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Evaluation Performance of the Steam Power Plant in Iraq Based on Energy and Exergy Analysis

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ABSTRACT

Al-Mosyab thermal power station in Iraq is the subject of a case study to apply energy and exergy analysis in this presented paper. The methodical equations derived from mass, energy, and exergy balancing equations for each part of the cycle were computed using software Engineering Equation Solver (EES). The exergy analysis shows that the plant's second law efficiency and entire exergy destruction are 34.91% and 412.6 MW, respectively. The boiler experiences the most significant losses since they destroy the most exergy. The effect of the condenser pressure rise and the change in cooling water temperature on the performance of the thermal unit was studied. The thermal and exergy efficiency are reduced by 0.16% and 0.14%, respectively; the net power output decreased by 3.61%, demonstrating the significant impact of condenser pressure on the load produced. As a result of a rise in cooling water inlet temperature, the thermal and second law efficiency decrease by 1.196% and 1.203%, respectively, while the net power decreases by 0.57%.

1. INTRODUCTION

Even with the availability of energy sources and fossil fuels (oil), The electricity sector in Iraq suffers from shortage of electric power, especially in light of population expansion. So, should be many initiatives are being taken to improve and enhance fossil fuel-powered steam plants in order to boost their effectiveness and lower energy losses. The disparity between global energy production and demand is getting less every day. Energy consumption is a key indicator of both a country's and a community's degree of development and quality of life. The capacity augmentation is necessary to meet these energy demands for effective use of energy resources; thermal system analysis is crucial. The first law of thermodynamics or energy analysis is the conventional method for analyzing thermal power systems. Inaccurate data on efficiency and losses cannot be gleaned from energy calculations predicated on the first law of thermodynamics. Consequently, there is considerable attention on effectively combining the first and second laws of thermodynamics [1]. Ray et al. [2] locating the causes of high irreversibility across a power cycle's various parts is helpful information for exergy analysis. Loss of usable work is easily measurable over time and under various operational conditions. When the pace at which a component's exergy is destroyed increases and its exergy efficiency falls below its design value, it is in a state of progressive deterioration. Rosen and Scott [3] supposed, the term "energy" is frequently employed in studies, including the study of energy production, transformation, and consumption. However, these studies on exergy are often more informative than those on energy. Exergy-related losses provide a more precise identification and description of the magnitudes of thermodynamic losses as well as their origins, locations, and causes. The energy industry may be seen more clearly with the help of exergy. Exergy analysis is helpful because it highlights potential sources of inefficiency in energy systems during the design phase. Cengel et al. [4] presented that exergy is the highest amount of useful work that a system is capable of producing in a given environment and state. When it comes to the optimization of intricate thermodynamic systems, the exergy investigation, which is founded on the second law of thermodynamics, has shown to be an extremely effective tool that can determine the locations and sizes of the biggest irreversibilities in these cycles. Rosen [5] explained that exergy analysis recognizes that while energy cannot be generated or destroyed, it can decline in quality until it reaches a point where it is completely equilibrated with the environment and is therefore no longer useful for completing tasks. Dewulf et al. [6] elucidated that when a system or resource is brought into equilibrium with its surroundings through reversible processes and is solely permitted to interact with the environment, the exergy is the maximum amount of useful work that may be obtained from that system or resource. Proper consideration must be given to the environment employed in the calculations, such as the so-called dead state. Al-Mubaddel et al. [7] the condenser is an essential component of thermal power plants that utilize the condensation process, which entails the transformation of saturated steam exhaust from the LP turbine into liquid water. In addition, non-condensable dissolved gases are eliminated. Utilizing a condenser in a thermal power unit also improves the efficiency of the power plant by rejecting heat to the environment; hence, they have examined the effect of environmental factors on the condenser of the steam power station. Aljundi [8] have investigated the impact of changing the environment's temperature from 283.15 to 318.15 K on the degradation of exergy on major portions of Al-Hussein thermal power plant in Jordan by employed energy and exergy analyses. Ameri et al. [9] evaluated the effect environment condition on the exergy efficiency of the Hamedan steam power plant at different loads. the study had shown the efficiency decreased with increased ambient temperature. Altering the condition dead state had been studied for C¸ayırhan thermal power plant located in Turkey [10]. The second law efficiency of station decreased with increased ambient temperature at constant pressure. Studied the effect climate condition and condenser pressure of Shahid Montazeri power plant shows that the decrease the performance of the station due to rise in vacuum pressure of condenser [11]. The investigators [12] examined impact of altering condenser pressure of North Refineries Company (MRC)/ Baiji/ Iraq appeared that the second law efficiency was growing.

The objective of the presented paper is to perform a power and energy assessment on the 225 MW Al-Mosyab steam power plant's No. 3 unit to determine where energy is lost and how much exergy is destroyed in each section of the station. In addition, this paper studies the effect of changing cooling water temperature and condenser pressure on plant effectiveness. Thus contributing to improving the performance of steam stations operating in Iraq.

2. PLANT DESCRIPTION

Al-Mosyab steam power plant, which was completed in 1990, designed to produce 1200 MW, the station has four separate units. The power station is located in the Babylon Governorate. At present day, the total available output reaches approximately 65% of the total rated capacity due to proper maintenance has not been performed and equipment being degraded due to the imposition of the economic embargo after the Gulf War.

Figure 1 shows a flow schematic for the power station. Table 1 lists the operating parameters for unit plant No. 3 at 225 MW load. Each power plant unit consists of a subcritical single drum radiant natural circulation boiler is a pressurized furnace with two regenerative air heaters, three turbines: (one HP, one IP, one LP) are connected with couplings, the generator is of liquid/hydrogen cooled type, three main boiler feedwater pumps, three condensate pumps, six closed feedwater heaters, and one open feedwater heater called deaerator (DTR), and a condenser.

Table 1. General current operation condition

Item	Value
Feedwater temperature	168°C
Mass flow rate of main steam	181.6 kg. s^{-1}
Main steam pressure	152 bar
Main steam temperature	539°C
Mass flow rate of fuel	14.68 kg. s^{-1}
Condenser pressure	0.1 bar
NCV (crude oil)	10074 kcal. Kg^{-1}
Cooling water temperature	24°C
Draft system	Force draft
Generator Rotating speed	3000 rpm

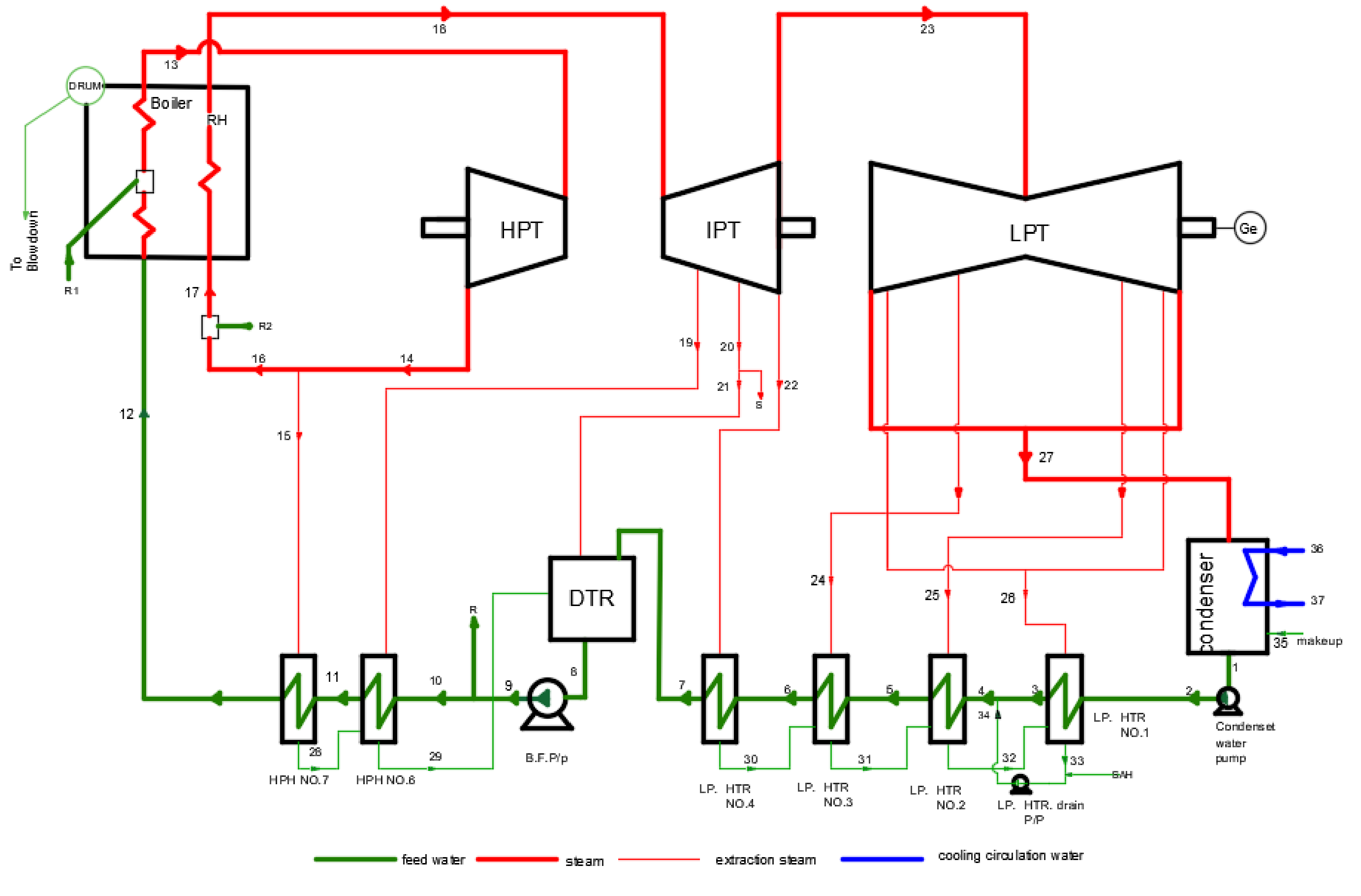

Figure 1. Diagram depiction of Al-Mosyab steam power plant's flow

3. MATHEMATICAL MODEL

Thermodynamic model equations are used to evaluate the performance of various plant components and the entire plant. For each control volume, the model equations are essentially derived from the fundamental laws of mass conservation, energy conservation, and exergy balance. All model equations are solved with engineering equation solver (EES) [13] software based on the readings of unit-3 summarised in Table 1 which displays the operating conditions under which the 225 MW of power it produces. These equations are applied to various plant components based on the following assumptions: environment references are (298 K and 1bar), steady state control volume. The kinetic and potential of energy and exergy were not taken into account as [14, 15].

Balance of mass, energy, and exergy are calculated as following:

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

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

$$\dot{X}_{heat} - \dot{W} + \sum \dot{m}_i x_i - \sum \dot{m}_e x_e = \dot{X}_{des} \tag{3}$$

where, $\dot{X}_{heat}$ is the rate of exergy transfer by heat can computed by:

$$\dot{X}_{heat} = \sum (1 - \frac{T_o}{T_k}) \dot{Q}_k \tag{4}$$

The specific exergy can get by:

$$\dot{X} = \dot{m} x \tag{5}$$

The specific exergy can get by:

$$x = (h - h_o) - T_o(s - s_o) \tag{6}$$

The net power has been calculated as [16]:

$$\dot{W}_{net} = \dot{W}_{u,HPT} + \dot{W}_{u,IPT} + \dot{W}_{u,LPT} - \dot{W}_{u,BFP} - \dot{W}_{u,CEP} \tag{7}$$

The exergy content of fuel which represent the exergy supply to the system is written as:

$$\dot{X}_{fuel} = \dot{m}_{fuel} * \varphi * LHV \tag{8}$$

where, φ is ratio of chemical exergy of liquid fuel and LVH is lower heating value represent the amount of NCV of crude oil at Table 1.

Power plant second law efficiency and exergy destruction are calculated by:

$$\eta_{\mathrm{II}} = \frac{\dot{W}_{net}}{\dot{X}_{fuel}} \tag{9}$$

$$\dot{X}_{des} = \sum \dot{X}_{des,compnent} \tag{10}$$

Power plant Thermal efficiency is computed by Eq. (11):

$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{BLR}} \tag{11}$$

where, the $\dot{Q}_{BLR}$ can calculated by:

$$\dot{Q}_{BLR} = (\dot{m}_{13} * h_{13} + \dot{m}_{18} * h_{18} + \dot{m}_{BD} * h_{BD}) - (\dot{m}_{12} * h_{12} + \dot{m}_{17} * h_{17} + \dot{m}_{R1} * h_{R1}) \tag{12}$$

4. RESULTS AND DISCUSSIONS

A comparison was made between the station simulation results under design conditions as shown in Table 2 with a 300 MW load to validate the EES programme results. The Table 3 revealed that the highest discrepancy between the design parameters and simulation results is 1.33%, which are agreeable values; hence, the mathematical model will be utilised to assess the station's energy and exergy under actual operating conditions with 225 MW of load.

Table 2. Design condition at 300 MW

Item	Equipment designation
Feedwater flow	244.6 kg. s^{-1}
Feedwater temperature	251.8°C
Mass flow rate of main steam	250.75 kg. s^{-1}
Main steam pressure	170 bar
Main steam temperature	538°C
Hot reheat steam pressure	83.3 bar
Hot reheat steam pressure	538°C
Condenser pressure	0.0653 bar
Cooling water temperature	23°C

Table 3. The contrast between the results and the current readings

	Design parameter	Simulation reading	Deviation%
Thermal efficiency	0.451	0.445	1.33%
Power output	300 MW	299.7 MW	0.1%

Table 4. Exergy destruction and thermal and second law efficiency

Component	Thermal efficiency %	Energy Losses MW	2nd Law efficiency%	Exergy destruction MW
BLR	94	36.266	45.61	356.9
COND	69	98.401	24.2	16.048
HPT	67	27.512	79.91	13.861
IPT	83.7	17.591	90.36	9.643
LPT	81.2	20.374	89.82	9.97
BFP	86	0.527	90.59	0.3569
CEP	84	0.070	85.49	0.06539
DTR	96	5.459	88	2.638
LPH1	N/A	N/A	54.61	0.522
LPH2	N/A	N/A	75	1.097
LPH3	N/A	N/A	84.33	0.8108
LPH4	N/A	N/A	88.56	0.7751
cycle	39.3	206.2	34.91	412.68

The energy and exergy analyses were performed and the results shown in Table 4 were obtained. The total exergy destroyed is 412.6 MW, and the plant's thermal and second law efficiency are 39.91% and 34.91%, respectively. According to the results of the energy study, the boiler is responsible for

17.58% of the total energy losses and the condenser for 47.72%. The exergy analysis indicated that the boiler destroyed 86.48% of the entire exergy, only 3.89% was destroyed in the condenser. Energy-based measures of efficiency are not always reliable, and may even be deceptive, since they do not guarantee a consumed energy quality. Furthermore, energy losses may be enormous in terms of quantity, but their poor quality [17].

The performance of the condenser is critical to the operation of an effective and dependable power plant. Accelerated corrosion and deposits in the boiler can be the result of air and cooling water leaks. High backpressure is another consequence of subpar condenser performance, which leads to less electrical output, decreased efficiency, and higher operation costs [18]. The pressure of the condenser rises due to a poor vacuum instrument. Figure 2 shows the effect of thermal, second law efficiency and net power output when the increased condenser pressure 0.06 bar to 0.24 bar. The results showed that the thermal efficiency of the thermal cycle decreases gradually by 3.6% from 39.39% to 37.97% The result is compatible as [19]. One way the condenser is used is to reject heat to the surrounding area, which helps the power plant run more efficiently. Steam flows as a saturated mixture at its pressure-specific saturation temperature in the condenser. Consequently, lowering the condenser pressure decreases the temperature of the steam, which reduces the amount of heat rejected to the environment and increases the condensation of a greater quantity of steam exiting the low pressure turbine, and vice versa. The 2nd law efficiency descends from 34.99% to 33.73% which means every 0.02 bar increasing in the condenser pressure so the 2nd law efficiency decreasing is 0.14% because increasing condenser pressure will rise the LP turbine back pressure that causes increasing saturated steam temperature. As a result, the temperature differential between the cooling water and condensing steam widens. thus, this lead increases entropy generation and irreversibility, this finding line up with earlier research as [20]. The net power has decreased from 229.63 MW to 221.3 by 0.92 MW for every 0.02 bar increased, which is consistent with as [21, 22], indicating that the condenser pressure has a considerable effect on the load produced.

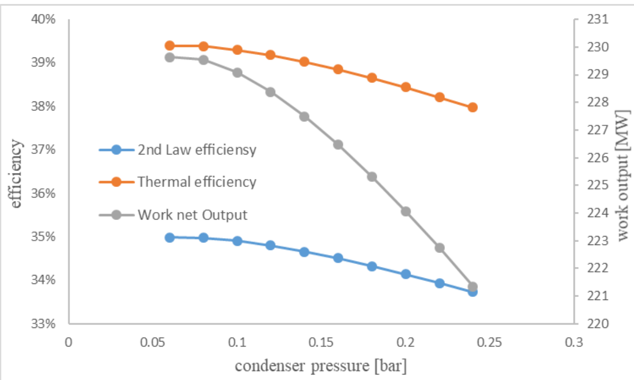

Figure 2. Effect condenser pressure on plant efficiency and output power

Figure 3 shows the effect the increasing condenser pressure from 0.06 bar to 0.24 bar on plant performance. The higher the condenser pressure, the higher the temperature of heat rejection to the environment, the higher the temperature difference between the working fluid and the cooling water, and the higher the entropy generated and irreversibilities [12], which is why the plant's exergy destruction rose by about 2% MW. Condenser exergy destruction by 2.96 MW for every 0.02 bar increment of condenser pressure. The condenser is not adiabatic; that is, the exergy of the lost heat at the boundary must be factored into the restored exergy if $T_b > T_0$. No effort is made to harness this exergy, and its destruction is permitted; nonetheless, the condenser is not to be held responsible for what happens beyond its walls. It makes it reasonable to think of a comprehensive system that covers the immediate surroundings of the device so that the borders of the new enlarged system are at T_0 if we are interested in the exergy destroyed during the process outside the confines of the device [5].

Figure 4 shows the effect of increasing the cooling water temperature changing value between (24°C - 32°C) on the plant's thermal and second law efficiency and net power. Notes that the plant thermal efficiency worsen by (1.196%). Also reveals that the second law efficiency get worse by (1.203%) where their values range from (34.91% - 34.49%). As well as shows that net output power decreases approximately by 0.14 MW for every 0.7°C increment of cooling water temperature.

Figure 5 turns out that increasing the temperature there is happening to reduce the performance of the actual work turbine by 0.56%, especially at low pressure turbine due to smaller expansion of the steam and this is confirmed by thermodynamics as [23, 24]. Moreover, the exergy destruction from the condenser has increased by 0.58%.

According to the Figure 6, increasing the cooling water temperature change from 24 C to 30 C causes the energy wasted from the thermal cycle to be average18.33 MW, and 0.57 MW of the power plant is destroyed by exergy for every 0.7°C increment.

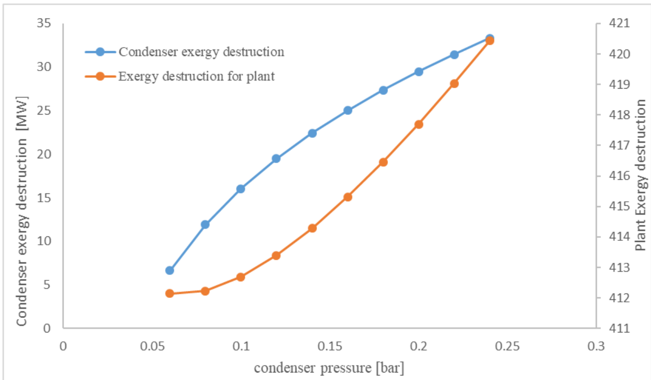

Figure 3. Effect condenser pressure on plant and condenser exergy

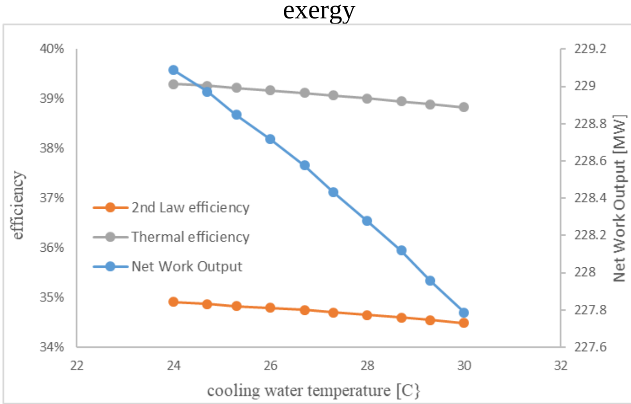

Figure 4. Effect inlet cooling water temperature on plant efficiency and output power

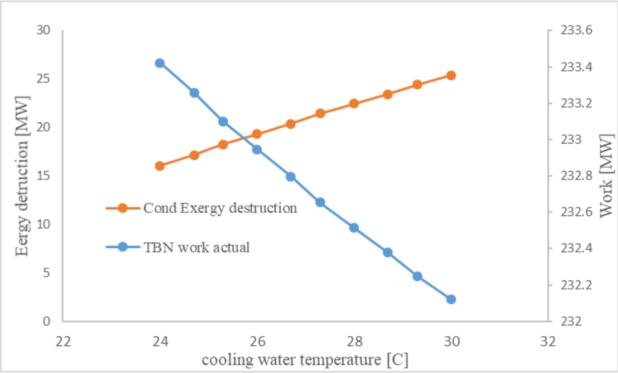

Figure 5. Effect inlet cooling water temperature on the turbine actual work and condenser exergy destruction

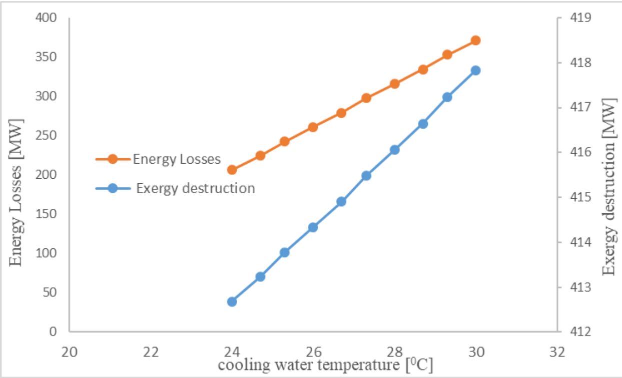

Figure 6. Effect inlet cooling water temperature on energy and exergy wasted

5. CONCLUSIONS

The exergy study estimates that the plant can destroy 412 MW of exergy. Most of the exergy waste comes from the boiler, at 86.48%. 3.36%, 2.3%, and 2.41% of the total exergy destruction occurred in the HP turbine, IP turbine, and (LP) turbine, respectively.

According to a comparison of the performance of the turbines, it becomes clear that the IP turbine is the most efficient in terms of the second law of thermodynamics at 90.36 percent, whereas the HP turbine is the least efficient (at 79.91%).

Increasing condenser pressure led to worse thermal and second law efficiencies. In additional the net power output can be decreasing by 3.61% MW and increase in the exergy destructions of the cycle by 2% MW.

The cooling water temperature significantly impacts the performance of the generating unit. It increases the heat wasted from the condenser, also impacting the efficiency of the steam power plant and controlling the turbine's output. Clearly, when the temperature of the cooling water inlet rises, this causes the thermal efficiency and second law efficiency can degrade by 1.196%, and 1.203%, respectively and the net power can fall by 0.57%. The total energy wasted and exergy destruction of the power plant increased by 18.33 MW and 0.57 MW, respectively.

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NOMENCLATURE

N.C.V	Net calorific value, kJ. kg^{-1}
h	Enthalpy, kJ. Kg^{-1}
P	Pressure, bar
s	Entropy, kJ. kg^{-1}. K^{-1}
$\dot{m}$	mass flow rate, kg. s^{-1}
$\dot{W}$	Work, kW
$\dot{Q}$	Heat, kW
$\dot{X}$	rate of exergy, kW
x	specific exergy kJ/kg^{-1}

Greek symbols

η	efficiency
φ	ratio of the chemical exergy (exergy factor)
η_{II}	second law efficiency

Subscripts

des	destruction
e	exit
i	inlet
K	surface properties
0	ambient
BD	Blow down
R1	spray water

Abbreviations

BFP	boiler feedwater pump
BLR	boiler
CEP	condensate extraction pump
Cond	condenser
DTR	Deaerator
FW	feedwater
HPT	high pressure turbine
HTR	heater
IPT	Intermediate pressure turbine.
LPH	low pressure heater