The International Journal of Engineering and Information Technology (IJEIT)
ijeit.misuratau.edu.ly
MISURATA UNIVERSITY

Energy and Exergy analysis of Umdabaker steam power plant in Sudan

Elamin A. A. Salih[1], alaminsalih2012@gmail.com, Musaab O. El-Faroug[1,2,*], musaabgaffar@gmail.com,
Salem A. Basher[2], salemibrahim114@yahoo.com, Amir Abubaker Musa[3], aamusaa@ub.edu.sa
[1]Mechanical Engineering Department, Faculty of Engineering, Elimam Elmahdi University, Kosti, Sudan
[2] Petroleum Engineering Department, Faculty of Energy and Mining Engineering, Sirte University, Marada, Libya
[3]Mechanical Engineering Department, College of Engineering, University of Bisha, Bisha, Saudi Arabia
* Corresponding author

Article History

Received 08 Sep, 2025
Revised 05 Nov, 2025
Accepted 13 Dec, 2025
Online 13 Dec, 2025

DOI:
https://doi.org/10.36602/ijeit.v14i1.578

Index Terms

Steam power plant, Energy analysis, Exergy analysis, Thermal efficiency, Exergy destruction, Dead-state temperature

Abstract

A comprehensive thermodynamic analysis of the 500 MW Umdabaker steam power plant in Sudan was conducted, evaluating energy and exergy performance under varying thermal conditions. All major components (boiler, turbine, condenser, pumps, and feedwater heaters) were assessed through computational modeling based on thermodynamic principles. The energy analysis revealed an overall plant thermal efficiency of 37.25%, with 52.7% of total energy losses being attributed to the condenser. Through exergy analysis, the boiler was identified as the primary source of usable energy loss (205.84 MW), while the condenser's contribution resulted in an overall exergy efficiency of only 35.8%. The impact of reference temperature variations (298.15 K to 318.15 K) was examined, showing boiler efficiency to be reduced from 43.8% to 41.1%, turbine efficiency to be slightly improved from 93.7% to 94.2%, and condenser efficiency to be dramatically decreased from 0.8% to 0.2% due to diminished temperature differentials.

تحليل الطاقة والإكسيرجي لمحطة الطاقة البخارية بأم دباكر في السودان

الامين ابوالقاسم عبدالحكم صالح[1]، مصعب عمر الفاروق مبارك[1،2،*]، سالم عبد العالي بشير[2]، امير ابوبكر موسى[3]
[1] قسم الهندسة الميكانيكية، كلية الهندسة، جامعة الامام المهدي، كوستي، السودان
[2] قسم هندسة النفط، كلية هندسة الطاقة والتعدين، جامعة سرت، مرادة، ليبيا
[3] قسم الهندسة الميكانيكية، كلية الهندسة، جامعة بيشة، بيشة، السعودية
* المؤلف المراسل

الملخص

تم إجراء تحليل ديناميكي حراري شامل لمحطة توليد الطاقة البخارية في أم دباكر بالسودان بقدرة 500 ميجاوات، حيث تم تقييم أدائها من منظور الطاقة والإكسيرجي تحت ظروف حرارية متغيرة. وتم تقييم جميع المكونات الرئيسية (المرجل، والتوربين، والمكثف، والمضخات، وسخانات مياه التغذية) من خلال النمذجة الحسابية القائمة على مبادئ الديناميكا الحرارية.

كشف تحليل الطاقة عن كفاءة حرارية إجمالية للمحطة بلغت 37.25%، مع نسبة 52.7% من إجمالي فاقد الطاقة تُعزى إلى المكثف. ومن خلال تحليل الإكسيرجي، تم تحديد المرجل كمصدر رئيسي لفقدان الطاقة القابلة للاستخدام (205.84 ميجاوات)، بينما أدت مساهمة المكثف إلى انخفاض الكفاءة الإجمالية للإكسيرجي إلى 35.8% فقط.

تم دراسة تأثير تغيرات درجة حرارة المرجع (من 298.15 كلفن إلى 318.15 كلفن)، وأظهرت النتائج انخفاض كفاءة المرجل من 43.8% إلى 41.1%، وتحسنًا طفيفًا في كفاءة التوربين من 93.7% إلى 94.2%، بينما انخفضت كفاءة المكثف انخفاضًا حادًا من 0.8% إلى 0.2% بسبب تناقص فروق درجات الحرارة.

الكلمات المفتاحية

محطة طاقة بخارية، تحليل الطاقة، تحليل الإكسيرجي، الكفاءة الحرارية، إتلاف الإكسيرجي، درجة حرارة الحالة الميتة

I. Introduction

A nation's energy consumption patterns directly mirror its economic development and quality of life. As populations expand, cities grow, and technology advances, energy demand surges - bringing with it environmental challenges like air pollution and climate change. Currently, fossil fuels dominate global electricity production (80%), with renewables making up the remaining 20% [1]. In Sudan, nearly half of all power generation capacity (43.7%) comes from thermal power plants [2], reflecting both the country's energy infrastructure and its development challenges.

The performance of thermal power plants (TPPs) is critically important from economic, policy, security, fuel, and environmental perspectives. Evaluating current TPP performance is essential for identifying improvement strategies. Traditionally, performance has been assessed using energy-based (First Law) criteria, such as electrical output and thermal efficiency. However, in recent decades, exergy analysis (Second Law) has emerged as a valuable tool for design, optimization, and efficiency assessment [3, 4]. Unlike conventional energy analysis, exergy analysis is capable of identifying both the magnitude and locations of irreversibilities within a system, while also providing accurate efficiency assessments at the component level. When these two analytical methods are combined, a more complete and effective framework for performance evaluation is achieved [5-7].

Significant research efforts have been dedicated to developing methodologies for improving thermal power plant efficiency [8-13]. A novel exergy auditing approach for boilers was introduced by Behbahaninia [9], where more than 38% of total exergy input was found to be lost through irreversibilities, yielding a boiler exergy efficiency of 53.70%. In the Al-Hussein power plant study conducted by Aljundi [13], the boiler was identified as the main source of exergy destruction, with potential for loss reduction through incoming air preheating and fuel-to-air ratio optimization. Further analysis by Vosoogh [14] demonstrated that decreasing the excess air ratio from 0.40 to 0.15 resulted in energy and exergy efficiency improvements of 0.19% and 0.37% respectively. Additional efficiency gains were achieved when flue gas temperature at the chimney exit was reduced from 137°C to 90°C, enhancing energy efficiency by 0.84% and exergy efficiency by 2.3%.

Bojeldain et al. [15] found that the boiler at the Derna Steam Power Plant was responsible for a significant 88% of the total exergy destruction, with the condenser and turbine contributing only minor amounts. In a similar study based on real operational data, Gungor Celik et al. [16] reported that the boiler accounted for 70% of the exergy loss, while components like the ejector operated with nearly ideal efficiency. Another case study involving a 750 MW combined-cycle plant showed that the combustion chamber and heat recovery steam generator were the primary sources of exergy destruction, contributing 53% and 32% respectively, whereas the condenser's share was just 1.7% [17]. Yin et al. [18] demonstrated that modifying the structure of the boiler, particularly through improved heat exchanger configurations, led to a modest but meaningful 1.1% increase in exergy efficiency. Additionally, an analysis of a 500 MW unit under different load conditions revealed that the plant operated more efficiently at full load, achieving an exergy efficiency of approximately 46.1%, while the steam turbine consistently maintained a high efficiency of about 77.6% [19].

This study conducts a detailed energy and exergy analysis of the Umdabaker steam power plant while it is operating at its full capacity. Key components including the boiler, turbine, condenser, pumps, and feedwater heaters are examined to assess overall energy efficiency and exergy performance across varying ambient conditions. The investigation focuses on identifying irreversibilities within the system and potential opportunities for performance enhancement.

II. Materials and Methods

A. Energetic performance analysis

System performance is evaluated through energetic analysis based on the First Law of Thermodynamics, where power output and thermal efficiency serve as key metrics. For individual components, performance is determined by analyzing input and output values calculated from fundamental thermodynamic properties, including enthalpy, pressure, temperature, entropy, mass flow rate, and steam quality. These parameters enable the power output of steam turbines to be accurately calculated.

$$W_T = \dot{m}_{in}(h_{in} - h_1) + (\dot{m}_{in} - \dot{m}_1)(h_1 - h_2) + (\dot{m}_{in} - \dot{m}_1 - \ldots \dot{m}_n)(h_{n-1} - h_n) \quad (1)$$

In the current analysis, the subscripts 1, 2, ..., n are used to represent the steam extraction points in the turbine. For modeling internal power consumption, consideration is given only to the energy consumed by the pumps. The necessary pump power is determined through the following simplified expression:

$$\dot{W}_p = \frac{\dot{m}(h_{out} - h_{in})}{\eta_p} \quad (2)$$

Here, η_p represents the efficiency of the pump. The net electrical power output of the system is determined using the following expression:

$$\dot{w}_{net} = \sum \dot{w}_t - \sum \dot{w}_p \quad (3)$$

The total heat energy needed in the boiler can be calculated using:

$$\dot{Q}_B = \frac{\dot{m}_{sh}(h_{sh,out} - h_{sh,in}) + \dot{m}_{rh}(h_{rh,out} - h_{rh,in})}{\eta_B} \quad (4)$$

Where, the subscripts of sh and rh indicate superheat and reheat conditions, respectively. Also, η_B denotes the boiler efficiency. The boiler inlet enthalpy ($h_{sh,in}$) in Eq(4). is calculated from the energy balance equation for the feed water heater:

$$(\dot{m}_s h_s)_{in} + (\dot{m}_{fw} h_{fw})_{in} = (\dot{m}_s h_s)_{out} + (\dot{m}_{fw} h_{fw})_{out} \quad (5)$$

In this formulation, the subscripts 's' and 'fw' are used to denote steam and feedwater, respectively. Additionally, it should be noted that the outlet temperatures of the remaining feedwater heaters are determined using the same methodology as presented in Equation (5). Finally, the thermal efficiency of the power plant can be calculated according to the following expression:

$$\eta_{th} = \frac{W^{\cdot}_{net}}{m^{\cdot}_{fuel} LHV} \quad (6)$$

Where, LHV is the lower heating value of crude oil. $m^{\cdot}_{fuel}$ crude oil flow rate and it is found as below:

$$m^{\cdot}_{fuel} = \frac{Q^{\cdot}}{LHV} \quad (7)$$

B. Exergetic performance analysis

Energy conversion systems are evaluated through Second Law-based exergy analysis, where irreversibilities and work potential are quantitatively assessed [7, 20]. In the current study, exergy efficiencies and destruction rates are examined at both component and system levels, with exergy loss per unit output being introduced as a novel performance metric. These analyses are based on steady-state conditions, with exergy destruction being derived from balance equations:

$$E^{\cdot}x = m^{\cdot}((h-h_o)-T_o(s-s_o)) \quad (8)$$

System performance is assessed through Second Law analysis using enthalpy (h) and entropy (s) to determine exergy efficiency. In this approach, the product-fuel methodology is employed to evaluate component effectiveness, where 'fuel' is defined as the exergy consumed and 'product' as the useful output. For systems utilizing crude oil, component-specific exergy destruction and efficiency are presented, with the total plant destruction calculated as the sum of all individual component
losses:

$$Ex_{D,total} = \sum (E^{\cdot}x_{D,i}) = Ex_{D,B} + Ex_{D,T} + Ex_{D,C} + Ex_{D,P} + Ex_{D,H}$$
(9)

For the whole thermal power plant, the exergy efficiency can be given as:

$$\eta_{Ex} = \frac{W^{\cdot}_{net}}{m^{\cdot}_{fuel}.ex_{fuel}} \quad (10)$$

The specific exergy of crude oil (ex_{fuel}) is known to vary considerably depending on its chemical composition. For coal, specific exergy values were obtained from well-documented sources in the literature. As part of this investigation, an additional performance metric is introduced: the exergy loss rate per unit power output, which is expressed as follows:

$$\zeta = \frac{Ex_{D,total}}{w^{\cdot}_{net}} \quad (11)$$

A more comprehensive assessment of power plant performance is enabled by integration both energetic and exergetic evaluation methods. This combined approach provides deeper insights that can be utilized for system optimization and efficiency improvements:

$$\text{Percentage Exergy Destruction} = \frac{E^{\cdot}x_{D,i}}{Ex_{D,total}} *100 \quad (12)$$

When a system is analyzed under steady-state conditions, with each component in Figure 1 considered as an independent control volume, both the exergy destruction rate and exergy efficiency can be calculated using the formulations provided in Table 1. Although various definitions of power cycle exergy efficiency are available, the chosen methodology offers two key advantages: not only are the irreversibilities from boiler heat transfer included, but also the exergy losses from fuel combustion and flue gas emissions are accounted for [13].

TABLE 1. The Exergy Destruction Rate and Exergy Efficiency Equations for Plant Component

	Exergy destruction rate	Exergy efficiency
Boiler	$X^{\cdot}_{D,boiler} = X^{\cdot}_{fuel} + X^{\cdot}_{in} - X^{\cdot}_{out}$	$\eta_{x^{\cdot}boiler} = \frac{x^{\cdot}_{out} - x^{\cdot}_{in}}{x^{\cdot}_{fuel}}$
Pumps	$X^{\cdot}_{D,pumps} = X^{\cdot}_{in} - X^{\cdot}_{out} + w^{\cdot}_{pump}$	$\eta_{x^{\cdot}pump} = 1 - \frac{x^{\cdot}_{D,pumps}}{w^{\cdot}_{pump}}$
Heaters	$X^{\cdot}_{D,heaters} = X^{\cdot}_{in} - X^{\cdot}_{out}$	$\eta_{x^{\cdot}heater} = 1 - \frac{x^{\cdot}_{D,heaters}}{x^{\cdot}_{in}}$
Turbine	$X^{\cdot}_{D,turbine} = X^{\cdot}_{in} - X^{\cdot}_{out} - W^{\cdot}_{el}$	$\eta_{x^{\cdot}turbine} = 1 - \frac{x^{\cdot}_{D,turbine}}{x^{\cdot}_{in} - x^{\cdot}_{out}}$
Condenser	$X^{\cdot}_{D,condenser} = X^{\cdot}_{in} - X^{\cdot}_{out} + W^{\cdot}_{f}$	$\eta_{x^{\cdot}condenser} = \frac{x^{\cdot}_{out}}{x^{\cdot}_{in} + w^{\cdot}_{f}}$
Cycle	$X^{\cdot}_{D,cycle} = \sum_{i=1}^{n} E^{\cdot}x_{D,i}$	$\eta_{x^{\cdot}cycle} = 1 - \frac{x^{\cdot}_{net,out}}{x^{\cdot}_{fuel}}$

Here, $w^{\cdot}_{el}$ denotes the electrical work output, while $w^{\cdot}_{f}$ represents the electrical work input to auxiliary components within the condenser system.

C. Plant Description

The 500 MW power plant is situated in the Umdabaker district near Rabak, consisting of four 125 MW steam turbine units. Each unit is equipped with two forced draft fans and two gas recirculation fans, both operating at 50% capacity for air management. Heavy Fuel Oil serves as the main fuel source, with dedicated pumping and heating systems (three 100% capacity units per boiler pair) being provided for its delivery. Startup operations are supported by Light Fuel Oil systems, where two pumps (each capable of 20% BMCR output) are shared across all boilers. Auxiliary systems, including steam and compressed air, are utilized for fuel atomization and line maintenance. Additional plant components consist of regenerative air preheaters, steam coil heaters, soot blowers, and redundant scanner cooling systems to ensure operational reliability.

The process flow diagram for an individual crude oil-fired power generation unit is displayed in Figure 1. Standardized symbols representing system components are included, with complete definitions provided in the accompanying legend. Extraction steam paths are shown by flow lines extending from the turbines, passing sequentially through the steam generator and reheater. The power generation system is composed of an integrated high/intermediate-pressure turbine, multiple low-pressure turbines, an electrical generator, and a condenser. Additional supporting equipment is incorporated, consisting of a condensate extraction pump, low- and high-pressure heat exchangers, an open-type deaerator (D/A), and a boiler feed pump.

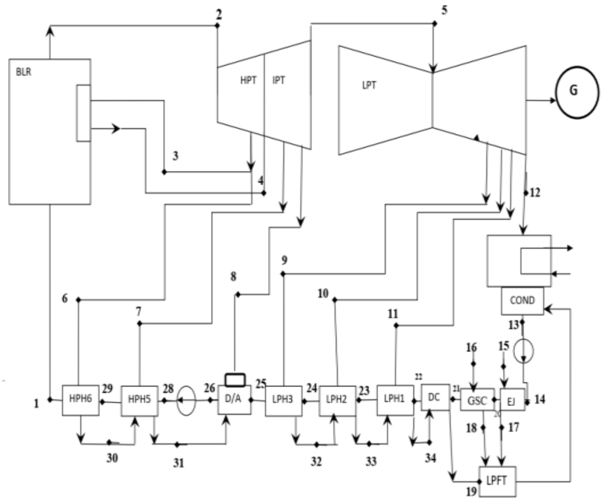

Figure 1. Process flow diagram for a single unit of the Crude oil-fired

Plant performance was evaluated under full-load conditions using combined first and second law analyses, with assessments conducted across a range of ambient temperatures (atmospheric pressure = 101.325 kPa). The properties of crude oil are detailed in Table 2, while water/steam characteristics at critical nodes were determined through Excel-based vertical integration, ensuring computational accuracy. The operating parameters of the Umdabaker thermal power plant, which form the basis for steam cycle analysis at full load, are presented in Table 3. All evaluations were performed using the turbine's maximum continuous rating (TMCR) of 125 MW as the reference condition.

III. RESULTS AND DISCUSSIONS

A. Energy analysis of the power plant

The energy balance of the power plant is presented in Table 4, revealing a thermal efficiency of 37.25% when calculated based on the higher heating value (HHV) of the crude oil feedstock. A substantial portion of input energy (52.7%) is found to be lost through condenser heat rejection and ultimately released to the environment through the cooling system. In contrast, boiler-associated energy losses are shown to represent a relatively minor fraction at only 11% of total energy input.

TABLE 2. PROPERTIES OF CRUDE OIL USED IN THE UMDABAKER THERMAL POWER PLANT

Property	value	Content	Result
density	939.6 kg/m^3	Carbon	84.6 %
Gravity @15°C	939.6 kg/m^3	Hydrogen	13 %
Kinematic viscosity @40°C	84.9 Cst	Oxygen	2.01 %
Kinematic viscosity @100°C	41.09 Cst	Nitrogen	0.12 %
Ash content	0.0009 %WT	Sulphur	0.13 %
Flash point	79 °C	HHV	46806.2 Kj/kg
Pumping Temp	+ 60 °C	LHV	43964 Kj/kg

TABLE 3. OPERATION CONDITION OF UMDABAKER THERMAL POWER PLANT

Operation Condition	value
Generator output power	125 MW
Main steam pressure	123.56 bar
Main steam temperature	535 deg
Main steam flow rate	380 t/h
Reheater temperature (hot)	535 deg
Reheater steam flow rate	310.5 t/h
Condenser pressure	0.077 bar

TABLE 4. ENERGY BALANCE OF THE POWER PLANT COMPONENTS AND PERCENT RATIO TO THE TOTAL ENERGY

Component	Heat loss	Percent ratio
Condenser	192.231	52.70
Net power	125	34.27
Boiler	40	10.97
Turbine	7.5	2.06
Total	364.731	100.00

B. Exergy analysis of the power plant

Exergy represents the maximum useful work that can be extracted from a system as it reaches equilibrium with its environment. Unlike energy, exergy is not conserved but is instead destroyed during system processes [21]. Reference points throughout the plant and their corresponding exergy rates are listed in Table 5.

The highest exergy values are observed during fuel combustion, while the lowest occur at the dead state, with significant losses occurring through exhaust gases leaving the furnace.

TABLE 5. EXERGY VALUES OF EACH STREAM. OF THE POWER PLANT WHEN TO = 298.15 K, PO = 101.3 KPA

Point	Description	H (KJ/KG)	S (KJ/KG)	ψ (kj/kg)	$\dot{x}$ (KW)
1	FEED WATER BEF BLR	1016.016	2.632	235.845833	24934.5648
2	MS BEFORE TURBINE	3434.368	6.571	1479.78498	156531.655
3	CRH	3076.259	6.634	1102.89253	95149.8475
4	HRH	3535.802	7.336	1353.13423	116738.95
5	LP I/L	3040.957	7.389	842.487283	68123.5217
6	EX TO HPH-6	3076.452	6.657	1096.22808	10389.5017
7	EX TO HPH-5	3289.272	7.384	1092.29303	6587.12775
8	EX TO D/A	3039.785	7.383	843.104183	3504.95271
9	EX TO LPH-3	2879.023	7.443	664.453183	2761.53387
10	EX TO LPH-2	2708.2	7.504	475.443033	1678.31391
11	EX TO LPH-1	2572.1	6.81927	543.495282	1812.39372
12	CONDENSER I/L	2396	7.183	258.949183	18109.0932
13	CONDENSER O/L	172	0.5857	1.93417777	167.155511
14	CEP (DISCHARGE)	174.338	0.5876	3.70569277	320.253381
15	APRDS TO EJEC	3048.674	7.144	923.251033	269.589302
16	APRDS TO GSC	3048.6734	7.144	923.250433	269.589126
17	EJEC-1 DRN TO LPFT	777.343	2.17048	134.775021	41.1737688
18	GSC DRN TO LPFT	418.677	1.3059	33.8835478	1.63759186
19	DRAIN COOLER DRN TO COND	208.082	0.69991	3.96446627	43.6915899
20	CONDENSATE WATER AFTER EJEC	181.332	0.61624	2.16067677	186.730008
21	CONDENSATE WATERGSC	183.004	0.6162	3.84460277	332.258261
22	CONDENSATE WATER AFTER DC	194.2884	0.65697	2.97342727	256.969532
23	CONDENSATE WATER AFTERLPH-1	283.384	0.92683	11.6102683	1003.3826
24	CONDENSATE WATER AFTERLPH-2	386.226	1.21805	27.6250253	2387.40993
25	CONDENSATE WATER AFTERLPH-3	505.0599	1.53105	53.1379753	4592.2901
26	CONDENSATE WATER AFTER-D/A	628.798	1.8338	86.6111628	9188.31842
27	FEED WATER AFTER BFP	650.949	1.84471	105.509346	11193.17
28	FEED WATER BEF HPH-5	640.893	1.8447	95.4563278	10092.0248
29	FEED WATER BEF HPH-6	808.011	2.2154	152.050123	16075.3472
30	HPH-6 DRAIN TO HPH-5	834.853	2.2938	155.517163	1473.91391
31	HPH-5 DRAIN TO D/A	666.8866	1.9228	98.1644128	1522.33371
32	LPH-3 DRN TO LPH-2	411.509	1.2866	32.4698428	134.944667
33	LPH-2 DRN TO LPH-1	308.5233	0.99992	14.9577848	114.965534
34	LPH-1 DRN TO DRAIN COOLER	295.95	0.9635	13.2431078	145.949642
35	AUX STEAM FROM CRH	3091.441	7.145	965.719883	4976.35456
36	DEAD STATE	104.9293	0.367231	0	0
37	CRUDE OIL	46948.2763	349482.969	46948.2763	349482.969

When the system is analyzed under steady-state conditions, with each component in Figure 1 treated as a separate control volume, the specific exergy of the fuel ($Xfuel^{\cdot}$) can be determined using the relationship $Xfuel^{\cdot}$ = γ × LHV. In this analysis, an exergy factor of γ = 1.06 is applied relative to the lower heating value (LHV), following the methodology established in previous research [7].

The computation of thermodynamic property variations in first-law analysis is unaffected by reference environment conditions. However, exergy-based (second-law) assessments are significantly influenced by dead-state parameter selection. To evaluate the extent of this influence, the dead-state temperature was systematically varied from 298.15 K to 318.15 K while atmospheric pressure was held constant at 101.325 kPa. The corresponding variations in total exergy flow rates at critical system locations are documented in Table 6.

Figure 2 presents the total exergy destruction rate at various reference environment temperatures, showing that the boiler consistently represents the largest source of exergy destruction across all examined dead-state conditions. As illustrated in Figure 3, minimal variation is observed in the exergy efficiencies of both the boiler and turbine with changing dead-state temperatures. However, significant efficiency differences are revealed when the dead-state temperature is increased from 298.15 K to 318.15 K: boiler efficiency is reduced from 43.8% to 41.1% due to increased exergy destruction during heat transfer [6], turbine efficiency is improved from 93.7% to 94.2% through enhanced work extraction [7] while condenser efficiency drops dramatically from 0.8% to 0.2% as exergy recovery potential is nearly eliminated by the reduced temperature gradient [22].

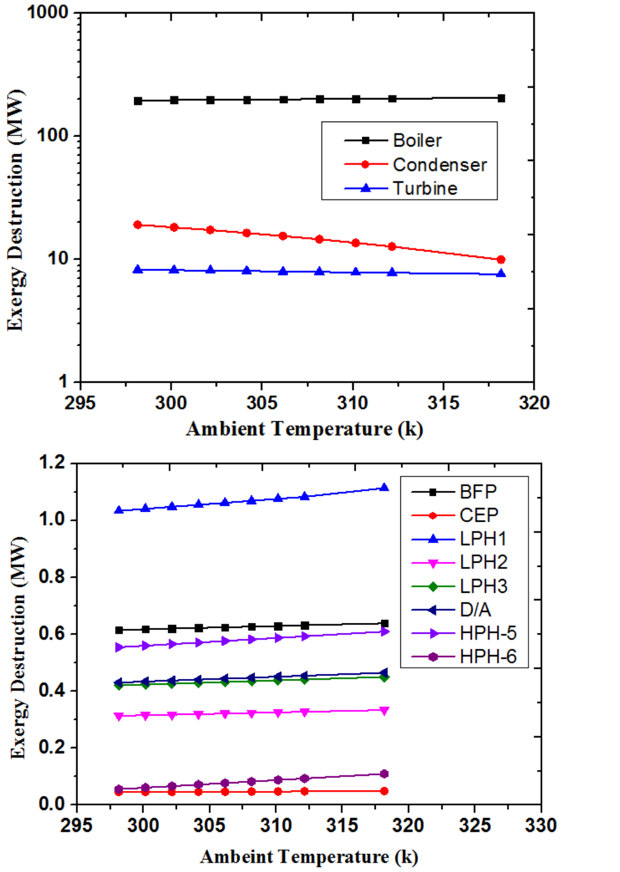

Figure 2. Total exergy destruction rate at different reference environment temperatures, MW

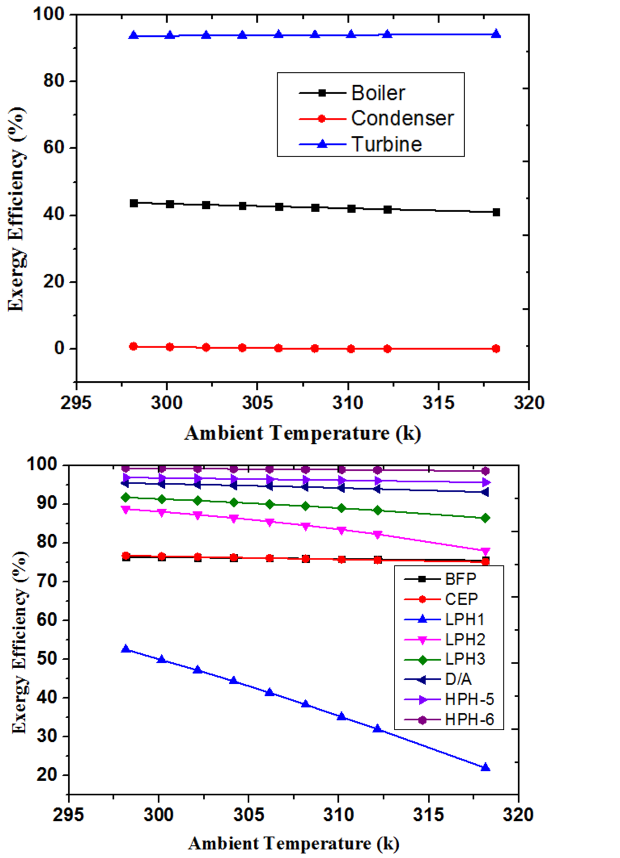

Figure 3. Total exergy efficiency at different reference environment temperatures

IV. CONCLUSIONS

An integrated thermodynamic evaluation of Sudan's 500 MW Umdabaker facility was carried out, examining both conventional and exergy-based performance metrics under different environmental conditions. Analysis of the plant's energy balance indicated an overall thermal conversion efficiency of 37.25%, with the majority of energy losses (52.7%) being attributed to condenser operations, while boiler-related losses constituted 10.97% of total energy input. Through second-law evaluation, the combustion chamber was determined to be the principal location of exergy degradation, with 205.84 MW of work potential being destroyed, whereas the condenser's limited effectiveness was tied to insufficient thermal driving forces - collectively producing a system-wide exergy efficiency of 35.8%. Investigation of temperature sensitivity demonstrated that raising the reference ambient from 298.15 K to 318.15 K led to a 6.2% reduction in boiler efficiency and a 75% decline in condenser performance, contrasted by a 0.5% enhancement in turbine output, underscoring the substantial impact of operating environment on thermodynamic behavior.

V. RECOMMENDATIONS AND FUTURE WORK

- The boiler is the major source of exergy destruction, responsible for about 43% of total steam plant losses. Priority should be given to boiler design enhancements and technical modifications to decrease irreversibilities.

- A component level investigation (furnace, flue gas combustion, reheater, superheaters, economizer, evaporators) is required to identify the root reasons of low efficiency.
- Conduct energy and exergy researches at variable loads for both boiler and turbine.
- An economic valuation of exergy destruction in terms of cost per megawatt for the boiler should be included.

[4] D. Sarkar, Thermal power plant: design and operation: Elsevier, 2015.

[5] R. Karwa, "Clausius statement of second law of thermodynamics: A review and engineering perspective of the law," International Journal of Mechanical Engineering Education, vol. 50, pp. 1025-1033, 2022.

[6] M. A. Rosen and I. Dincer, "Exergy as the confluence of energy, environment and sustainable development," Exergy, an International journal, vol. 1, pp. 3-13, 2001.

[7] T. J. Kotas, The exergy method of thermal plant analysis: Paragon Publishing, 2012.

[8] M. Elhelw and K. S. Al Dahma, "Utilizing exergy analysis in studying the performance of steam power plant at two different operation mode," Applied Thermal Engineering, vol. 150, pp. 285-293, 2019.

[9] A. Behbahaninia, S. Ramezani, and M. L. Hejrandoost, "A loss method for exergy auditing of steam boilers," Energy, vol. 140, pp. 253-260, 2017.

TABLE 6. TOTAL EXERGY RATE AT DIFFERENT REFERENCE ENVIRONMENT TEMPERATURES, MW

point	**Temperature (K)**								
	298.15	**300.15**	**302.15**	**304.15**	**306.15**	**308.15**	**310.15**	**312.15**	**318.15**
1	24.9346	24.4527	23.987	23.5235	23.0653	22.6124	22.1644	21.7245	20.4329
2	156.532	155.216	153.917	152.62	151.328	150.042	148.76	147.487	143.694
3	95.1498	94.0661	92.9956	91.9268	90.8624	89.8023	88.7462	87.6967	84.5711
4	116.739	115.534	114.342	113.152	111.967	110.786	109.609	108.438	104.949
5	68.1235	66.9857	65.8602	64.7364	63.6167	62.501	61.389	60.2833	56.9875
6	10.3895	10.27	10.152	10.0341	9.91676	9.79987	9.68341	9.56768	9.22302
7	6.58713	6.50233	6.41845	6.33469	6.25125	6.1681	6.08523	6.00282	5.75721
8	3.50495	3.44651	3.38869	3.33096	3.27345	3.21614	3.15902	3.10222	2.93293
9	2.76153	2.7026	2.64431	2.58609	2.52809	2.4703	2.4127	2.35541	2.18467
10	1.67831	1.62783	1.57788	1.52801	1.47832	1.4288	1.37944	1.33036	1.18405
11	1.81239	1.76927	1.72665	1.68411	1.64173	1.59952	1.55746	1.51566	1.39114
12	18.1091	17.1539	16.2093	15.2661	14.3265	13.3904	12.4575	11.53	8.7661
13	0.16716	0.12699	0.09999	0.07475	0.05396	0.03743	0.02489	0.01898	2.43E-02
14	0.32025	0.27976	0.25243	0.22686	0.20575	0.18889	0.17601	0.16978	0.17409
15	0.26959	0.26562	0.2617	0.25779	0.25389	0.25	0.24613	0.24228	0.23081
16	0.26959	0.26562	0.2617	0.25779	0.25389	0.25	0.24613	0.24228	0.23081
17	0.04117	0.04006	0.039	0.03794	0.0369	0.03587	0.03486	0.03387	0.03099
18	0.00164	0.00155	0.00146	0.00138	0.0013	0.00122	0.00114	0.00107	0.00086
19	0.04369	0.03605	0.03009	0.02436	0.01919	0.01456	0.01044	0.00717	0.0003
20	0.18673	0.14128	0.10901	0.07849	0.05242	0.03061	0.01279	0.0016	0.00558
21	0.33226	0.28682	0.25455	0.22404	0.19798	0.17617	0.15836	0.14718	0.13666
22	0.25697	0.20448	0.16517	0.12761	0.0945	0.06565	0.04079	0.02256	0.00055
23	1.00338	0.90425	0.81829	0.73409	0.65434	0.57885	0.50734	0.44247	0.27088
24	2.38741	2.23794	2.10165	1.96711	1.83703	1.7112	1.58935	1.47415	1.15155
25	4.59229	4.38872	4.19833	4.00969	3.82551	3.64557	3.46963	3.30033	2.81543
26	9.18832	8.8742	8.57624	8.28044	7.99011	7.705	7.42479	7.15272	6.36479
27	11.1932	10.8767	10.5765	10.2783	9.98571	9.69828	9.41575	9.14137	8.34649
28	10.092	9.77667	9.47743	9.18034	8.8887	8.60226	8.3207	8.04726	7.25511
29	16.0753	15.6816	15.304	14.9285	14.5585	14.1937	13.8337	13.4819	12.4546
30	1.47391	1.43713	1.40179	1.36665	1.33199	1.2978	1.26405	1.23102	1.13447
31	1.52233	1.47365	1.42734	1.38134	1.33614	1.2917	1.24798	1.20544	1.08198
32	0.13494	0.12719	0.12006	0.11302	0.1062	0.09958	0.09315	0.08704	0.06981
33	0.11497	0.10503	0.09626	0.08765	0.07943	0.07159	0.06411	0.05722	0.03858
34	0.14595	0.1325	0.12073	0.10918	0.09821	0.08777	0.07784	0.06876	0.04446
35	4.97635	4.90636	4.83715	4.76804	4.6992	4.63062	4.56227	4.49432	4.29183
36	0	0	0	0	0	0	0	0	0
37	349.483	349.483	349.483	349.483	349.483	349.483	349.483	349.483	349.483

REFERENCES

[1] J. Davenport and N. Wayth, "Statistical review of world energy," Energy institute, 2023.

[2] I. J. Al‐Rikabi, A. A. Omara, M. A. Abuelnour, A. A. Abuelnuor, A. E. Mohamed, and N. A. Ismail, "Renewable Energy in Sudan: Current Status and Future Prospects," Engineering Reports, vol. 7, p. e13116, 2025.

[3] K. Annamalai, I. K. Puri, and M. A. Jog, Advanced thermodynamics engineering: CRC press, 2011.

[10] J. Clay and J. Mathias, "Energetic and exergetic analysis of a multi-stage turbine, coal-fired 173 MW power plant," International Journal of Exergy, vol. 27, pp. 419-436, 2018.

[11] A. Geete, "Application of exergy and entransy concepts to analyses performance of coal fired thermal power plant: a case study," International Journal of Ambient Energy, vol. 42, pp. 1032-1043, 2021.

[12] D. Mitrović, D. Zivkovic, and M. Laković, "Energy and exergy analysis of a 348.5 MW steam power plant," Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, vol. 32, pp. 1016-1027, 2010.

[13] I. H. Aljundi, "Energy and exergy analysis of a steam power plant in Jordan," Applied thermal engineering, vol. 29, pp. 324-328, 2009.
[14] V. Amir, "Improving steam power plant efficiency through exergy analysis: ambient temperature," in 2nd international Conference on Mechanical, Production and Automobile Engineering (ICMPAE) Singapore, 2012, pp. 209-212.
[15] A. Bojeldain, Y. Aldali, and M. Alshaikh, "Energy and exergy analysis of Derna steam power plant and the impact of varying the different parameters on exergy destruction," مجلة أكاديمية الجبل للعلوم الأساسية والتطبيقية, vol. 1, pp. 10-18, 2022.
[16] A. Gungor Celik and U. Aydemir, "Energy, Exergy Analysis and Sustainability Assessment of a Thermal Power Plant Operating in Various Environmental Conditions Using Real Operational Data," Sustainability, vol. 17, p. 1417, 2025.
[17] M. Elwardany, A. Nassib, H. A. Mohamed, and M. Abdelaal, "Energy and exergy assessment of 750 MW combined cycle power plant: A case study," Energy Nexus, vol. 12, p. 100251, 2023.
[18] H. Yin, Y. Jin, L. Li, and W. Lv, "Numerical investigation on the impact of exergy analysis and structural improvement in power plant boiler through co-simulation," Energies, vol. 15, p. 8133, 2022.
[19] M. Kurkus-Gruszecka, Ł. Szabłowski, O. Dybiński, P. Krawczyk, K. Badyda, and G. Kotte, "Exergy Analysis of 500 MW Power Unit Based on Direct Measurement Data," Energies, vol. 18, p. 2762, 2025.
[20] A. Raja, A. P. Srivastava, and M. Dwivedi, Power plant engineering: New Age International, 2006.
[21] M. Kanoglu, I. Dincer, and M. A. Rosen, "Understanding energy and exergy efficiencies for improved energy management in power plants," Energy policy, vol. 35, pp. 3967-3978, 2007.
[22] Y. Cengel and M. Boles, Thermodynamics An Engineering Approach 8ed: McGraw-Hill Education. NY, 2014