

# Analysis of Performance & Efficiency of Combined Power Plant Using MATLAB Fmincon Optimization Technique

Umesh Kumar<sup>1\*</sup>, Santosh Kumar Mishra<sup>2</sup>, Manoj Kumar Pal<sup>3</sup>

<sup>1</sup>Research Scholar, Department of Mechanical Eng., BIT Durg, India

<sup>2,3</sup>Professor, BIT Durg, India

E-mail:umeshsahu51@gmail.com

**Abstract:** Natural gas is widely regarded as the cleanest fossil fuel, offering low greenhouse gas emissions and producing no particulate matter during combustion. As global energy demand grows, optimizing the performance of such plants becomes increasingly important. An in-depth analysis is carried out in this work MATLAB-based modelling and simulation of a natural gas-fuelled combined cycle power plant was performed, integrating fmincon optimization to enhance performance. The plant was evaluated from energy, exergy and environmental perspectives. The analysis identified the combustion chamber as the most influential component on system efficiency. Critical operational variables were found to be the gas steam ratio, air fuel ratio, pressure ratio of compressor. Optimization using a thermal efficiency based objective function led to a 22.35% improvement in thermal efficiency and a 24.76% reduction in exergy destruction. Furthermore, The results confirm that advanced modelling, simulation, and optimization approaches can guide optimal design, ensure efficient operation, and minimize effect of combined power plants on the environment. Using fmincon with a thermal efficiency-driven objective function, the optimization achieved. The findings demonstrate that MATLAB's "find minimum of constrained nonlinear multivariable function" (fmincon) optimization framework, coupled with detailed thermodynamic modelling, is a powerful tool for pre-investment plant design, real-time operational optimization, and performance enhancement of combined power plants, while ensuring minimal environmental impact.

**Keywords:** *Combined power plant, MATLAB simulation, fmincon optimization, Energy and exergy analysis. Thermal efficiency, Sustainable power generation.*

## 1. Introduction

Energy has always been at the center of industrial and social development. CCPPs are preferred for electricity production because they provide greater thermal efficiency compared to using steam or gas turbines alone (Ali et al., 2020). Therefore, the optimal design of such cycles is of great importance due to increasing fuel prices and decreasing fossil fuel resources (Ameri et al., 2008). In this context, combined cycle power plants (CCPPs) have gained prominence worldwide. A CCPP integrates a gas turbine (Brayton cycle) with a steam turbine (Rankine cycle) through a Heat Recovery Steam Generator (HRSG). Modern combined power plant achieve thermal efficiencies above 60% by utilizing the

hot exhaust gases from the gas turbine to produce steam that drives the Rankine cycle. which is far greater than the 35–40% efficiency usually obtained from simple cycle systems. (Dhar Garg et al., 2013) This makes them one of the most efficient fossil-fuel-based power generation technologies available today (Ahmadi & Dincer, 2011). A combined power plant is created by coupling a Brayton cycle with a Rankine cycle. In this setup, the hot exhaust gases from the gas turbine are not released directly into the atmosphere but are instead utilized in a heat recovery steam generator (Nadir & Ghenaiet, 2015). The HRSG absorbs this heat energy to generate steam, which then powers a steam turbine linked to another generator. This arrangement significantly

10.48047/jocaaa.2024.33.07.54

improves overall cycle efficiency while also providing high power output from the same fuel input (Riady et al., 2019). Based on these advantages and less emission, CCPP have widely been used all around the world (Ahmadi & Dincer, 2011). Enhancing thermal efficiency while minimizing exergy destruction contributes to more power production, lower operating costs, and improved sustainability. Due to this reason, the present study is dedicated to the efficiency of the power plants operated by natural gas (Balku, 2017). Numerous studies have been devoted to evaluating the performance of combined gas–steam power plants through energy and exergy analyses supported by optimization techniques (Dhar Garg et al., 2013). One such investigation introduced an approach that reformulates a simulation-based physical model of a combined power plant into a structure suitable for optimization. This adaptation makes it possible to apply efficient algorithms aimed at improving start-up characteristics. investigated the thermal performance of a heat recovery steam generator (HRSG) within a combined gas–steam power plant by applying thermodynamic optimization through a genetic algorithm (Balku, 2017). The research emphasized evaluating transfer of energy between the steam vapour and steam liquid side under base-load conditions. Findings indicated that the high-pressure evaporator (HP-EVP) was produced for the major exergy destruction among the plant's components. They also observed that increasing the HRSG inlet gas temperature beyond 650 °C yielded only marginal gains in both thermal and exergy efficiencies of the bottoming cycle, suggesting an upper limit for efficiency improvements under this condition.(El-Masri, 1987). (Taghavi et al., 2013) embedded a genetic algorithm within MATLAB to optimize combined cycle plant. Their optimization framework used the total cost, defined as the sum of operating and capital costs, as the objective function (Taghavi et al., 2013). A genetic algorithm-based

computer code was employed to handle this multi-objective problem. Their findings highlighted the critical influence of key design parameters namely the inlet temp. of gas turbine, pressure ratio of compressor and HRSG pinch point temperature on plant performance. They concluded that even small variations in these parameters could lead to substantial changes in both cost and efficiency outcomes. (Khan et al., 2017) examined three alternative HRSG configurations within the exhaust gas temperature range of 350 °C to 650 °C. Their analysis, conducted using a particle swarm optimization algorithm, demonstrated that introducing an additional pressure level in the HRSG improved steam cycle performance regardless of the outlet temperature of turbine (Pattanayak et al., 2017). A complementary case study conducted at the Montazar Ghaem power plant in Iran further demonstrated the practical benefits of system improvements.(Balku, 2017) It was shown that incorporating a cooling system at the compressor inlet reduced the intake air temperature by 3.2%, which in turn led to a 1.138% increase in both thermal efficiency and net power output during the hottest month of the year (Nadir & Ghenaiet, 2015). Additionally, the combustion chamber, which typically exhibited the highest level of exergy destruction, experienced a notable reduction in irreversibility after implementation of the cooling system (Mishra & Kumar Sahu, n.d.). Research on modeling, simulation, and optimization is not confined solely to energy-related applications but has also proven valuable across a wide range of industrial processes. For example, (Topal & Tanbay, 2023) demonstrated that a developed cracker model could be effectively applied to real-time optimization and control in fluid catalytic cracking systems within the petrochemical industry. Similarly, (Tiwari et al., 2010) employed a comparable methodology incorporating mass balances, microbiological interactions, and gravity fluxes along with simulation and optimization studies to determine the aeration sequence in an

alternating system. The findings were then benchmarked against a conventional activated sludge process. In this case, sequential quadratic programming (SQP) was used as the optimization method, and its performance was compared with that of genetic algorithm (GA) based approaches for constraint handling. The results showed SQP to be both reliable and computationally efficient, offering significant time savings (Kaviri et al., 2012).

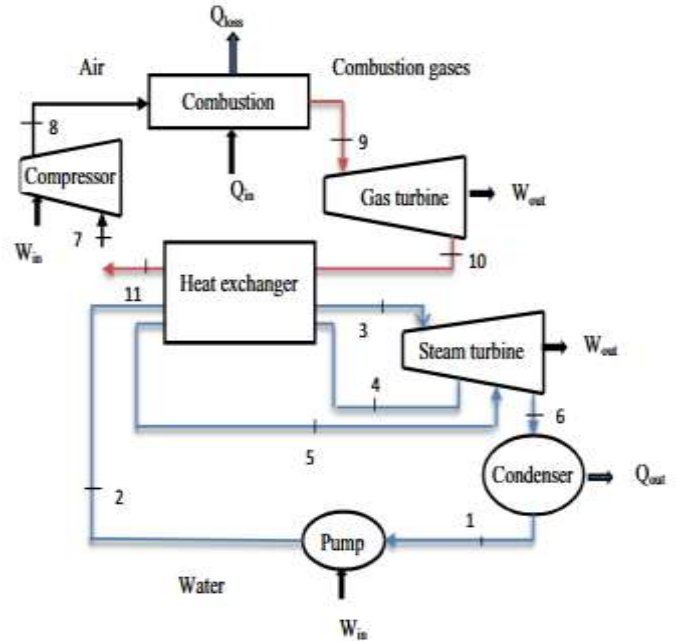
Expanding on previous methodologies, this study formulates a detailed model of a combined gas–steam power plant. The analysis incorporates mass, energy, entropy, and exergy considerations, with system-level simulations used to evaluate efficiency while reflecting the operational characteristics of major plant components. In the subsequent stage, the model is integrated with an optimization algorithm to determine optimal decision parameters (Elfeituri & Gehani, 2017). Two distinct optimization objectives are considered: in the first formulation, the thermal efficiency is maximized, while in the second case a new efficiency

## 2. Modelling, Simulation and Optimization

This study examines a fundamental configuration of a combined power plant, as depicted in Fig. 1. The system is modeled using energy balance, entropy balance and exergy balance equations and is then simulated based on defined input parameters. Initially, the analysis evaluates exergy destruction across the main components. In the subsequent phase, an optimized algorithm is employed to refine the decision variables and determine their optimal values.

### 2.1 Modelling

The proposed system is a basic combined arrangement of the topping cycle consists of pressure (LP) steam turbines, a heat recovery steam generator, a condenser, and a feedwater pump.



**Fig.1.** Flow diagram for a simple combined gas

The thermodynamic model of the plant is formulated using mass, energy, and entropy balance equations for each main component (Balku, 2017).

The modeling approach is based on the following assumptions:

1. The plant functions under steady state operation.
2. Variations in potential and kinetic energy are considered insignificant.
3. Air is treated as ideal gas for all operating states.
4. Combustion products are assumed to possess the same thermodynamic properties as air.

Because the system is considered at steady state, the mass inflow to each unit equals the mass outflow, eliminating the need for separate mass balance equations. However, energy and exergy balances are developed for all major units, with their formulations presented as follows (Dhar Garg et al., 2013).

#### 2.1.1 Air Compressor and Gas Turbine

Assuming that air behaves as an ideal gas, the corresponding enthalpy, entropy, and relative pressure (Pr) values are determined using the ideal gas property tables. For an ideal gas process, the entropy variation can be represented as a function of temp. and pressure

10.48047/jocaaa.2024.33.07.54

according to the following relation:

$$S_{out} - S_{in} = (S^{\circ}_{out} - S^{\circ}_{in}) - R \ln \frac{P_{out}}{P_{in}} \quad (1)$$

$$S_{out} = S_{in} \quad (2)$$

$$S^{\circ}_{out} = S^{\circ}_{in} + R \ln \frac{P_{out}}{P_{in}} \quad (3)$$

$$\frac{P_{out}}{P_{in}} = \frac{\exp(S_{out}/R)}{\exp(S_{in}/R)} \quad (4)$$

$$\left(\frac{P_{out}}{P_{in}}\right)_{(s = \text{const.})} = \frac{P_{r,out}}{P_{r,in}} \quad (5)$$

$$\eta_c = \frac{h_{out,s} - h_{in}}{h_{out} - h_{in}} \quad (6)$$

$$h_{out} = h_{in} - \eta_{Tg} (h_{in} - h_{out,s}) \quad (7)$$

### 2.1.2 Combustion chamber

The enthalpy of gases at the outlet of the combustion chamber is calculated based on the energy balance principle, which includes an efficiency factor representing the fraction of heat carried away by exhaust gases, with the rest corresponding to heat losses from the chamber.

$$\dot{m}_{air} (h_{air})_{in} + \dot{m}_{fuel} LHV_{fuel} + \dot{m}_{fuel} h_{fuel} = (\dot{m}_{air} + \dot{m}_{fuel}) \quad (8)$$

$$(h_{air})_{out} + (1 - \eta_c) (\dot{m}_{air} (h_{air})_{in} + \dot{m}_{fuel} LHV_{fuel} + \dot{m}_{fuel} h_{fuel}) \quad (9)$$

Energy Balance Applied to the HRSG

$$\dot{m}_s (h_{out} - h_{in})_{forHP} + \dot{m}_s (h_{out} - h_{in})_{forLP} \quad (10)$$

### 2.1.3 Overall energy balance

$$\dot{Q}_{in} = \dot{m}_{fuel} LHV_{fuel} + \dot{m}_{air} (h_{air})_{in} + \dot{m}_{fuel} h_{fuel} \quad (11)$$

$$\dot{W}_{net\ plant} = (\dot{W}_{net\ gas} + \dot{W}_{net\ steam}) = (\dot{W}_{T\ gas} - \dot{W}_{C\ gas}) + (\dot{W}_{T\ stea} - \dot{W}_{P,water}) \quad (12)$$

$$\eta_{th} = \frac{\dot{W}_{net,plant}}{\dot{Q}_{in}} \quad (13)$$

## 2.2 Simulation of a Combined gas-steam turbine cycle

Combined power plant model outlined in Section 2.1 was simulation using a MATLAB algorithm. The simulation requires 20 predefined parameters, including the inlet temperature air compressor, inlet temperature of fuel, compressor and gas turbine pressure ratios, isentropic efficiency of the compressor, gas turbine, L.P turbine and H.P turbine as well as the efficiencies of the pump, HRSG and combustion chamber. Additional inputs include the inlet and outlet pressures of pump, flow rate of fuel, air/fuel and gas/steam ratios, steam inlet pressure to the LP turbine, exhaust gas temperature from the HRSG, the lower heating value of the fuel, and steam inlet

temperature to the HP turbine (Balku, 2017). Steam and air properties were obtained using the online algorithms in references (Ganjehkaviri et al., 2014). The simulation employed the power plant model from Section 2.1 incorporating mathematical equations, thermodynamic concept and physical laws with the assigned parameter values listed in Table 1.

## 2.3 Optimization

Finding the factor of decision making that optimize the goal function is the formulation of the optimization issue in this study. Two distinct optimization scenarios are examined. The thermal efficiency of the combined power plant is the goal function in the first scenario, and it is written as follows:

$$\eta_{th} = \frac{\dot{W}_{net,plant}}{\dot{Q}_{in}} \quad (14)$$

The thermal efficiency of the plant ( $\eta_{th}$ ) is calculated as the total net power generated ( $\dot{W}_{net,plant}$ ) divided by the thermal energy supplied at the inlet ( $\dot{Q}_{in}$ ). In the second optimization case, the goal function is the plant's exergy efficiency, a performance metric that accounts for combined energy and exergy efficiencies, and is given by:

$$\eta_{enex} = \frac{\dot{W}_{net,plant}}{\dot{X}_{dest}} \quad (15)$$

**Table1** Simulation parameter and their assigned values

Parameter	Value	Unit
Temperature of entering air compressor	26	°C
Inlet temperature to fuel combustor	25	°C
Compressor pressure ratio	11	-
Gas turbine pressure ratio	11	-
Compressor isentropic efficiency	89	%
Gas turbine isentropic efficiency	88	%
High-press turbine isentropic efficiency	88	%
Low-press turbine isentropic efficiency	89	%
Efficiency of combustion chamber	90	%
HRSG efficiency	90	%
Pump suction pressure	11	kPa

10.48047/jocaaa.2024.33.07.54

Pump discharge pressure	5960	kPa
Fuel mass flow rate	45	kg/s
Ratio of air to fuel	41	-
Ratio of gas to steam	8.9	-
Steam entry temperature to HP turbine	470	°C
Steam inlet pressure to LP turbine	1010	kPa
Exhaust gas temp. leaving HRSG	202	°C
Fuel lower heating value (LHV)	47,320	kJ/kg

The overall net power output of the plant ( $W_{\text{net plant}}$ ) is normalized by the total exergy destruction ( $X_{\text{dest}}$ ) to define a new performance efficiency index. This indicator helps to identify the design parameters that deliver maximum power output while minimizing exergy losses, without altering the quality or quantity of fuel input. Consequently, this newly defined objective function can serve as an alternative to the conventional multi-objective optimization methods typically used in power cycle assessment. The objective functions are constrained by governing equations derived from energy, entropy, and exergy balances. These constraints can take the form of either linear or nonlinear relationships. The factor of decision making employed in the optimized process include:

- Inlet temp. of the compressor
- Compressor pressure ratio and the corresponding inverse for the gas turbine
- Inlet pressure of the pump
- Discharge pressure of the pump
- Exhaust gas temperature at the HRSG outlet
- Steam inlet pressure to the low-pressure turbine
- Steam inlet temperature to the high-pressure turbine
- Ratio of Air fuel
- Ratio of Gas steam

Thus, the combined gas–steam cycle optimization involves nine decision variables, each bounded within specific upper and lower limits. Out of the 20 predefined

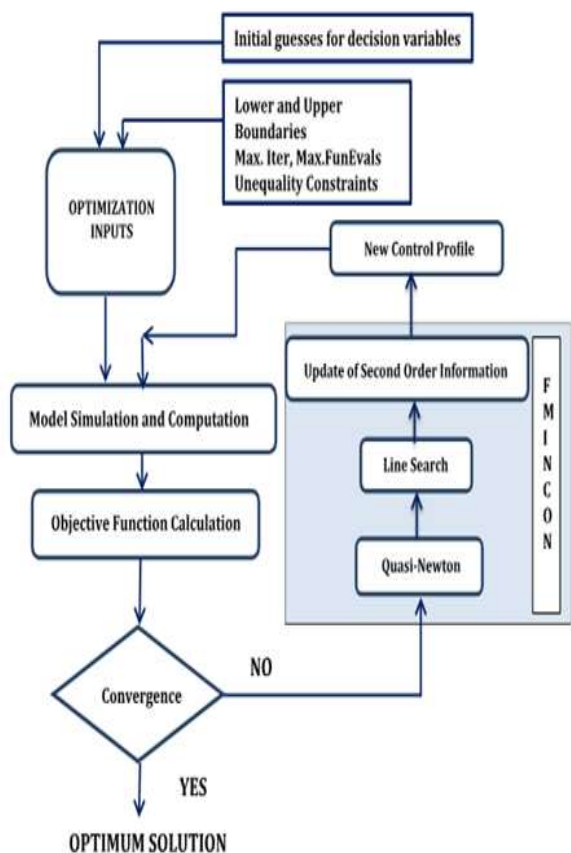
input parameters, these nine are selected as adjustable variables, with initial values assigned at the start of the optimization. At every iteration, the thermophysical properties of steam and air are calculated using thermodynamic property correlations, as the decision variables are updated (Balku, 2017). The cycle model introduced in Section 2.1, which incorporates mathematical formulations, thermodynamic principles, and physical constraints, is embedded within an optimization framework coded in MATLAB. This setup evaluates the factor of decision making to optimized the defined goal function. While genetic algorithms are commonly applied in similar studies, the optimization method used here has already been tested and validated in previous research, demonstrating efficiency, robustness, and suitability for constrained optimization problems (Ali et al., 2020).

#### 2.4. Optimization Solution Procedure

The objective of the optimized is to establish a control vector consisting of the decision variables. The process is carried out through the following steps:

1. Define the quantity and type of decision variables to be considered.
2. Define maximum and minimum constraints for them.
3. Provide initial estimates for the elements of the control vector.
4. Set values for other system parameters.
5. Specify maximum allowable constraint violations.
6. Define stopping criteria.
7. Run the cycle simulation using the assigned initial estimates as starting values.
8. Evaluate the goal function.
9. Check decision parameter constraints.
10. Employ MATLAB's *fmincon* function to solve the formulated optimized problem.
11. Iterate the procedure from step 6 until the minimum value of the goal function is obtained. The complete optimization strategy is illustrated in the flowchart shown

in Fig. 2, where  $y$  represents the vector of factor of decision making.

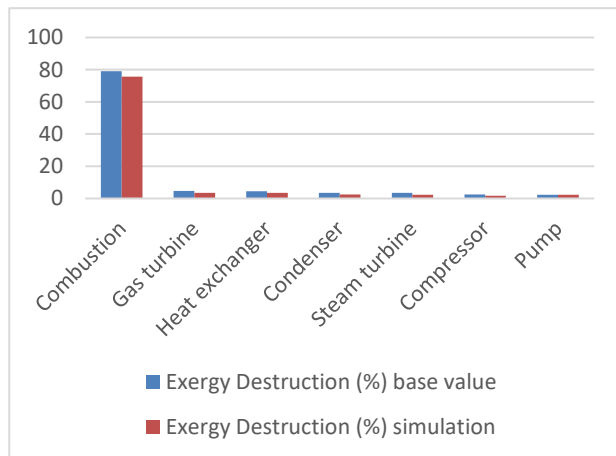


**Fig.2.** Flow chart of algorithm (Balku, 2017)  
 The MATLAB subroutine *fmincon* (find minimum of a constrained nonlinear multivariable function) is employed for the optimization. This solver provides four available algorithms: interior-point, sequential quadratic programming (SQP), active-set, and trust-region reflective methods (Balku, 2017). In the present work, the first optimization problem is addressed using the active-set approach. The selected subroutine determines the constrained minimum of a multivariable function and is designed to handle problems of the following general form:

$$\begin{aligned} &\min f(y) \text{ subject to:} \\ &A \times y \leq B, \quad A_{eq} \times y = B_{eq} \quad (\text{linear constraints}) \\ &C(y) \leq 0, \quad C_{eq}(y) \leq 0 \quad (\text{nonlinear constraints}) \\ &y^L \leq y \leq y^U \quad (\text{lower and upper boundaries}) \end{aligned}$$

**3. Results**  
**3.1 Simulation Results**

A combined power plant was modeled using energy, entropy and exergy balance relations for all major components. The simulation was carried out with 20 predefined input parameters, as listed in Table 1. The key subsystems analyzed include the air compressor, combustion chamber, gas turbine, HRSG, high pressure and low pressure steam turbine, condenser and pump. The simulation results indicate that the combined cycle delivers a thermal efficiency of 44.50%, with the combustion chamber contributing approximately 80.83% of the total exergy destruction. The distribution of exergy destruction among the various plant components is presented in Figure 3. In the computational procedure, the efficiencies of all units were initially assumed to be 90%. The results confirm that the combustion chamber is the primary source of irreversibility, followed by the HRSG.



**Fig.3.** Exergy Destruction in plant units  
 A second simulation was conducted to examine the impact of improving combustion efficiency on overall plant performance. The results indicate that enhancing combustion efficiency significantly boosts overall efficiency. Specifically, increasing the combustion unit’s efficiency from 90% to 99% raises the plant’s overall thermal efficiency to 52.85% and reduces total exergy destruction by 21.25%, as summarized in Table 2.

**Table 2** Exergy Destruction in plant units

Unit	Exergy Destruction (%)	
	Base value	Simulation
Combustion	80.83	63.5
Gas turbine	~5	~5
Heat exchanger	~5	~5
Condenser	~5	~5
Steam turbine	~5	~5
Compressor	~5	~5
Pump	~5	~5

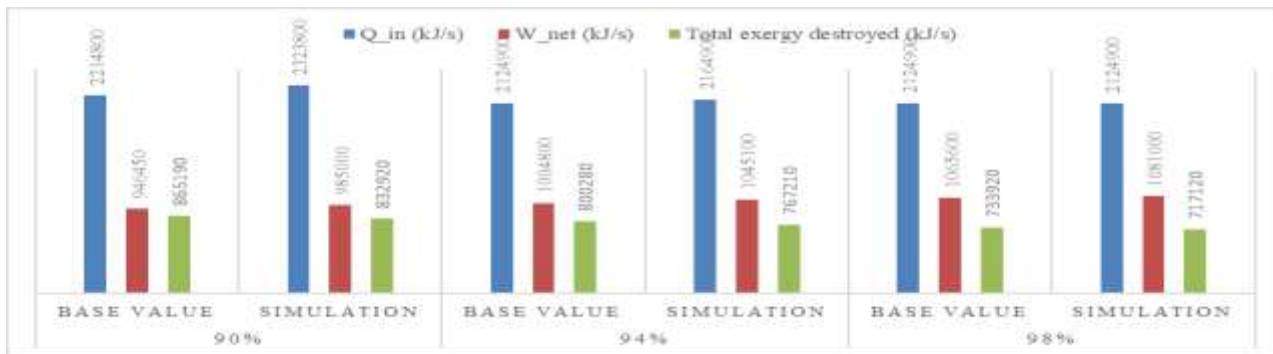
10.48047/jocaaa.2024.33.07.54

Combustion	79.12	75.6
Gas turbine	4.65	3.43
Heat exchanger	4.56	3.45
Condenser	3.45	2.43
Steam turbine	3.45	2.31
Compressor	2.44	1.74
Pump	2.33	2.3

**3.2 Optimization Results**

During the optimization phase, 9 variables were selected from the original set of 20 simulation inputs to serve as the decision parameters. Two optimization problems were formulated: the first adopted the overall thermal efficiency as the objective function, while the second employed the energy exergy efficiency. The baseline values of the decision variables for the reference plant are listed in Table 3. Optimization was performed using MATLAB’s *fmincon* solver to determine the values of these variables that maximize the respective objectives. For all simulations, component efficiencies including the compressor isentropic efficiency, gas turbine, high and low-pressure turbines, pump and the energy transfer efficiencies of both the combustion chamber and HRSG were kept constant at 90%. The lower heating value of natural gas was assumed as 47,320 kJ/kg at 26 °C, with a fuel mass flow rate of 45 kg/s. The decision variables were allowed to vary between 0.2 and 1.9 times their baseline values; values outside this interval were excluded due to limitations in the thermophysical property database. The optimization outcomes identified three parameters as the

most influential: the compressor and gas turbine, pressure ratio, air fuel ratio and gas steam ratio. These variables consistently approached their maximum allowable limits, while the remaining decision parameters exhibited only marginal or negligible changes. As summarized in Table 4, when thermal efficiency was defined as the objective, the cycle efficiency improved from 44.50% to 52.87%, net power output increased by 22.50%, and exergy destruction was reduced by 22.60%. In the second case, where energy exergy efficiency was maximized, the thermal efficiency again reached 52.87%, but exergy destruction was reduced further, by 23.60%. The energy exergy efficiency consequently increased from 82.28% to 89.23%. Table.5 indicates the convergence process for the first optimization problem. The negative form of the thermal efficiency objective decreased from -0.444961 to -0.545294 after 30 iterations, corresponding to a 22.55% rise in thermal efficiency and a 54.49% improvement in energy–exergy efficiency, without any violation of constraints. In the second optimization case, the interior-point algorithm was employed (progression given in Table 6). Here, the objective function, expressed as the negative of the energy exergy efficiency, decreased from -1.092822 to -1.766626 after 144 iterations, again with no constraint violations. All cycle simulation and optimization were carried out in the MATLAB environment.



**Fig.4.** Different Combustion Efficiencies\_1 results of Simulation

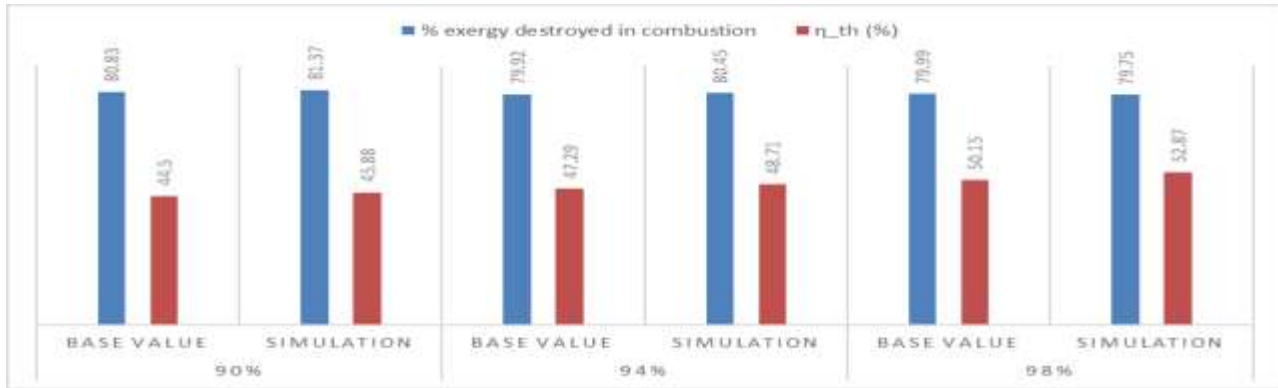


Fig.5.Different Combustion Efficiencies\_2 results of Simulation

Table.3. Different Combustion Efficiencies results of Simulation

Parameter	Value					
	90%		94%		99%	
	Base value	Simulation	Base value	Simulation	Base value	Simulation
Q <sub>in</sub> (kJ/s)	2214800	2323800	2124900	2164900	2124900	2124900
W <sub>net</sub> (kJ/s)	946450	985000	1004800	1045100	1065600	1081000
Thermal efficiency (η <sub>th</sub> ) (%)	43.4	44.6	45.31	47.67	49.12	53.66
Overall exergy destroyed (kJ/s)	865190	832920	800280	767210	733920	717120
Contribution of combustion to exergy destruction (%)	80.83	81.37	79.92	80.45	79.99	79.75

Table.4. Decision variable the assigned and optimum value

Parameter Description	Unit	Baseline values	Optimized values -1	Optimized values -2	Optimized values -3
Inlet temp. of Air Compressor	°C	26	26.2	26.4	26.6
Compressor Pressure Ratio	-	10	12.9	12.7	13.2
Suction pressure of Pump	KPa	11	9.2	9.25	9.3
Delivery pressure of Pump	KPa	5960	5980	5990	6000
Ratio of Gas steam	-	8.8	14.4	15.6	15.7
Ratio of Air fuel	-	41	37.3	37.8	35.2
Steam temperature at HP turbine inlet	°C	470	472	473	474
Steam pressure at LP turbine inlet	kPa	1010	1012	1013	1014
Exhaust gas temp. at HRSG outlet	°C	202	203.2	204.6	206
Ambient humidity	%	58	57	57	56
Cooling water inlet temperature	°C	25	24	23.5	23
Condenser pressure	kPa	10	9.5	9.3	93
HRSG pinch point temperature difference	°C	15	14	13.8	13.2
Steam turbine isentropic efficiency	%	85	87	87.5	90
Gas turbine isentropic efficiency	%	88	90	90.5	90

Table.5.Optimization Results for the Combined Gas–Steam Power Plant

Parameter	Unit	Initial Value	First algorithm		Second algorithm		Third algorithm	
			Optimized	%Change	Optimized	% Change	Optimized	%Change
$Q_{in}$	kJ/s	221480	2124900	0	2124900	0	2124900	0
$W_{net}$	kJ/s	946450	1148600	21.35	1149500	21.45	1150112	21.5
$\eta_{th}$	%	45.5	53.53	17.6	54.95	20.76	55.67	22.35
Total exergy destroyed	kJ/s	865190	679290	21.48	660930	23.61	650940	24.76
Energy-exergy efficiency	%	82.28	87.15	9	88.66	11	89.23	13

Table.6.the Step of the optimization algorithm

Iteration	F count	f(x)	Feasibility	First-order optimality	Norm of step
0	10	-1.08e+00	0e+00	4.865e-002	6.159 e-002
1	20	-1.09672e+00	0e+00	4.848 e-002	3.166 e-002
2	30	-1.117032e+00	0e+00	4.996 e-002	1.637 e-002
3	40	-1.124247e+00	0e+00	5.539 e-002	7.876 e-002
4	50	-1.17101e+00	0e+00	4.517 e-002	1.986 e-002
5	61	-1.71215e+00	0e+00	4.177 e-002	7.295 e-002
6	71	-1.715617e+00	0e+00	4.192 e-002	3.487 e-002
7	81	-1.731064 e+00	0 e+00	3.96 e-002	4.124 e-002
8	93	-1.749317 e+00	0 e+00	4.046 e-002	3.559 e-002
9	105	-1.765318 e+00	0 e+ 01	4.197 e-002	2.69 e-002
10	124	-1.766496 e+00	0 e+ 01	4.196 e-002	2.943 e-002
11	144	-1.766626 e+00	0 e+ 02	4.326 e-002	2.943 e-002

Table.7.The list of Constraints for Optimization(Ahmadi & Dincer, 2011)

Constraints	Rationale		efficiency.
$TTT < 1560^{\circ}K$	Limited by material temperature resistance	$\eta_p$	Limited by commercial availability of pump efficiency
$r_{comp} < 23$	Restricted by compressor commercial availability	$m_{DB} < 1.9 \text{ kg/s}$	Restricted by superheater temperature limitations
$\eta_{comp} < 0.88$	Bound by commercially achievable compressor efficiency	$4.9 \text{ bar} < P_{con} < 14.9 \text{ bar}$	Heat efficiency limitation
$\eta_{GT} < 0.87$	Bound by commercially achievable gas turbine efficiency.	$T_{main}$	Limited by material temp. constraints
$P_{main} < 110 \text{ bar}$	Restricted by commercially available operating pressures	$T_{18} > 120 \text{ }^{\circ}C$	To prevent sulfuric acid condensation in exhaust gases
$\eta_{sr}$	Constrained by commercial availability of steam reheater	$4.9 \text{ }^{\circ}C < PP < 29.9 \text{ }^{\circ}C$	Constraint based on the second law of thermodynamics

**Conclusion:-**

Optimizing the design and operation of such systems is of great significance. In this work, a simplified model of a combined power plant was formulated using the fundamental balance equations of mass, energy, entropy, and exergy. Simulation results identified the contribute most to exergy destruction within the revealing that the

combustion chamber is the dominant source. Although modern plants already achieve higher Performance improvements driven by progress in combustion systems and turbine design simulations confirm that combustion remains the largest contributor to exergy losses. During the optimization process, the simplified model of the

combined gas vapor power plant was simulated using an optimized algorithm to determine the optimized decision variable values. Two separate algorithms were applied, each based on a different objective function, and their performances were compared. The initial objective function aimed to maximize the plant's Power plant efficiency while the second focused on maximizing the combined exergy energy efficiency. The optimization results indicate that the most critical decision variables for plant performance are the gas-steam mass ratio, air-to-fuel mass ratio and pressure ratios of both compressor and the gas turbine. In particular, the gas steam mass ratio and the compressor pressure ratio tend to Move toward the higher limit operational limits and would surpass them if constraints were removed, although such conditions would be impractical in real world systems. Other decision variables showed minimal variation during optimization. Applying the first algorithm, which focuses on maximizing thermal efficiency, demonstrates that adjusting the decision variables while maintaining the same thermal energy input leads to an improvement in the plant's thermal efficiency. A comparison of the two methods reveals that the second approach achieves slightly greater gains in the dual objectives of thermal efficiency and exergy energy efficiency making it the more effective optimization strategy. In this work, a framework is developed for assessing the performance of combined cycle power plants and optimizing their operation by selecting the most significant parameters and determining their ideal values. Adopting the most efficient operating parameters can yield notable economic and environmental benefits. The study introduces a new efficiency concept that integrates Energy and exergy efficiencies serve as objective functions in the optimization framework for power system evaluation. Utilizing this new metric can lead to improved optimization results. With the proposed approach, it is possible to determine the best decision Variable for a

combined cycle plant while simultaneously boosting thermal efficiency and minimizing destruction of exergy.

## References

- Ahmadi, P., & Dincer, I. (2011). Thermodynamic analysis and thermoeconomic optimization of a dual pressure combined cycle power plant with a supplementary firing unit. *Energy Conversion and Management*, 52(5), 2296–2308. <https://doi.org/10.1016/j.enconman.2010.12.023>
- Ali, M. S., Shafique, Q. N., Kumar, D., Kumar, S., & Kumar, S. (2020). Energy and exergy analysis of a 747-MW combined cycle power plant Guddu. *International Journal of Ambient Energy*, 41(13), 1495–1504. <https://doi.org/10.1080/01430750.2018.1517680>
- Ameri, M., Ahmadi, P., & Khanmohammadi, S. (2008). Exergy analysis of a 420 MW combined cycle power plant. *International Journal of Energy Research*, 32(2), 175–183. <https://doi.org/10.1002/er.1351>
- Balku, Ş. (2017). Analysis of combined cycle efficiency by simulation and optimization. *Energy Conversion and Management*, 148, 174–183. <https://doi.org/10.1016/j.enconman.2017.05.032>
- Dhar Garg, P., Dehiya, S., Barasiya, A., Rahangdale, A., Shankar Kumawat, V., Student, Mt., Gandhi Proudhyogiki Vishwavidyalaya Bhopal, R., Pradesh, M., & Professor, A. (2013). Exergy and Efficiency Analysis of Combined Cycle Power Plant. *International Journal of Scientific & Engineering Research*, 4(1), 2013. <http://www.ijser.org>
- Elfeituri, I., & Gehani, H. El. (2017). Energy and Exergy Analysis for Unit13E1 of Benghazi Combined

- Cycle Power Plant. *Libyan Journal for Engineering Research (LyJER)*, 1. www.lyjer.uob.edu.ly
- El-Masri, M. A. (1987). *Exergy Analysis of Combined Cycles: Part 2-Analysis and Optimization of Two-Pressure Steam Bottoming Cycles*. <http://asme.org/terms>
- Ganjehkaviri, A., Mohd Jaafar, M. N., Ahmadi, P., & Barzegaravval, H. (2014). Modelling and optimization of combined cycle power plant based on exergoeconomic and environmental analyses. *Applied Thermal Engineering*, 67(1–2), 566–578. <https://doi.org/10.1016/j.applthermaleng.2014.03.018>
- Kaviri, A. G., Jaafar, M. N. M., & Lazim, T. M. (2012). Modeling and multi-objective exergy based optimization of a combined cycle power plant using a genetic algorithm. *Energy Conversion and Management*, 58, 94–103. <https://doi.org/10.1016/j.enconman.2012.01.002>
- Khan, M. N., Tlili, I., & Khan, W. A. (2017). Thermodynamic Optimization of New Combined Gas/Steam Power Cycles with HRSG and Heat Exchanger. *Arabian Journal for Science and Engineering*, 42(11), 4547–4558. <https://doi.org/10.1007/s13369-017-2549-4>
- Mishra, S., & Kumar Sahu, M. (n.d.). *THERMODYNAMIC PERFORMANCE INVESTIGATION OF GAS/STEAM COMBINED CYCLE BASED ON EXERGY ANALYSIS*.
- Nadir, M., & Ghenaiet, A. (2015). Thermodynamic optimization of several (heat recovery steam generator) HRSG configurations for a range of exhaust gas temperatures. *Energy*, 86, 685–695. <https://doi.org/10.1016/j.energy.2015.04.023>
- Pattanayak, L., Sahu, J. N., & Mohanty, P. (2017). Combined cycle power plant performance evaluation using exergy and energy analysis. *Environmental Progress and Sustainable Energy*, 36(4), 1180–1186. <https://doi.org/10.1002/ep.12546>
- Riady, M. I., Santoso, D., & Bustan, M. D. (2019). Thermodynamics Performance Evaluation in Combined Cycle Power Plant by Using Combined Pinch and Exergy Analysis. *Journal of Physics: Conference Series*, 1198(4). <https://doi.org/10.1088/1742-6596/1198/4/042006>
- Taghavi, M., Abdollahi, M., & Salehi, G. (2013). Thermodynamic and Thermo Economic Optimization of Combined Cycle Power Plant. *International Journal of Materials, Mechanics and Manufacturing*, 186–190. <https://doi.org/10.7763/ijmmm.2013.v1.40>
- Tiwari, A. K., Islam, M., & Khan, M. N. (2010). Thermodynamic Analysis of Combined Cycle Power Plant. In *International Journal of Engineering Science and Technology* (Vol. 2, Issue 4).
- Total, G., & Tanbay, T. (2023). Energy and exergy analysis of the 1220 MW natural gas-fired Hamitabat combined cycle power plant. *International Journal of Energy Studies*, 8(4), 781–808. <https://doi.org/10.58559/ijes.1327547>
- Ahmadi, P., & Dincer, I. (2011). Thermodynamic analysis and thermoeconomic optimization of a dual pressure combined cycle power plant with a supplementary firing unit. *Energy Conversion and Management*, 52(5), 2296–2308. <https://doi.org/10.1016/j.enconman.2010.12.023>
- Ali, M. S., Shafique, Q. N., Kumar, D., Kumar, S., & Kumar, S. (2020). Energy and exergy analysis of a 747-MW combined cycle power plant Guddu. *International Journal of Ambient Energy*, 41(13), 1495–1504. <https://doi.org/10.1080/01430750.2018.1517680>
- Ameri, M., Ahmadi, P., & Khanmohammadi, S. (2008). Exergy analysis of a 420 MW combined cycle

- power plant. *International Journal of Energy Research*, 32(2), 175–183. <https://doi.org/10.1002/er.1351>
- Balku, Ş. (2017). Analysis of combined cycle efficiency by simulation and optimization. *Energy Conversion and Management*, 148, 174–183. <https://doi.org/10.1016/j.enconman.2017.05.032>
- Dhar Garg, P., Dehiya, S., Barasiya, A., Rahangdale, A., Shankar Kumawat, V., Student, Mt., Gandhi Proud yogiki Vishwavidyalaya Bhopal, R., Pradesh, M., & Professor, A. (2013). Exergy and Efficiency Analysis of Combined Cycle Power Plant. *International Journal of Scientific & Engineering Research*, 4(1), 2013. <http://www.ijser.org>
- Elfeituri, I., & Gehani, H. El. (2017). Energy and Exergy Analysis for Unit13E1 of Benghazi Combined Cycle Power Plant. *Libyan Journal for Engineering Research (LjJER)*, 1. [www.lyjer.uob.edu.ly](http://www.lyjer.uob.edu.ly)
- El-Masri, M. A. (1987). *Exergy Analysis of Combined Cycles: Part 2-Analysis and Optimization of Two-Pressure Steam Bottoming Cycles*. <http://asme.org/terms>
- Ganjehkaviri, A., Mohd Jaafar, M. N., Ahmadi, P., & Barzegaravval, H. (2014). Modelling and optimization of combined cycle power plant based on exergoeconomic and environmental analyses. *Applied Thermal Engineering*, 67(1–2), 566–578. <https://doi.org/10.1016/j.applthermaleng.2014.03.018>
- Kaviri, A. G., Jaafar, M. N. M., & Lazim, T. M. (2012). Modeling and multi-objective exergy based optimization of a combined cycle power plant using a genetic algorithm. *Energy Conversion and Management*, 58, 94–103. <https://doi.org/10.1016/j.enconman.2012.01.002>
- Khan, M. N., Tlili, I., & Khan, W. A. (2017). Thermodynamic Optimization of New Combined Gas/Steam Power Cycles with HRSG and Heat Exchanger. *Arabian Journal for Science and Engineering*, 42(11), 4547–4558. <https://doi.org/10.1007/s13369-017-2549-4>
- Mishra, S., & Kumar Sahu, M. (n.d.). *THERMODYNAMIC PERFORMANCE INVESTIGATION OF GAS/STEAM COMBINED CYCLE BASED ON EXERGY ANALYSIS*.
- Nadir, M., & Ghenaiet, A. (2015). Thermodynamic optimization of several (heat recovery steam generator) HRSG configurations for a range of exhaust gas temperatures. *Energy*, 86, 685–695. <https://doi.org/10.1016/j.energy.2015.04.023>
- Pattanayak, L., Sahu, J. N., & Mohanty, P. (2017). Combined cycle power plant performance evaluation using exergy and energy analysis. *Environmental Progress and Sustainable Energy*, 36(4), 1180–1186. <https://doi.org/10.1002/ep.12546>
- Riady, M. I., Santoso, D., & Bustan, M. D. (2019). Thermodynamics Performance Evaluation in Combined Cycle Power Plant by Using Combined Pinch and Exergy Analysis. *Journal of Physics: Conference Series*, 1198(4). <https://doi.org/10.1088/1742-6596/1198/4/042006>
- Taghavi, M., Abdollahi, M., & Salehi, G. (2013). Thermodynamic and Thermo Economic Optimization of Combined Cycle Power Plant. *International Journal of Materials, Mechanics and Manufacturing*, 186–190. <https://doi.org/10.7763/ijmmm.2013.v1.40>
- Tiwari, A. K., Islam, M., & Khan, M. N. (2010). Thermodynamic Analysis of Combined Cycle Power Plant. In *International Journal of Engineering Science and Technology* (Vol. 2, Issue 4).
- Total, G., & Tanbay, T. (2023). Energy and exergy analysis of the 1220 MW natural gas-fired Hamitabat combined cycle power plant. *International Journal of Energy Studies*, 8(4), 781–

808. <https://doi.org/10.58559/ijes.1327547>