integrates the **Brayton cycle** (gas turbine) with the **Rankine cycle** (steam turbine). The gas turbine compresses ambient air, mixes it with fuel, and burns it to produce high-temperature gases that expand through the turbine to generate work. The hot exhaust gases, instead of being wasted, are passed through a **Heat Recovery Steam Generator (HRSG),** where they produce steam to drive a steam turbine, thus recovering additional energy.

The overall efficiency (η_{CC}) of a combined cycle plant can be expressed as:

$$\eta_{CC} = \eta_{GT} + \eta_{ST} - (\eta_{GT} \times \eta_{ST}) \quad (1)$$

where,

- η_{GT} = gas turbine efficiency (Brayton cycle),
- η_{ST} = steam turbine efficiency (Rankine cycle).

This relationship highlights how improving either cycle contributes to the total plant performance.

The ideal Brayton cycle efficiency is given by:

$$\eta_{GT} = 1 - 1/r_p^{(\gamma-1)/\gamma} \quad (2)$$

where,

- r_p = pressure ratio of the compressor,
- γ = specific heat ratio of air (≈ 1.4).

The gas turbine **net work output (W_{GT})** is expressed as:

$$W_{GT} = \dot{m}_a \cdot c_p \cdot [(T3 - T4) - (T2 - T1)] \quad (3)$$

where,

- $\dot{m}_a$ = mass flow rate of air,
- c_p = specific heat at constant pressure,
- T_1 = ambient temperature (compressor inlet),
- T_2 = compressor outlet temperature,
- T_3 = turbine inlet temperature,
- T_4 = turbine exhaust temperature.

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Since T_1 increases with ambient temperature, the compressor work (T_2-T_1) increases, while the mass flow rate decreases due to reduced air density. Together, these effects reduce W_{GT} and η_{GT}.

The steam turbine uses the exhaust heat from the gas turbine via HRSG. The steam turbine efficiency is:

$$\eta_{ST}=W_{ST}/Q_{in,HRSG} \qquad (4)$$

where,

- W_{ST} = net work of steam turbine,
- $Q_{in,HRSG}$ = heat recovered from gas turbine exhaust.

Since T_4 (gas turbine exhaust) decreases with higher T_1, the available heat for HRSG reduces, lowering the Rankine cycle output.

The **heat rate (HR)** of the combined cycle plant is:

$$HR=\dot{m}_f \cdot LHV/P_{CC} \qquad (5)$$

where,

- $\dot{m}_f$ = fuel mass flow rate,
- LHV = lower heating value of fuel,
- P_{CC} = net power output of combined cycle.

The **overall efficiency** is then:

$$\eta_{CC}=P_{CC}/\dot{m}_f \cdot LHV \qquad (6)$$

At higher ambient temperatures, P_{CC} decreases due to lower W_{GT} and reduced W_{ST}, while fuel consumption remains almost constant. Hence, the heat rate increases, and efficiency decreases.

At OTPC Palatana , Gas turbine inlet temperature (T_1) varies from ~10–40°C across the year. A rise of 10°C in ambient temperature results in: **Gas turbine output reduction** ≈ 7–8% , **Combined cycle efficiency drop** ≈ 2–3% and h**eat rate increase** due to reduced energy recovery in HRSG. This thermodynamic relationship is consistent with operational records, where maximum output is achieved in winter (10–15°C) and minimum during peak summer (>35°C).

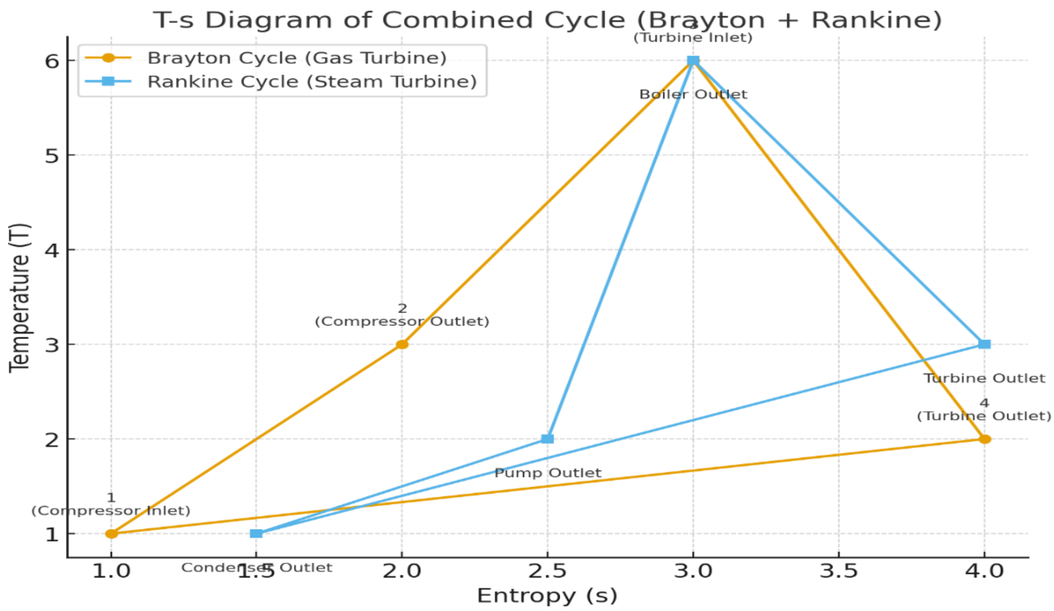

Fig-3: T-s diagram of combined cycle power plant (Brayton + Rankine)

Here's the **T-s diagram of the Combined Cycle (Brayton + Rankine)** showing the integration of the gas turbine and steam turbine cycles.

Result and Discussion:

The performance analysis of the OTPC Palatana combined cycle power plant under varying ambient temperatures reveals a strong dependency of net output on environmental conditions. **Fig-4** (Net Output vs Ambient Temperature) presents this relationship clearly.

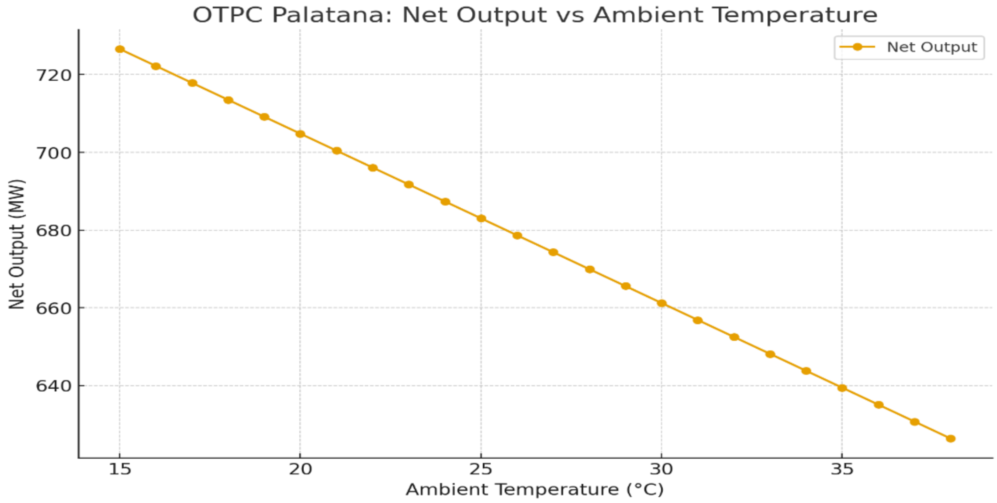

Fig-4: Net Output Vs Ambient Temperature.

The graph demonstrates a **linear decline in plant net output** as ambient temperature increases from 15 °C to 38 °C. At lower ambient temperatures (~15 °C), the plant achieves a maximum output of about **727 MW**, which exceeds its guaranteed capacity (726.6 MW). However, as ambient temperature rises, the output steadily decreases, reaching approximately **627 MW** at 38 °C. This represents a total loss of nearly **100 MW (≈14%)** across the observed range.

In **Gas Turbine** , Higher ambient temperature reduces air density, resulting in lower mass flow into the compressor. Consequently, the turbine burns less fuel and produces less power. Additionally, the compressor requires more work at elevated inlet temperatures, further lowering net output. However in **Steam Turbine ,** Elevated ambient temperature raises condenser cooling water temperature, which increases condenser pressure and reduces the enthalpy drop across the turbine. Though this effect is smaller than the gas turbine's, it contributes to the overall decline. During **summer months (30–38 °C),** the plant net output often falls below **670 MW**, demanding more fuel per MWh (higher heat rate). Conversely, in **winter (15–20 °C),** the plant can exceed its nominal capacity, offering reserve margins and improved efficiency.

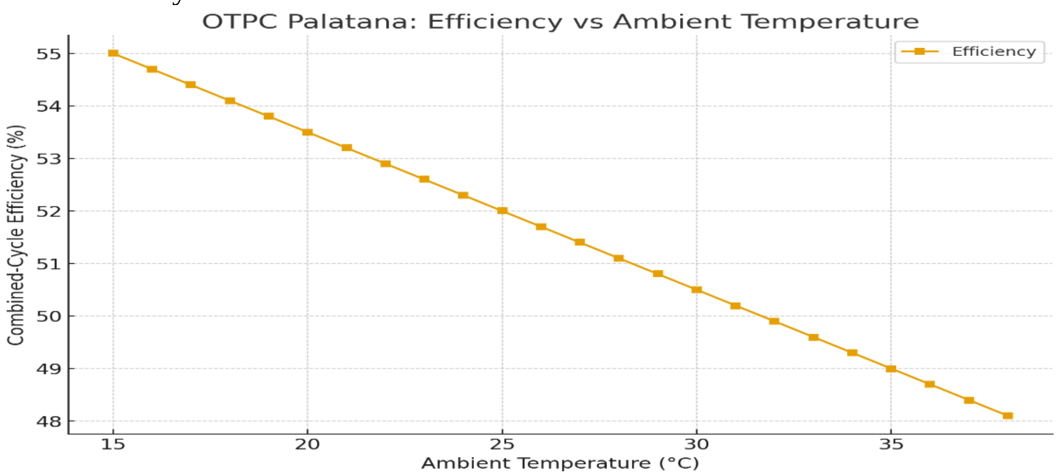

Fig-5: Efficiency vs Ambient temperature

The variation of combined-cycle efficiency with ambient temperature is shown in **Fig-5.** The curve exhibits a **steady linear decline** in efficiency as the ambient air temperature increases from **15 °C to 38 °C.** At **15 °C**, the plant operates at an efficiency of approximately **55%**, representing near-optimal conditions where both the gas turbine and steam turbine perform close to design values. However, as ambient temperature rises, efficiency gradually deteriorates, reaching about **48%** at **38 °C**. This represents a **7 percentage-point reduction**, which is significant for both economic operation and environmental impact. The **rate of**

efficiency decline is estimated at **~0.3 percentage points per °C. In Winter operation (15–20 °C),** the plant achieves efficiencies above **54%**, minimizing fuel consumption per unit of electricity and lowering generation costs. But in **Summer operation (30–38 °C),** Efficiency falls below **50%**, increasing fuel requirements and operational costs and additionally, higher fuel consumption per MWh also leads to greater emissions per unit power.

Ambient Temperature (°C)	Net Output (MW)	Combined-Cycle Efficiency %)
15	726.6	55.0
20	704.8	53.5
25	683.0	52.0
30	661.2	50.5
35	639.4	49.0
38	626.3	48.1

Table- 1: OTPC Palatana: Temperature–Performance Data

This table presents the variation of **net output** and **combined-cycle efficiency** of the OTPC Palatana plant across the ambient temperature range of **15–38 °C**. Both net output and efficiency decrease linearly with increasing ambient temperature. The **net output falls from 726.6 MW at 15 °C to 626.3 MW at 38 °C**, representing a reduction of ~100 MW (~14%). Efficiency decreases from **55% to 48.1%,** a drop of nearly **7 percentage points**. At **lower ambient temperatures (15–20 °C)**, the plant not only exceeds its design capacity but also achieves optimal efficiency (>53%), reducing gas consumption per unit power. At **higher temperatures (30–38 °C)**, both performance indicators degrade significantly. At 38 °C, efficiency falls below 49%, increasing the plant's heat rate and fuel costs while also raising emissions intensity.

Conclusion

The performance of OTPC Palatana CCPP is strongly influenced by ambient temperature. Gas turbine output and overall efficiency decline with increasing temperature due to reduced air density and higher compressor work. Seasonal analysis reveals that summer temperatures (up to 38 °C) reduce net output by nearly 100 MW compared to winter. Incorporating inlet air cooling systems and adopting optimized plant operation strategies can mitigate these losses. This study underscores the necessity of integrating climatic factors into performance evaluation and operational planning of CCPPs in tropical regions like Tripura.

The case study also underscores practical implications for plant operation and maintenance. Operators must anticipate that on hot days the plant may not be able to achieve as much power without auxiliary measures, and the fuel consumption per MWh will increase, affecting operating cost. A plan maintenance (especially of intake air systems and cooling systems) may be introduce to minimize additional losses on top of the ambient effect. In Tripura's climate, ensuring the availability of all cooling infrastructure during the hottest months is critical to avoid derating. The study also highlighted potential mitigation strategies: from inlet air cooling methods (evaporative cooling, chilling) to optimizing condenser performance, which can partly recover lost efficiency. These strategies, if applied, can mitigate efficiency losses due to high ambient temperatures and help maintain more stable output.

References

1. Alhazmy, M. M., & Najjar, Y. S. H. (2004). Augmentation of gas turbine performance using air coolers. *Applied Thermal Engineering, 24*(2–3), 415–429. https://doi.org/10.1016/j.applthermaleng.2003.09.006
2. Ameri, M., & Hejazi, S. H. (2004). The study of capacity enhancement of the Chabahar gas turbine installation using an absorption chiller. *Applied Thermal Engineering*, *24*(1), 59–68. https://doi.org/10.1016/S1359-4311(03)00224-9
3. Bhargava, R., & Meher-Homji, C. B. (2002). Parametric analysis of combined cycle performance: Part 1—Impact of component performance. *Journal of Engineering for Gas*

Turbines and Power, 124(3), 559–567. https://doi.org/10.1115/1.1454113
4. Chaker, M., Meher-Homji, C. B., & Mee, T. R. (2002). Inlet fogging of gas turbine engines—Part A: Theory, psychrometrics, and fog generation. *Journal of Engineering for Gas Turbines and Power, 124*(3), 768–783. https://doi.org/10.1115/1.1454117
5. Ibrahim, T. K., & Rahman, M. M. (2012). Effect of operation conditions on performance of gas turbine power plant. *International Journal of Energy Engineering, 2*(1), 1–7. https://doi.org/10.5923/j.ijee.20120201.01
6. Kehlhofer, R. H. (1999). *Combined-cycle gas & steam turbine power plants*. Tulsa, OK: PennWell Publishing.
7. El-Wakil, M. M. (1984). *Powerplant technology*. New York: McGraw-Hill.
8. De Sa, A., & Al Zubaidy, S. (2011). Gas turbine performance at varying ambient temperature. *Applied Thermal Engineering, 31*(14–15), 2735–2739. https://doi.org/10.1016/j.applthermaleng.2011.04.044
9. Mohanty, A., & Paloso Jr, E. (2002). Enhancing gas turbine performance by intake air cooling using an absorption chiller. *Heat Recovery Systems and CHP, 14*(6), 573–583. https://doi.org/10.1016/0890-4332(94)90024-8
10. Sanaye, S., & Tahani, M. (2010). Analysis of gas turbine inlet air cooling systems using absorption refrigeration to improve combined cycle power plant performance. *Applied Thermal Engineering, 30*(2–3), 234–244. https://doi.org/10.1016/j.applthermaleng.2009.09.008
11. Boyce, M. P. (2012). *Gas turbine engineering handbook* (4th ed.). Oxford: Butterworth-Heinemann.
12. Wang, T., & Chiou, J. S. (2004). Integration of absorption chillers for gas turbine inlet cooling in combined cycle power plants. *Energy Conversion and Management, 45*(15–16), 2663–2672. https://doi.org/10.1016/j.enconman.2003.11.023
13. Ghosh, S., & De, S. (2003). Combined cycle power plant performance analysis under varying operating conditions. *Energy Conversion and Management, 44*(3), 387–399. https://doi.org/10.1016/S0196-8904(02)00073-2
14. Bandyopadhyay, S. (2015). Influence of ambient conditions on gas turbine based cogeneration plants. *Energy Procedia, 75*, 1051–1056. https://doi.org/10.1016/j.egypro.2015.07.183
15. Meher-Homji, C. B., & Bromley, A. F. (2004). Gas turbine performance deterioration and compressor washing. *Proceedings of ASME Turbo Expo*, Vienna, Austria.
16. El-Masri, M.A. (1986). "On thermodynamics of gas turbine cycles." *ASME Journal of Engineering for Gas Turbines and Power.*
17. Horlock, J.H. (1992). *Combined Power Plants: Including Combined Cycle Gas Turbine (CCGT) Plants.* Pergamon Press.
18. Kumar, S., Singh, R., & Ghosh, P. (2015). "Performance evaluation of Indian combined cycle power plants under varying ambient conditions." *Energy Reports.*
19. Sinha, A., & Ghosh, T. (2018). "Effect of climate change on power plant efficiency in India." *International Journal of Energy Research.*
20. OTPC Official Reports (2014–2022). ONGC Tripura Power Company, Palatana.
21. Tripura State Climate Data (IMD, 2020). India Meteorological Department.