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Energy and Exergy Analysis of the Al-Khalij 1400 MW Thermal Power Plant in Sirt, Libya

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Abstract

This study presents the first comprehensive thermodynamic evaluation of a 350 MW reheat steam unit at the Al-Khalij Thermal Power Plant in Sirt, Libya. Energy and exergy analyses were applied to assess component-wise performance under full-load operating conditions and to examine the influence of ambient temperature variations typical of Mediterranean coastal environments.

The results demonstrate that the steam generator (boiler) is the principal source of irreversibility, accounting for approximately 88% of total exergy destruction. This high level of destruction is primarily attributed to combustion processes and the significant temperature gradients across heat transfer surfaces. In contrast, the turbine system exhibited strong performance, achieving an exergetic efficiency of 86.3%, which reflects the advantages of modern reheat parameters in maximizing work output and minimizing moisture losses. Regenerative feedwater heaters and auxiliary pumping systems also performed efficiently, with efficiencies ranging between 71% and 96%, thereby contributing to cycle stability. The condenser, while associated with substantial energy rejection, contributed only 3.6% of total exergy destruction due to the inherently low quality of the rejected heat.

Sensitivity analysis revealed that increasing the reference environment temperature from 283 K to 303 K leads to a slight decline in boiler and turbine efficiencies, while condenser efficiency improves under the same conditions. Overall, the Al-Khalij unit achieved an exergetic efficiency of 30.3%, a value consistent with contemporary reheat steam cycles. These findings establish a benchmark for Libya's thermal generation sector, identify the boiler as the most critical area for improvement, and provide practical guidance for enhancing efficiency in large-scale power plants operating under Mediterranean environmental conditions.

Keywords: Energy analysis, Exergy destruction, Libya power plant, Thermal power plant efficiency,

1. Introduction

Thermodynamic analysis of thermal power plants is a fundamental tool for evaluating performance and identifying opportunities for improvement. Conventional energy analysis, based on the First Law of Thermodynamics, provides information on energy conversion efficiency but does not account for the quality of energy. Exergy analysis, derived from the Second Law, offers a more comprehensive assessment by quantifying the useful work potential of energy and locating the sources of irreversibility within the system [1].

Exergy is defined as the maximum useful work obtainable when a system is brought into equilibrium with its surroundings through a reversible process. Unlike energy balances, which measure only the quantity of energy, exergy analysis evaluates both the quantity and quality of energy transformations, thereby providing deeper insight into inefficiencies [2–8]. In thermal power plant studies, exergy analysis is typically considered the third stage of evaluation, following mass and energy balances. Its primary objective is to determine the magnitude and location of irreversibilities, guiding improvements in existing systems or supporting the design of new, more efficient processes [9]. Exergy losses represent the portion of exergy rejected to the environment, while exergy destruction reflects the irreversibility occurring within the system boundaries.

The Al-Khalij Thermal Power Plant, located near Sirt on Libya's Mediterranean coast, is one of the country's largest generating stations. It is a conventional steam cycle facility consisting of four identical units, each rated at 350 MW, for a total installed capacity of 1,400 MW [9]. The plant operates on dual fuel—primarily natural gas, with heavy and light fuel oil as backup—and utilizes seawater from the Mediterranean for condenser cooling. As a reheat steam cycle plant, Al-Khalij represents a modern design compared to older non-reheat units, offering higher efficiency and improved reliability for large-scale electricity supply in Libya.

The present study applies detailed energy and exergy analysis to a single 350 MW unit of the Al-Khalij plant. By evaluating component-wise exergy destruction and efficiency, the analysis identifies the dominant sources of irreversibility and quantifies the overall cycle performance. Special attention is given to the boiler, turbines, condenser, and regenerative feedwater heaters, as these components play a decisive role in plant efficiency. In addition, the sensitivity of exergetic performance to changes in ambient temperature is examined, providing insights into the impact of environmental conditions on plant operation. The results are intended to serve as a benchmark for Libya's thermal generation sector and to highlight opportunities for efficiency improvement in large-scale reheat steam cycles.

1.1 Objectives of the Study

The main objectives of this study are:

- To perform a detailed energy and exergy analysis of the Al-Khalij 350 MW reheat steam power plant unit.
- To quantify component-wise exergy destruction and efficiency, with emphasis on the boiler, turbines, condenser, and regenerative feedwater heaters.
- To evaluate the overall cycle performance and establish a benchmark for large-scale thermal generation in Libya
- under Mediterranean coastal conditions.
- To assess the sensitivity of exergetic efficiency to ambient temperature variations, thereby identifying the influence of environmental conditions on plant operation.
- To provide recommendations for efficiency improvement and highlight the role of reheat cycles in modern thermal power plant design.

2. METHODOLOGY

This study applies a comprehensive thermodynamic evaluation of the Al-Khalij 350 MW reheat steam unit, based on both the First and Second Laws of Thermodynamics. Each major component of the cycle was treated as a control volume operating under steady-state conditions. The analysis combined operational data from the plant's Distributed Control System (DCS) with design specifications provided in the plant operation manual.

2.1 Plant Description

Al-Khalij Thermal Power Plant is a large steam-based generating station located on the Mediterranean coast west of Sirt, Libya. The plant has a total installed capacity of 1400 MW, consisting of four identical 350 MW steam-turbine units. Each unit operates on a conventional Rankine cycle with reheat and regenerative feedwater heating, and typically delivers a net output close to its design rating under stable operating conditions. The station uses natural gas as the primary fuel, with light and heavy fuel oil available as backup, providing operational flexibility during variations in gas supply.

The plant is strategically positioned along the coastline, allowing the use of seawater from the Mediterranean as the cooling medium for its surface condensers. Each unit includes a high-pressure (HP), intermediate-pressure (IP), and low-pressure (LP) turbine section, a multi-stage boiler system, seven feedwater heaters, a deaerator, and the associated condensate and boiler-feed pumping systems. Al-Khalij Power Plant is equipped with modern control and monitoring facilities, fuel-handling systems, seawater intake structures, and electrical switchgear rooms. Commissioned in the early 2000s, the plant remains a key contributor to the Libyan electrical grid, supplying power to Sirt, Misrata, and surrounding regions. Figure 3.1 presents a simplified schematic diagram of the 350 MW unit and its major components.

Table 1: Operating condition of the al-khalij power plant (350 mw)

Operating Condition	Value
Acting Power (Load)	315 MW
Reacting Power @ Generator	65 MVAR
Frequency	50 Hz
Turbine Power Output (Gross)	350 MW
Main Steam Pressure	15.85 MPa
Main Steam Temperature	538.1 °C
Hot Reheat Pressure	3.95 MPa
Hot Reheat Temperature	538.1 °C
Thermal Efficiency	39.5%

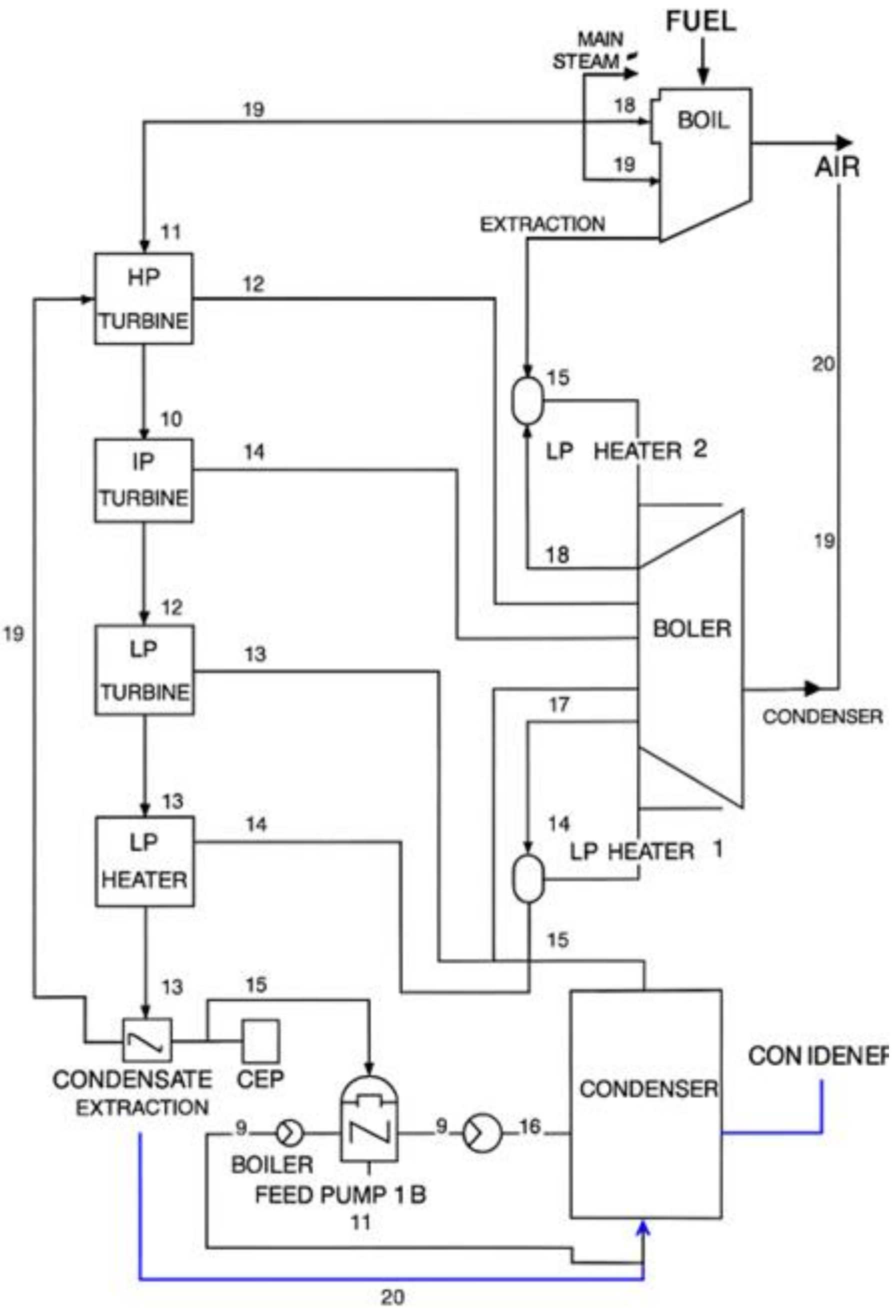

Fig. 1 Schematic diagram of Al-khalij plant

Table 2: properties of heavy fuel oil used in al-khalij power plant

Property	Value
Flash point	80 °C
Kinematic Viscosity @ 40°C	1200 cSt
Boiling point	350 °C
Specific gravity	0.98
Density @15°C	980 kg/m³
vapour pressure@20°C	0.1mmHg
Vapour density	N/A
Lower Heating Value (LHV)	40,000 kJ/kg

2.2 *Energy Analysis of Components in the Al-Khalij Power Plant*

This section presents the fundamental governing equations used to evaluate the energy performance of the main components within the 350 MW reheat power cycle at the Al-Khalij Power Plant.

2.2.1 Steam Turbine

The steam turbine employed in the Al-Khalij plant is a multi-stage reheat turbine.

Mass balance:

$$\dot{M}_{main} + \dot{M}_{reheat,in} = \dot{M}_{exhaust} + \sum \dot{M}_{extraction,i}$$

Energy balance is given by:

$$\dot{M}_{main} h_{main} + \dot{M}_{reheat,in} h_{reheat,in} = \dot{M}_{exhaust} h_{exhaust} + \sum \dot{M}_{extraction,i} h_i + \dot{W}_{turbine}$$

Exergy destruction within the turbine is calculated using:

$$\dot{E}_{D,turbine} = \left(\sum \dot{E}_{in} - \sum \dot{E}_{out}\right) - \dot{W}_{turbine}$$

Work Output (*W*): *W* = 350,000$ kW.

2.2.2 Condenser

The condenser removes latent heat from the exhaust steam and transfers it to the Mediterranean seawater.

The energy balance for the condenser is expressed as:

$$\dot{M}_{steam}(h_{in} - h_{out}) = \dot{M}_{cw} c_{p,cw}(T_{out} - T_{in})$$

The exergy destruction in the condenser is determined by:

$$\dot{E}_{D,cond} = (\dot{E}_{steam,in} - \dot{E}_{condensate,out}) - (\dot{E}_{cw,out} - \dot{E}_{cw,in})$$

2.2.3 Boiler Feed Pump (BFP)

The boiler feed pump increases the feedwater pressure to the required operating level of 15.85 MPa.

Mass balance is:

$$M_{in} = M_{out}.$$

The energy balance is given by:

$$W_{pump} = M(h_{out} - h_{in}).$$

The exergy destruction associated with the pump is calculated as:

$$ED_{pump} = W_{pump} - (E_{out} - E_{in}).$$

2.2.4 High-Pressure Heaters (HPH1 and HPH2)

The high-pressure heaters utilize extraction steam to increase the feedwater temperature prior to its entry into the steam generator.

The mass balance relations are expressed as:

$$M_{fw,in} = M_{fw,out} \text{and } M_{ext} = M_{drain}.$$

The energy balance is given by:

$$M_{fw}(h_{fw,out} - h_{fw,in}) = M_{ext}(h_{ext} - h_{drain}).$$

The exergy destruction within the high-pressure heaters is calculated as:

$$ED_{HPH} = (E_{ext} - E_{drain}) - (E_{fw,out} - E_{fw,in}).$$

2.2.5 Low-Pressure Heaters (LPH1 and LPH2)

The low-pressure heaters operate in a manner similar to the high-pressure heaters but at lower pressure levels downstream of the condensate pump.

The mass balance for the heaters is:

$$M_{cond,in} = M_{cond,out}.$$

The energy balance is expressed as:

$$M_{cond}(h_{out} - h_{in}) = M_{ext}(h_{ext} - h_{drain}).$$

The exergy destruction in the low-pressure heaters is given by:

$$ED_{LPH} = (E_{ext} - E_{drain}) - (E_{cond,out} - E_{cond,in}).$$

2.2.6 Deaerator

The deaerator is a direct-contact feedwater heater used to remove dissolved gases from the feedwater.

The mass balance relationship is:

$$M_{in,water} + M_{ext,steam} = M_{out,feedwater}.$$

The energy balance is expressed as:

$$M_{in}h_{in} + M_{ext}h_{ext} = M_{out}h_{out}.$$

The exergy destruction associated with the deaerator is calculated using:

$$ED_{dea} = (E_{in} + E_{ext}) - E_{out}.$$

2.2.7 Condensate Receive Tank (CRT)

The condensate receive tank collects the drainage streams from the feedwater heaters before the fluid is pumped back into the power cycle.

The mass balance is given by:

$$\sum M_{drains} = M_{out}.$$

The energy balance is expressed as:

$$\sum M_{drains} h_{drains} = M_{out} h_{out}.$$

The exergy destruction in the condensate receive tank is calculated as:

$$ED_{CRT} = \sum E_{in} - E_{out}.$$

2.2.8 Steam Generator (Boiler)

The steam generator is the primary component responsible for exergy destruction due to fuel combustion.

The energy balance for the boiler is expressed as:

$$\dot{Q}_{fuel} = \dot{m}_{fuel} \times LHV_{fuel}$$

$$\dot{Q}_{fuel} = \dot{M}_{steam}(h_{out} - h_{in}) + \Delta H_{reheat}$$

The exergy destruction in the boiler is calculated using:

$$\dot{E}_{D,boiler} = \dot{E}_{fuel,ch} + \dot{E}_{air,in} + \dot{E}_{fw,in} - \left(\dot{E}_{steam,out} + \dot{E}_{reheat,out} + \dot{E}_{gas,out}\right)$$

3. RESULTS AND DISCUSSION

3.1 Analysis of Plant Performance at Full Load

The energy and exergy analysis of the Al-Khalij 350 MW reheat steam unit was carried out under full-load operating conditions using the thermodynamic relations and component equations presented in Table 3. The reference environment was set at $T_0 = 298.15\ K$and $P_0 = 1.01325\ bar$. Thermodynamic properties at 20 critical state points, including mass flow rates, enthalpy, entropy, and specific exergy, are listed in Table 4. These values provide the baseline for evaluating the performance of each component in the cycle.

3.2 Component-Based Exergy Performance

The results of the exergetic evaluation for individual plant components are summarized in Table 5. The total exergy destruction rate for the entire 350 MW unit was 735,506 kW, resulting in an overall plant exergetic efficiency of 30.32%.

- Steam Generator (Boiler): As illustrated in Table 5 and Figure 2, the boiler is the primary source of exergy destruction, accounting for 647,797 kW (88.05%) of the total plant irreversibilities. This high rate of destruction is attributed to the large temperature gradients inherent in heat transfer and the chemical irreversibilities of the combustion process. The exergetic efficiency of the boiler was determined to be 43.25%.
- Turbine Units: The turbine system demonstrated a high exergetic efficiency of 86.32%. With a net work output of 350,000 kW, the exergy destruction within the turbine was 55,453 kW, representing only 7.55% of the total plant losses (Table 5, Figure 2).
- Condenser: The condenser accounted for 26,618 kW (3.63%) of exergy destruction with an efficiency of 37.46%. Although the condenser rejects a significant amount of energy, its contribution to exergy destruction is relatively minor due to the low quality of the discharged heat.
- Feedwater Heaters and Pumps: The regenerative components (HPH and LPH) showed high exergetic efficiencies ranging from 71.07% to 92.02%, while the Boiler Feed

Pump (BFP) operated at 95.57% efficiency, consuming 2,850 kW of work. The deaerator also performed efficiently at 95.17%, with minimal exergy destruction.

3.3 Effect of Ambient Temperature on Exergetic Efficiency

The sensitivity of the plant's performance to changes in the reference environment temperature (T_0) was analyzed across a range from 283 K to 303 K. The resulting variations in total exergy rates at critical points are documented in Table 6, while the impact on component efficiencies is quantified in Table 7.

- Boiler and Turbine Trends: As ambient temperature increases from 283 K to 303 K, a slight decline in efficiency is observed. The boiler efficiency drops from 44.25% to 42.91%, and turbine efficiency decreases from 87.12% to 86.06% (Table 7, Figure 3). This inverse relationship occurs because a higher T_0reduces the exergy potential of the steam relative to the environment.
- Condenser Trend: Conversely, the condenser efficiency exhibits a positive correlation with ambient temperature, rising from 36.44% to 37.78% (Table 7, Figure 3). This improvement is attributed to the narrowing temperature difference between the condensing steam and the cooling water.

Table 3: Exergy destruction rate and exergy efficiency equations for al-khalij plant components

Component	Exergy Destruction Rate ($\dot{E}_D$)	Exergy Efficiency (η_{ex})
Boiler (Reheat)	$\dot{E}_{D,B} = \dot{X}_{\text{Fuel}} + \dot{X}_{\text{in}} - \dot{X}_{\text{out}}$	$\eta_{ex,B} = \frac{\dot{X}_{\text{out}} - \dot{X}_{\text{in}}}{\dot{X}_{\text{Fuel}}}$
Turbine (HP/IP/LP)	$\dot{E}_{D,T} = \dot{X}_{\text{in}} - \dot{X}_{\text{out}} - \dot{W}_T$	$\eta_{\text{ex},T} = \frac{\dot{W}_T}{\dot{X}_{\text{in}} - \dot{X}_{\text{out}}}$
Pump (BFP/CEP)	$\dot{E}_{D,P} = \dot{X}_{\text{in}} - \dot{X}_{\text{out}} + \dot{W}_P$	$\eta_{ex,P} = \frac{\dot{X}_{\text{out}} - \dot{X}_{\text{in}}}{\dot{W}_P}$
Heater (HPH/LPH)	$\dot{E}_{D,H} = \dot{X}_{\text{steam, in}} - \dot{X}_{\text{drain}} - (\dot{X}_{fw,\text{out}} - \dot{X}_{fw,\text{in}})$	$\eta_{ex,H} = \frac{\dot{X}_{fw,\text{out}} - \dot{X}_{fw,\text{in}}}{\dot{X}_{\text{steam, in}} - \dot{X}_{\text{drain}}}$
Condenser	$\dot{E}_{D,C} = (\dot{X}_{\text{steam, in}} - \dot{X}_{\text{cond}}) - (\dot{X}_{cw,\text{out}} - \dot{X}_{cw,\text{in}})$	$\eta_{ex,C} = \frac{\dot{X}_{cw,out} - \dot{X}_{cw,in}}{\dot{X}_{\text{steam, in}} - \dot{X}_{\text{cond}}}$
Deaerator	$\dot{E}_{D,Dea} = \sum\dot{X}_{\text{in}} - \dot{X}_{\text{out}}$	$\eta_{\text{ex, Dea}} = \frac{\dot{X}_{\text{out}}}{\sum X_{\text{in}}}$
Overall Cycle	$\dot{E}_{D,\text{cycle}} = \sum\dot{E}_{D,\text{components}}$	$\eta_{\text{ex,cycle}} = \frac{\dot{W}_{\text{net}}}{\dot{X}_{\text{Fuel}}}$

Table 4: Thermodynamic Properties and Exergy Rates at Critical State Points (T = 298.15 K, P = 101.325 kPa)

Point	Description	P (bar)	T (°C)	m˙ (kg/s)	h (kJ/kg)	s (kJ/kg·K)	ψ (kJ/kg)	E˙x (MW)
1	Condenser Outlet (Condensate)	0.086	43.4	224.5	181.8	0.617	1.8	0.42
2	CEP Outlet (To LPH 1)	16.5	44.3	224.5	184.2	0.622	3.5	0.78
3	LPH 1 Outlet	14.8	75.6	224.5	316.5	1.020	15.7	3.55
4	LPH 2 Outlet	13.2	110.2	224.5	462.4	1.418	43.6	9.78
5	Deaerator Inlet	11.5	110.2	224.5	462.4	1.418	43.6	9.78
6	Deaerator Outlet (Suction)	10.2	180.8	305.2	766.4	2.145	130.8	39.9
7	BFP Outlet (High Pressure)	185.4	185.2	305.2	788.6	2.158	149.2	45.6
8	HPH 2 Outlet	178.2	215.4	305.2	922.8	2.441	199.1	60.7
9	HPH 1 Outlet (Final Feedwater)	172.5	248.6	305.2	1078.4	2.785	252.3	76.9
10	Boiler Outlet (Main Steam)	165.0	540.0	305.2	3402.1	6.398	1500.4	457.8
11	HP Turbine Exhaust (CRH)	42.5	345.2	272.4	3075.4	6.522	1136.5	309.5
12	Reheater Outlet (HRH)	38.2	540.0	272.4	3536.8	7.215	1391.2	379.0
13	IP Turbine Exhaust	11.2	352.4	245.8	3165.2	7.485	939.5	230.9
14	LP Turbine Inlet	10.5	352.4	245.6	3165.2	7.485	939.5	230.9
15	LP Turbine Exhaust (To Condenser)	0.089	43.4	210.4	2355.4	7.514	121.5	25.5
16	HPH 1 Steam Extraction	42.5	345.2	32.8	3075.4	6.522	1136.5	37.3
17	HPH 2 Steam Extraction	22.4	265.8	18.5	2940.2	6.615	973.8	18.0
18	Deaerator Steam Extraction	10.2	180.8	12.4	2780.4	6.725	780.4	9.6
19	LPH 2 Steam Extraction	4.8	120.5	14.2	2650.2	6.885	602.5	8.5
20	LPH 1 Steam Extraction	1.2	75.6	10.6	2510.4	7.052	412.3	4.3

Table 5: Calculated result of exergy efficiency and exergy destruction of different components of al-khalij plant

COMPONENTS	Ein (kW)	Eout (kW)	W (kW)	Ed (kW)	% ED	% EF	% OF TOTAL Ed
TURBINE	405,453	0	350,000	55,453	13.68	86.32	7.55
HPH 1	17,420	16,030	0	1,390	7.98	92.02	0.19
HPH 2	13,830	12,726	0	1,104	7.98	92.02	0.15
LPH 1	3,650	2,595	0	1,055	28.90	71.10	0.14
LPH 2	2,800	1,990	0	810	28.93	71.07	0.11
CRT	1,850	1,792	0	58	3.14	96.86	0.01
BOILER FEED PUMP	13,420	15,675	-2,850	595	4.43	95.57	0.08
DEAERATOR	12,950	12,324	0	626	4.83	95.17	0.09
CONDENSER	42,560	15,942	0	26,618	62.54	37.46	3.63
BOILER	1,145,000	497,203	0	647,797	56.58	43.25	88.05
TOTAL PLANT	1,145,000	-	347,150	735,506	-	30.32	100.00

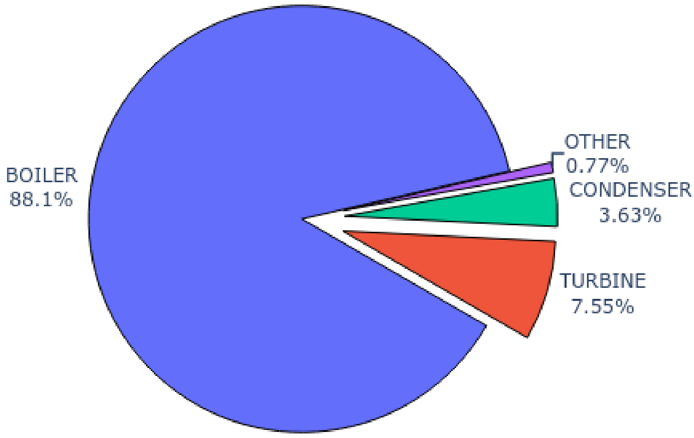

Figure 2: Percentage composition of exergy destruction of Components

TABLE 6: Total Exergy Rate (X) at Different Reference Environment Temperatures

Point	Description	283 K (MW)	288 K (MW)	293 K (MW)	298 K (MW)	303 K (MW)
1	HP Turbine Extraction 1 44	169.1	166.5	163.9	161.4	158.8
2	HP Turbine Extraction 2	148.5	146.2	144.0	141.7	139.5
3	IP Turbine Inlet (Reheat) 55	200.2	197.1	193.9	190.8	187.6
4	IP Turbine Extraction 1	170.4	167.7	165.1	162.4	159.8
5	IP/LP Transition Inlet 6666	135.2	133.0	130.9	128.7	126.6
6	LP Turbine Outlet (Exhaust) 7777	30.2	27.9	25.7	23.4	21.2
7	Condenser Outlet (Hotwell) 88	1.14	0.90	0.67	0.43	0.20
8	Condensate Pump Outlet	1.35	1.11	0.88	0.64	0.41
9	LP Heater 1 Outlet	2.50	2.22	1.94	1.66	1.38
10	LP Heater 2 Outlet	4.80	4.45	4.10	3.75	3.40
11	LP Heater 3 Outlet	7.90	7.42	6.94	6.46	5.98
12	LP Heater 4 Outlet	12.1	11.4	10.7	10.0	9.3
13	Deaerator Inlet	15.6	14.8	14.0	13.2	12.4
14	Deaerator Outlet (Storage)	18.2	17.3	16.4	15.5	14.6
15	Boiler Feed Pump Outlet	20.1	19.2	18.3	17.4	16.5
16	HP Heater 5 Outlet	23.5	22.4	21.3	20.2	19.1
17	HP Heater 6 Outlet	27.8	26.5	25.2	23.9	22.6
18	HP Heater 7 Outlet	31.4	30.0	28.6	27.2	25.8
19	Boiler Inlet (Final Feedwater) 99	33.2	31.8	30.4	29.0	27.6
20	Boiler Outlet (Main Steam) 10101010	238.4	234.6	230.8	227.1	223.3

Table 7: Reference temperature against calculated result of exergy efficiency of different components of the al-khalij plant

Ref T (K)	Boiler % EF	Turbine % EF	Condenser % EF
283	44.253	87.124	36.442
288	43.918	86.859	36.781
293	43.582	86.591	37.119
298	43.247	86.323	37.458
303	42.911	86.056	37.783

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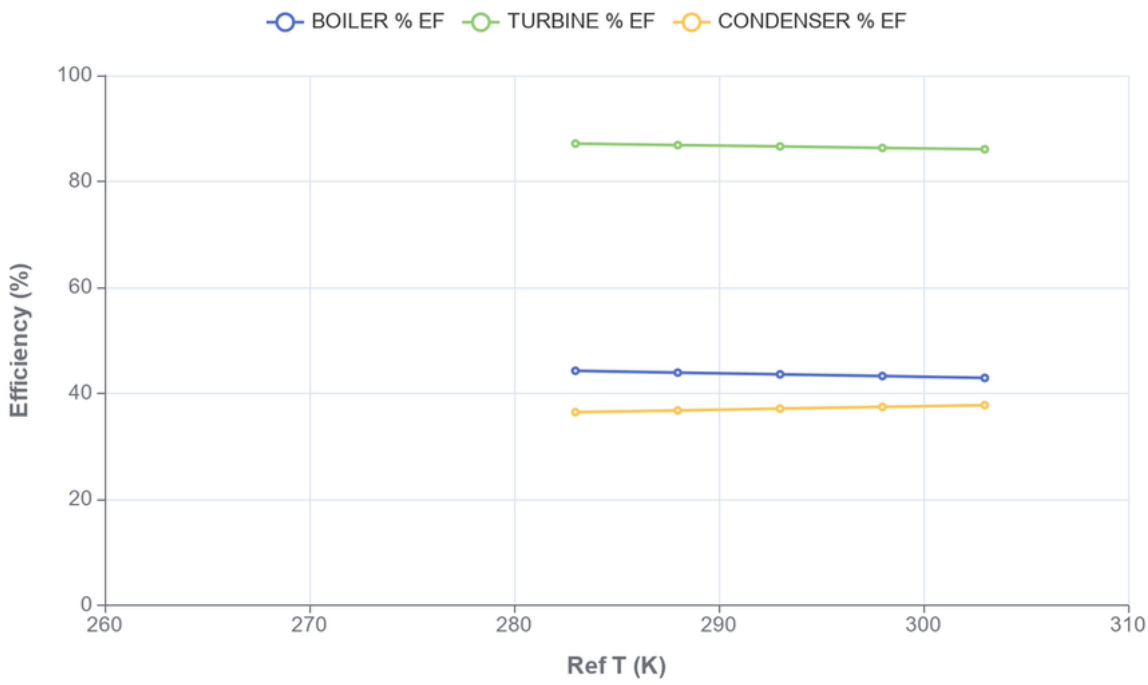

Fig. 3 graph of reference environment temperature against boiler, turbine and condenser

4. Conclusion

This study has presented a detailed energy and exergy analysis of the Al-Khalij 350 MW reheat steam power plant unit, one of Libya's most important thermal generation facilities. The results highlight the central role of the boiler as the dominant source of irreversibility, responsible for nearly 88% of the total exergy destruction. This outcome is consistent with the inherent inefficiencies of combustion and the large temperature gradients involved in heat transfer. In contrast, the turbine system demonstrated strong performance, with an exergetic efficiency above 86%, confirming the benefits of advanced reheat steam parameters in reducing losses and improving output.

Auxiliary components such as feedwater heaters, pumps, and the deaerator showed high efficiencies, underscoring their contribution to overall cycle stability and performance. The condenser, while associated with significant energy rejection, accounted for a relatively small fraction of exergy destruction due to the low quality of heat discharged to the environment. Sensitivity analysis further revealed that ambient temperature has a measurable impact on component efficiencies: boiler and turbine performance decline slightly as the reference temperature rises, while condenser efficiency improves under the same conditions.

Overall, the Al-Khalij plant achieved an exergetic efficiency of approximately 30.3%, which is in line with modern reheat steam cycle plants and provides a benchmark for large-scale thermal generation in Libya. These findings emphasize the importance of focusing improvement efforts on boiler design and combustion processes, while maintaining the strong performance of turbine and regenerative systems. Beyond its technical insights, the study offers practical guidance for enhancing efficiency in Libya's thermal power sector and contributes to the broader understanding of how environmental conditions shape plant performance.

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