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An Attitude to Investigate Exergy and Energy Performance of Thermal Power Plant in Iraq

Hayder R. Shaheed[1-a] . Raoof M. Radhi[2-b] –. Hayder Noori Mohammed[3-c]

MSc student, University of Kerbela

University of Warith Al-Anbiyaa

Member of staff, Mech. Eng. Dept., University of Kerbela

Kerbela, Iraq
Author Emails

alwessawih@gamil.com

raoofkunv@gmail.com

hayder.mohammed@uokerbala.edu.iq

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Abstract
Despite its availability of fossil fuels, which is the basic energy source used to generate electricity, Iraq still suffers from a shortage of electric power supplies, given that most of their existing steam power does not operate at their designed production capacities and thus reduces its production efficiency. An energy and exergy analysis of the Mossaib steam plant, built in the 1980s and has a production of (1200) MW rated output, can help identify the locations of losses and discover the components that will facilitate the development of the station if work is carried out to maintain, develop, and improve its efficiency and preserve energy sources. In Engineering Equations Solver (EES), a code is built to estimate energy loss, energy efficiency, rate of energy and exergies, second law efficiency, and exergy destruction for each part of the plant by considering the actual value range of operating parameters. The analysis focuses on the sources of exergy destruction that occur in the plant components, revealing that the highest destruction occurs in the boiler, followed by the high-pressure (HP) turbine, then the low-pressure (LP) turbine, and then the condenser. Finally, the intermediate pressure (IP) turbine shows the least exergy destruction compared with other turbines.

Keywords: Numerical Analysis; exergy; energy performance; Iraq's thermal power plants

Nomenclature

Symbols:

$\dot{Q}$: heat (KW)	h: enthalpy (KJ/Kg)
$\dot{m}$:mass flow rate (Kg/s)	P: pressure (bar)
$\dot{X}$:rate of exergy (KW)	s: entropy (KJ/Kg. K)

x: specific exergy (kJ/Kg)
$\dot{W}$: work (KW)
C.V :calorific value (kJ/kg).
T: temperature (^oC)

Abbreviations:

B.D: blow down
BFP: boiler feedwater pump
BLR: boiler
C: carbon
CEP: condensate extraction pump
Cond.: condenser
CW: condensate water
Deaerator: DTR
FW: feedwater
HPH high pressure heater
HPT: high pressure turbine
HTR: heater
H_2: hydrogen
IPT: Intermediate pressure turbine.
LHV: lower heating value
LPH low pressure heater
LPT: low pressure turbine
O_2: oxygen
PSH: primary superheater
R: desuperheated spray water
RH: reheat
SAH: steam air heater
SL: Sulphur
SSH: secondary superheater
STM: steam
TBN: turbine
WTR: water

Subscripts

BD: blow down
ch: chemical
des: destruction
e: exit
i: inlet
K: surface properties.
0: ambient
ph: physical
ss: isentropic

Greek Symbols

η: efficiency.
φ: The ratio of the chemical exergy of liquid fuel to lower heating value.
η_{II}: second law

1. Introduction

Iraq's population is rapidly expanding, which is being accompanied by a continual flow of people relocating from the countryside to the cities and contributing to overpopulation. This population rise had evident effects on economic and social life due to the growing requirement for energy and electrical sources [1]. Iraq's net power output increased by 8% year on average between 2008 and 2018, with a predicted total of 78 billion kilowatt-hours (kWh). The summer months in Iraq are when most energy is consumed. The accessible or effective output capacity is significantly less than the built capacity because of poor transmission infrastructure, dysfunctional or broken power plants, and low utilisation rates [2]. Electrical energy is becoming more and more in demand. The efficiency of plants must therefore be maintained through minimizing energy losses. Only by determining the sources, causes, and extent of the loss can this objective be accomplished. The performance and thermodynamic characteristics of the plants can be investigated to carry out the analytical methods, which considerably aids efforts to create and upgrade thermal power plants. Traditional analyses of thermal power plants cannot be trusted because they don't give an accurate picture of the thermodynamic system's actual losses. In contrast, the exergy analysis strategy provides a practical, appropriate, and inexpensive method for assessing and improving steam power facilities [3], [4]. To identify system defects, the system's energy balance is insufficient. Exergy analysis is a powerful method for evaluating energy quality that makes it easy to pinpoint energy losses in a system and improves the effectiveness of intricate thermodynamic systems [4, 5]. Exergy analysis utilizing the second rule of thermodynamics is the most efficient technique for evaluating the thermodynamic performance of systems [5]. Determining the second law efficiencies for a complex system with its individual components plays a significant role in such analyses. Continuous attempts have been made to analyze and assess the operation of a thermal power plant as well as to find energy loss and energy destruction [6].

In order to assess energy loss and exergy destruction, a thorough search of published literature was conducted for exergy and energy analysis in steam power plants. In this regard, numerous published papers with comparable study objectives that were conducted in various places and maybe using various methods can be identified. The focus of published investigations [7–16] is on energy and exergy assessments, followed by the quantity and location of exergy destruction. Investigations into the performance of nine sub-critical power plants [7] reveal that the boiler experienced the greatest exergy destruction. When compared to HP and LP turbines at these facilities, IP turbines exhibited the highest energy efficiency. Similar to this, the furnace destroyed the most energy, followed by the turbine and the condenser [8]. Additionally, studies on a 50 MW steam power plant [9] yielded information on energy destruction and component losses. The supercritical steam power plant and combined cycle are the subject of another attempt, and once again, the steam generator in both cases experienced the greatest exergy destruction, which was then followed by the condenser and exhaust gas in the case of the steam power plant and the combined cycle, respectively. In the cycle, the turbine's exergy degradation is minimal [10]. In a combined cycle power plant, exergy and energy analysis is done to determine the energy loss, energy efficiency, and exergy destruction of each plant component [11]. The 173 MW subcritical power station is used as a case study [12]. Thermal and exergy efficiencies that were calculated were determined to be (32.8%) and (33.7%), respectively. The boiler accounts for a higher percentage of the total exergy destroyed (84.4%) compared to other components. The environment state influence [13] on the exergy destruction and exergy efficiency on a thermal power plant in Jordan was studied in literature, and another study [14] looked at the efficiency of a combined cycle employing hybrid fuel. The boiler, which suffered a major loss in terms of energy destruction, was the main cause of system irreversibility. Similar results were found when the operation of a 220 MW Egbin steam power plant in Nigeria was studied [15]. The boiler was the principal component with the highest exergy destruction, followed by the turbine and the condenser with the lowest exergy destruction. Again, [15] investigated the impact of raising the temperature at which steam is superheated on the efficiency and amount of energy lost. The heat recovery from the water boiler drum blowdown and its impact on energy destruction and second law efficiency are examined in an analysis of the Zarand steam power plant [16].

The main objective of the present study is to examine the performance of the Al-Mossaib Thermal Power Plant by using exergy and energy analyses based on actual information obtained from the plant to improve understanding of its behaviour and performance, and provide a base case reference for its efficiency improvement investigations and when establishing a new steam power plant.

2. Plant description

The current study presents an exergy and energy analysis for the Al-Mossaib Thermal Power plant in Babylon, Iraq, with the individual unit capacity of 320 MW at maximum capacity and is considered one of the largest and most important plants in the country. The amount of its produce is 15% of the total power electric produced in Iraq [17]. The power plant consists of four 300 MW rated output power generation units that were commissioned in 1989. This power plant remains one of the latest and largest in capacity among the operable power plants in Iraq at present. Each generating unit contained are shown in **Error! Reference source not found.**: (i) Steam Turbine (TBN) – three turbines with speed 3000 rpm as high, intermediate, and low, respectively 15 stages blade (single flow) for HPT, 15 stage blade for (single flow) IPT, and 14 (2×7 double flow) for LPT, which receives dry steam from the boiler and rotates a shaft coupled to the rotor of the generator to generate power; (ii) a Boiler (BLR) including a primary superheater (PSH), secondary superheater (SSH), a reheater (RH), an economiser (ECO), and two air preheater, the first is a steam air heater that is supplied by steam (STM) and the other is a regenerative rotary air heater, consisting of a large number of heat plates are arranged in multiple sections and in the form of three layers and two Forced draft fans (FDF) supply the air to the boiler; (iii) Condenser – surface type, the cooling water is from the Euphrates river; (iv) Pumps – three condensate extraction pump (CEP) after condenser and three boiler feedwater pump (BFP) after deaerator; (v) Feedwater Heaters (FWH) consisting of five low pressure feedwater heaters, four of which are closed type and the fifth is open-type feedwater heater called deaerator, with two high pressure feedwater heaters pressure. Table 1 displays a brief of the operating factors of the AL-Mossaib Thermal Power Plant at rated load. Table 2 shows the actual operation information related to different points of the power plant.

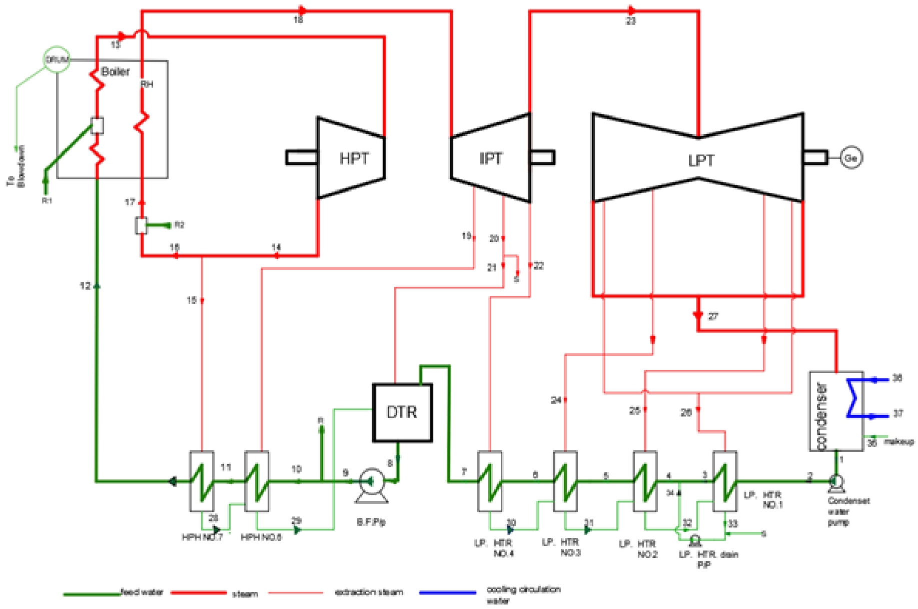

Figure 1 Schematic drawing of the Mossaib steam power plant

Table 1 Summary of the Operating Parameter of AL-Mossaib Thermal Power Plant

Rated Output	300 MW
Main Steam Flow	980 t/h at MCR (Maximum Continuous Rating)
Main Steam Temperature	538 ^{0}C
Main Steam Pressure	169 bar
Reheat Steam Temperature	538 ^{0}C
Draft system	Forced Draft
Exhaust Pressure	6.4 KPa
Rating Speed	3000 rpm
Cooling water	River water

Table 2 Actual operation readings of thermal power plant

Points	ṁ [kg/s]	P [bar]	T [^{o}C]
1	150.435	0.10001	41.6
2	150.435	25	46.6
3	150.435	25	58.0
4	185.833	25	59.0
5	185.833	25	89.0
6	185.833	25	116
7	185.833	25	145
8	194.444	7	160
9	194.444	163	168
10	182.778	163	168
11	182.778	163	168

R_1	7.222	163	168
R_2	4.444	163	168
12	182.778	163	168
13	181.667	152	539
14	181.667	30.6	350
B.D	8.333	163	220
15	0.000	30.6	350
16	181.667	30	350
17	186.111	30	326
18	186.111	28.5	538
19	0.000	14.5	440
20	15.347	7	351
21	8.611	7	351
SAH	6.736	7	351
22	9.061	3.89	291
23	161.704	3.89	291
24	8.060	1.95	213
25	8.519	0.85	143
27	3.023	0.45	81.0
28	142.102	0.10001	41.6
29	0.000	30.6	227
30	0.000	14.5	166
31	9.061	3.89	123
32	17.121	1.95	96.0
33	25.639	0.85	66.0
34	28.663	0.85	66.0
35	35.398	25	66.0
36	7372.000	0.8	24.0
37	7372.000	0.8	33.0

3. Mathematical model of exergy and energy analysis

3.1 System components model

The mathematical model is solved by using the Engineering Equation Solver (EES). The steam power plant operation is considered in the steady state situation. The energy balance of the system is insufficient to rule out the possibility of system flaws. Exergy analysis could be used to quickly identify any energy losses in a system. It is an effective instrument for measuring energy quality, which contributes to the efficiency of intricate thermodynamic systems. Pressure loss throughout the pipelines and changes in potential and kinetic energy are assumed negligible

Mass and energy balance equations is writing as [18]:

$$\sum \dot{m}_i = \sum \dot{m}_e, \tag{1}$$

$$\dot{Q}-\dot{W}=\sum \dot{m}_i h_i-\sum \dot{m}_e h_e \tag{2}$$

Exergy analysis based on the second law of thermodynamics provides a clear understanding of exergy loss to the environment and internal irreversibility [19].

Exergy balances for any control volume at steady state at base situation (T_o=25 ºC and P_o=1.01bar).can be expressed as [20, 21]:

$$\sum \left(1-\frac{T_o}{T_k}\right)\dot{Q}_k - \dot{W} + \sum \dot{m}_i x_i - \sum \dot{m}_e x_e - \dot{X}_{des} = 0, \tag{3}$$

The term $\sum(1-\frac{T_o}{T_k})\dot{Q}_k$ is the rate of exergy transfer by heat; T is Absolut temperature

The magnitude of the specific exergy in every state is determined as [22]:

$$x = (h - h_o) - T_o(s - s_o). \tag{4}$$

The rate of exergy calculated by Eq. (5)

$$\dot{X} = \dot{m}[(h - h_o) - T_o(s - s_o)]. \tag{5}$$

The plant component's exergy destruction rate and second law efficiency are summarised in Table 3

Furthermore, the exergy of fuel at the boiler inlet can be calculated as [23]:

$$\dot{X}_{fuel} = \dot{m}_{fuel} * \varphi * LHV, \tag{6}$$

where the (φ) can be estimated using the following semi-empirical relation of liquid oil as [24]:

$$\varphi = 1.0401 + 0.1728\frac{H_2}{C} + 0.0432\frac{O_2}{C} + 0.2169\frac{Sl}{C}(1 - 2.0628\frac{H_2}{C}), \tag{7}$$

where C, H_2, O_2, and Sl are the mass fractions of Carbon, Hydrogen, Oxygen, and Sulphur, respectively.

The ($\dot{W}_{net}$) represents the actual plant cycle output and is evaluated by subtracting the pumps work from the power produced by all of the turbines.

$$\dot{W}_{net,TBN} = \dot{W}_{u,HPT} + \dot{W}_{u,IPT} + \dot{W}_{u,LPT} - \dot{W}_{u,pumps} \tag{8}$$

The thermal and plant energy efficiencies is calculating as [25]

$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{BLR}} \tag{9}$$

$$\eta_{PP} = \frac{\dot{W}_{net}}{\dot{Q}_{fuel}} \tag{10}$$

Table 3 exergy destruction, and 2nd law efficiency equations of various components

	Exergy destruction	second law efficiency
Turbines	$\dot{X}_{desTBN} = (\dot{X}_i - \dot{X}_e) - \dot{W}_u$	$\eta_{IITBN} = \frac{\dot{W}_{uTBN}}{(\dot{X}_i - \dot{X}_e)}$
Boiler	$\dot{X}_{des,BLR} = \dot{X}_{fuel} + \dot{X}_{in,BLR} - \dot{X}_{e,BLR}$	$\eta_{II,BLR} = \frac{\dot{X}_{BLR,e} - \dot{X}_{BLR,i}}{\dot{X}_{fuel}}$
Condenser	$\dot{X}_{des,cond} = \dot{X}_{cond} - \left(1 - \frac{T_0}{T_K}\right)\dot{Q}_{cond,rej}$	$\eta_{II,cond} = 1 - \frac{\dot{X}_{des,cond}}{\dot{X}_{in,cond}}$
Deaerator	$\dot{X}_{des,DTR} = \dot{X}_{in} + \dot{X}_{out}$	$\eta_{IIDTR} = 1 - \frac{\dot{X}_{desDTR}}{\dot{X}_{inDTR}}$
Closed feedwater heaters	$\dot{X}_{des,HTR} = (\dot{X}_{stm} + \dot{X}_{CWi} - \dot{m}_{CWe}) - (\dot{X}_{FWe} - \dot{X}_{FWi})$	$\eta_{II,HTR} = \frac{\dot{X}_{FWe} - \dot{X}_{FWi}}{\dot{X}_{stm} + \dot{X}_{CWi} - \dot{m}_{CWe}}$
	$\dot{X}_{des,HTR} = (\dot{X}_{stm} + \dot{X}_{CWi}) - (\dot{X}_{FWe} - \dot{X}_{FWi})$	$\eta_{II,HTR} = \frac{\dot{X}_{FWe} - \dot{X}_{FWi}}{\dot{X}_{stm} - \dot{m}_{CWe}}$
Pumps	$\dot{X}_{despump} = (\dot{X}_e - \dot{X}_i) - \dot{W}_u$	$\eta_{II} = \frac{\dot{W}_{u\,pump}}{(\dot{X}_e - \dot{X}_i)}$
Overall power plant	$\dot{X}_{despump} = \sum \dot{X}_{des,components}$	$\eta_{II,PP} = \frac{\dot{W}_{net}}{\dot{X}_{fuel}}$

4. Validation

The steam power plant has been simulated using EES software, and the result is compared with the design situation state at (70%) of the full load. Comparatively, Table 4 Demonstrates good compatible between both findings.

Table 4. Comparison between the results of solver code software and the reading of design reading of P.P.

	Design reading	Simulating	Percentage deviation
Thermal efficiency	0.449	0.443	1.336 %
Load	210 MW	211.5 MW	0.714 %

5. Results and discussion

Figure 2 presents the percentages of energy losses at various plant locations and clarifies the distribution of energy losses at 225 MW. The condenser has the highest energy loss (98.4 MW), as shown in Table 5 , and accounts for approximately more than 47 of the total energy loss. At the boiler, the energy loss is 36MW, as shown in Table 5, accounting for 17.588% of the total. Figure 2 also shows that the energy losses at the high-pressure turbine is higher than those of the intermediate and low pressure turbines, with (27.512) MW, representing (13.342%) of the overall losses. The analysis reveals that the IPT and LPT have worthy amounts of energy losses but less than HPT at about 17 and 20 MW, respectively, and combining the percentages of (8.531%) and (9.881%) of the full energy losses. As for the pumps, the boiler water feed pump has higher energy losses at 0.5 MW, which accounts for (0.255%) of the total losses, than that of the condensate water extraction pump at (0.07) MW, which represents (0.034%) of the total power loss for the cycle. The energy loss at the deaerator is (5.4) MW, which forms (2.647%) of the total losses cycle.

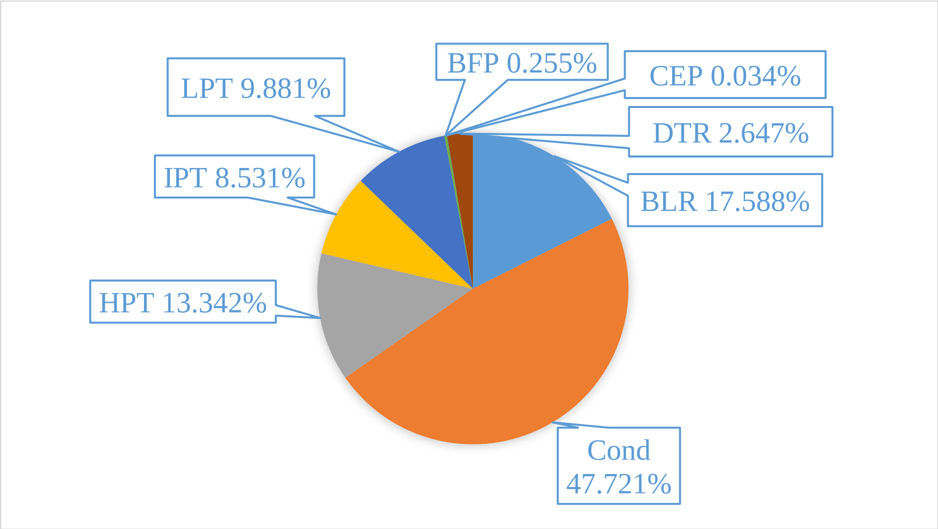

Figure 2 The proportion of energy loss in different components

Table 5 Energy losses at different component

Component	Energy Losses [MW]
BLR	36.266
Cond	98.401
HPT	27.512
IPT	17.591
LPT	20.374
BFP	0.527
CEP	0.070
DTR	5.459

In addition, Figure 3 illustrates that the right and left halves of the energy balances, which represents energy outputs and inputs of the cycle. The right half demonstrates the magnitude of the energy inputs to the cycle, which represents the amount of fuel energy transferred to the working fluid. The left half represents the net power output, which is 37% of the energy input to the cycle, and the amount of heat rejected from the cycle at the condenser is 36% [26]. The boiler and turbines also contribute to cycle energy losses, forming a percentage of 5.87% and 10.57%, respectively. For the other miscellaneous energy outputs from the losses from other components of the cycle accounts for 10.5%.

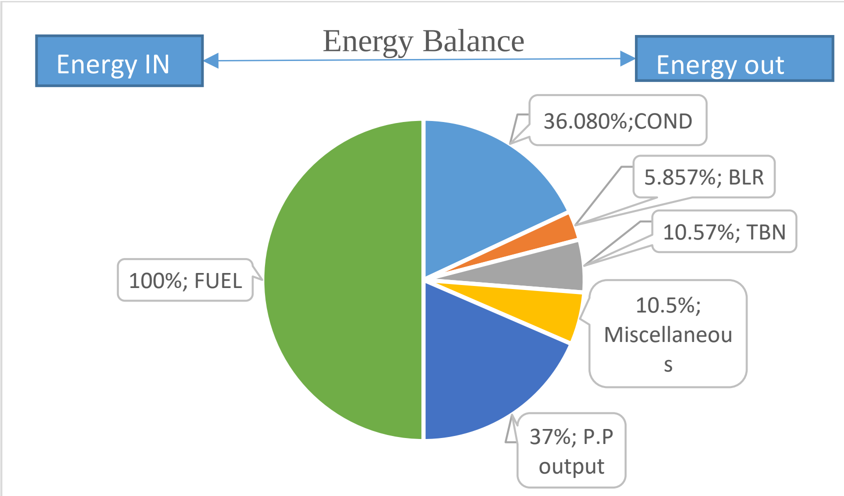

Figure 3 overall energy balance

Figure 4 demonstrates the exergy destruction at the plant's components. The boiler suffers a huge exergy destruction at (356.9) MW, as demonstrates in Table 6, , accounting for (86.48%) of the total destroyed plant exergy inputs. The high boiler irreversibility is because the combustion that is irreversible, and to a large difference in temperature and incomplete combustion [27]. The HPT destroys exergy at 13.861 MW, representing (3.36%) of the total destroyed of exergy. In addition, the destroyed exergy at IPT is (9.6) MW, accounting for (2.34%) of the overall exergy destruction and is lower than that of HPT and IPT. The exergy destruction at LPT is (9970) MW, forming (2.416%) of the total exergy destruction, while that at caused by the condenser is (16.048) MW, sharing (3.89%) of the overall exergy destruction since it rejects the heat at the approximately constant temp variance and is because of the steam phase change. The BFP contributes (0.086%) of the total destroyed exergy at (0.3569) MW, while the CEP shares (0.02%)at (0.065) MW. For the feedwater heaters, that LPH1 has an exergy destruction of(0.522) MW that accounts for (0.13%) of the overall exergy destruction. At LPH4, the destroyed exergy is (0.7751) MW, which accounts for (0.188%) of the overall exergy destruction. LPH2 and LPH3 shows energy destructions of (1.097) and (0.8108) MW, respectively, which contribute (0.27%)and (0.196%) of the total exergy destruction, respectively.

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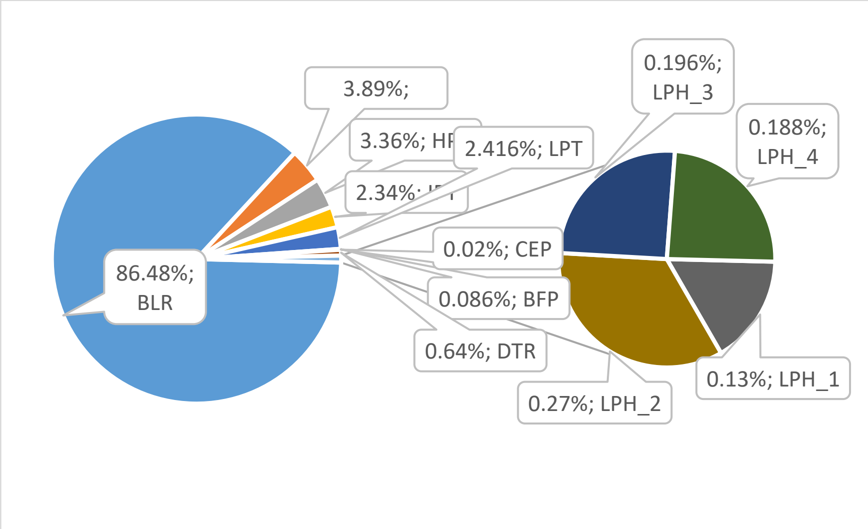

Figure 4The proportion of exergy destruction at different components of SPP

Table 6 The contribution of components of Power Plant for exergy destruction

Component	Exergy destruction [MW]
BLR	356.9
Cond	16.048
HPT	13.861
IPT	9.643
LPT	9.97
BFP	0.3569
CEP	0.06539
DTR	2.638
LPH_1	0.522
LPH_2	1.097
LPH_3	0.8108
LPH_4	0.7751

Figure 5 shows the right and left half of the energy balances, which stand for the cycle's energy imports and outputs. The left half of the diagram illustrates the net power output, which is (34.91%) of the exergy input to the cycle, while the right half shows the magnitude of the exergy inputs as the amount of fuel exergy delivered to the cycle. (0.78%) of the cycle's heat is rejected at the condenser. The boiler has the greatest energy loss, accounting for 54.43% of all energy inputs. Turbines contribute 5.1% of the cycle's exergy losses, whereas the remaining exergy outputs from the other components' losses make up (4.84%) of the inputs' total exergy.

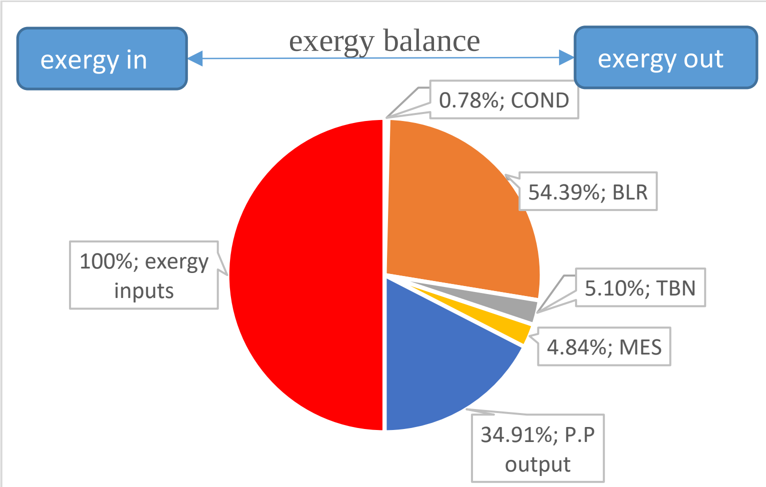

Figure 5overall exergy balance

Figure 6 shows the second law efficiency associated with the power plant components The IPT is highly efficient with (90.36%) given that the irreversibility is the lowest compared with HPT and LPT. The second law efficiency of HPT is (79.9%), less than approximately (9.91%) from that of LPT, which has (89.82%) and appears more efficient than HPT. The boiler has the second law efficiency of (45.61%). Given that the boiler feedwater pump efficiency is higher than that of the condenser extraction pump, reaching (90.59%) and (85.49%), respectively. For feedwater heaters, the deaerator has second law efficiency of (88.84%) and is thus more efficient than closed feedwater heaters. The second law efficiency of LPH4 is (88.56%), better than those of LPH1,2,3, at (54.61%), (75.02%), and (84.33%), respectively.

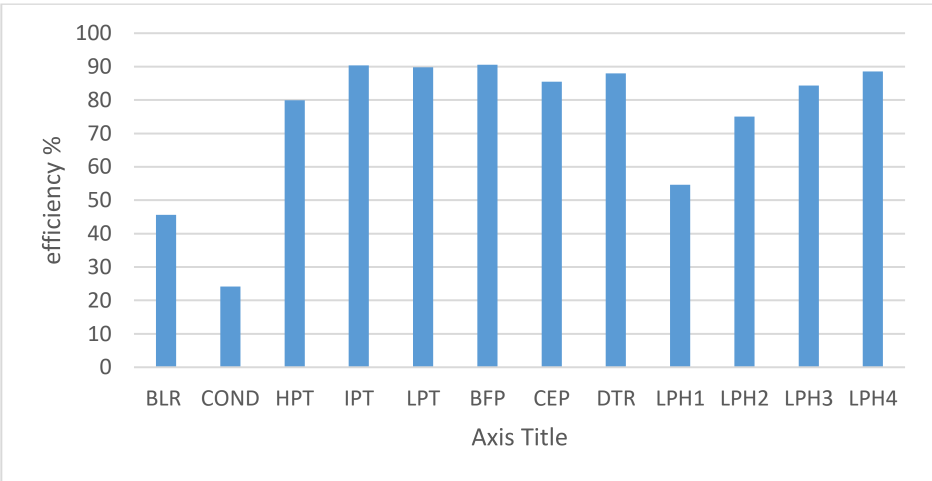

Figure 6 2nd law efficiencies of various component

Figure 7 shows the thermal, plant, and second law efficiencies, which are 39.3%, 37%, and 34.91%, respectively. The difference in power plant and second law efficiencies is because the specific chemical exergy of liquid fuel being a little greater than its specific energy determined by its low heating value [3].

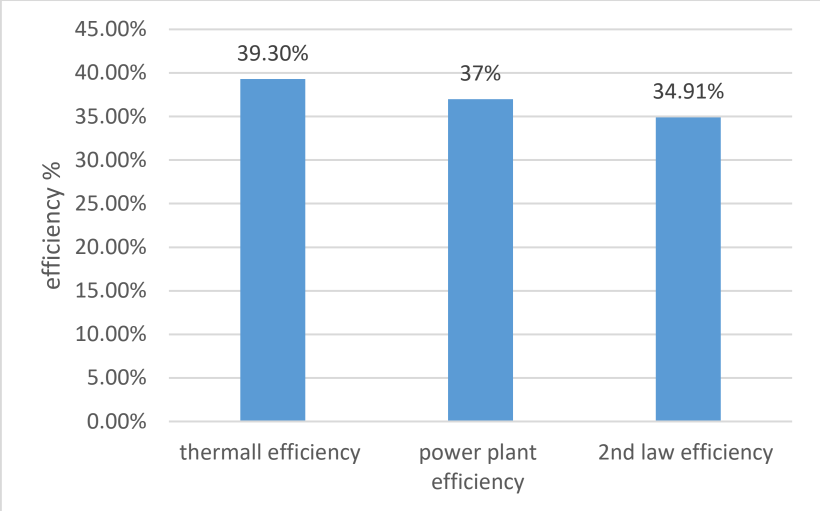

Figure 7 energy and 2nd law efficiency of thermal power plant

6. Conclusions

- All the gear in this steaming power station research study was evaluated for exergy effectiveness, exergy destruction, energy efficiency, and energy loss. The results of this investigation are listed below:
- The thermal, plant, and second law efficiencies are 39.3%, 37%, and 34.81%, respectively.
- The greatest heat energy loss of the plant occurs at the condenser, with accounts for approximately 47% of the total loss, followed by that at BLR with 17.588%.
- The boiler is one of the most crucial components of the steam plant and the one that destroys the most exergy, accounting for around (86%) of the total destruction compared to the condenser's (3.89%). Therefore, the plant's second law efficiency only slightly rises as a result of condenser upgrades. The boiler, the plant's most inefficient component, offers substantial opportunity to increase efficiency by lowering the irreversibility of the steam generator via adjustments to its combustion and/or heat transfer.
- The exergy destruction of HPT is more than those at IPT and LPT by (13.861 MW) due to the increase temperature of the steam leaving the former.
- The highest exergy destruction at feedwater heaters is observed in LPH2 at 0.189% of the total destroyed of the exergy. The second law efficiency for closed feedwater is usually less than that of the open feedwater heater.
- Energy analysis findings incorrectly conclude that practically all power plant losses were related to the heat rejected by the condensers, despite the fact that energy studies statistically and explicitly show that the condensers are only partially to blame for these losses.

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