Energy Auditing of Thermal Power plant

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Abstract - *The world and Jordan in particular, are facing the scarcity of fossil fuel sources on which it is mainly dependent for generating electric power. Therefore, energy management and conservation in any power plant can be achieved through energy audit. In this study, a preliminary energy audit of a thermal power plant at Jordan phosphate mines industrial complex was conducted, that produce 14.36 MW at full load. This work evaluated the performance of power plant components and identified required improvements based on energy loss by comparing the design performance (reference) with the present performance (actual). The results showed a deviation in the present performance of all components for which the energy audit was conducted from the design performance. Percentages deviation of present efficiency from design efficiency of power plant components.as follows: FD fan efficiency 3.77 %, condenser efficiency 3.08 % and the biggest deviation was in boiler efficiency by 4.9 %, because there was a poor quality of feed water and fuel, also the heat loss by flue gases and blow down. Several solutions have been proposed that contribute to improving the efficiency of the power plant.*

***Key Words*: Thermal power plant; energy conserving; energy audit; efficiency.**

Nomenclature

g Gravitational acceleration (9.8 m/s^2).
H Head (m).
h Specific Enthalpy (kJ/kg).
hr hour.
$\dot{m}$ Mass flow rate of water (m^3/s).
P Pressure (bar).
Q Quantity of steam generated per hour (kg/hr).
q Quantity of natural gas used (m^3/hr).
Spec specific power consumption of pump (KWh/m^3).
T Temperature (°C).

1. INTRODUCTION

One of the most important challenges and problems facing the world, and Jordan in particular, is the decrease in non-renewable energy sources and their depletion over time. Where there are two important points facing Jordan with regard to the issue of energy: the first point increased continuous demand on the energy and the other point limited local resources and their inability to cover this great demand for energy. Jordan's energy demand is increasing at a rate of 3% annually. To meet these needs, Jordan imports 94 % of fossil fuels such as oil and gas. Which causes a violation of the state treasury due to the instability of fuel prices. Therefore, the government decided to rely on renewable energy sources to provide 10 % of its energy needs, as electric power generation increased during the year 2020 from 1.13 GW to 1.8 GW. Therefore, energy must be well conserved and managed, so it is better to rely primarily on renewable energy sources [1].

Electricity in Jordan is generated through conventional (non-renewable) power plants and renewable energy plants of different generation methods. However, more reliance is placed on thermal power plants, which are conventional plants [2]. Where thermal power plant continuously converts the energy of fossil fuels such as oil, coal or gas in to mechanical work then in the end into electricity energy. It works by Rankine cycle, which includes four main components: boiler, turbine, condenser and pump. Total thermal power plant efficiency depends on the efficiencies of these components. Where the thermal efficiency is as index of how well the plant is existence operated as compared to the design characteristics.

Energy management and conservation in any power plant can be accomplished by an energy audit. Energy audit is defined as a systematic procedure to ensure efficient use of energy with maximum efficiency by identifying, measuring and controlling areas of energy loss, as well as identifying alternative technologies within their technical and economic availability. There should be an inclusive study and analysis of many parts of the power plant to know how and where the energy is used and to choose the methods to save energy, also provide solutions to reduce energy consumption. Energy audit works to minimize the amount of energy input into the system but it does not affect the power output of the system.

There are two main types of energy audit. Where it classified according to the depth of the auditing requires, the methods used to collect the necessary data, the amount of costs that can be reduced and recommendations. In addition to, the time spent to carry out audit which depends on the size of power plant. The first type is a preliminary energy audit (walk-through): this type is simple and does not take much time, may only need a few days. It largely depends on the available documents and a short visit to the power plant. It includes approximately 70% of the total power plant and the economic analyzes are limited. It is sometimes used to determine the need for a detailed audit. The second type is detailed energy audit this approach demands inclusive registration and analysis of energy consumption in all components of power plant about 95 % of the total energy is computed. Where many portable measuring devices are installed and they are the main approved source of data needed to conduct the audit, such as gas analyzer, digital manometers, digital thermometers, leak detector, etc. It contains an accurate engineering recommendation and must behave a preliminary energy audit before it. Which takes a longer time and the results are more accurate compared to the preliminary audit.

2. LITERATURE SURVEY

The purpose of this work was to show energy auditing and energy management for boiler, turbine, condenser, coal and furnace. . The result indicate that in the boiler radiation loss happens because of weak insulation and there was humidity in coal Led to loss in wet and dry stack about 6.10 % and 5.13 % respectively. The problem was in turbine due to leakage of air and inflow gasses, and lifespan of turbine blades depressed because of the amount of oxygen that entered the turbine through makeup water is the water that is added to recover for losses such as losses resulting from evaporation, but the condenser faced a reduction in condenser space about 0.025 kg/m^3 a result of insufficient quantity of cooling water, unclean pipes and air losses, in addition, there was a difference in hot well temperature between actual and designed 33 and 44 ,respectively. With regard to the furnace showed that decrease in performance due to the radiation waste was above from 6 % [3].

This study showed methods that enhance the efficiency of a steam power plant by raising the parameters of steam at inlet turbine, as plants that produce steam at (25 MPa, 600 °C) are 3 % more efficient than the surrounding areas that produce steam at (30 MPa, 566 °C). Also through reduction the parameters of steam at outlet turbine, as the efficiency increased by 2.2 % when reducing exhaust pressure from 6 KPa to 4 KPa. The third method is the pre heating of the feed water, which uses heat from extracting steam from the turbine, 14 although when increasing the pre-heating stages leads to an increase in the efficiency of the plant, but it increases the cost of establishing the plant [4].

In another study, it was found that the performance of the components decreases with reducing the load, except for the boiler. Also the overall efficiency at load drop from 250 MW to 125 MW decreased from 38.5 % to 34.63 %. Where the main energy losses were in the condenser and turbine generator. Although the boiler efficiency is lower than the design, it is satisfactory. One of the most important recommendations made is that the station should operate at the highest load in order to improve efficiency, reduce the temperature of the flue gases to the minimum permissible, clean the condenser tubes, improve the performance of the cooling tower, improve the design of the turbine blades and check seals in the turbine [5].

3. DESCRIPTION OF THERMAL POWER PLANT

The thermal power plant at Jordan phosphate mines industrial complex is located in the Gulf of Aqaba, south of Jordan, about 18 km from the city center near the borders of the Kingdom of Saudi Arabia. The power plant produces 14.36 MW works by Rankine cycle. The fuel used for the combustion process in the boiler is natural gas. Figure 3.1, shows the power plant components through schematic diagram. Also the Table 3.1, displays the thermodynamic properties of working fluid at each point on schematic diagram. The properties of natural gas and air are also presented in a Table 3.2.

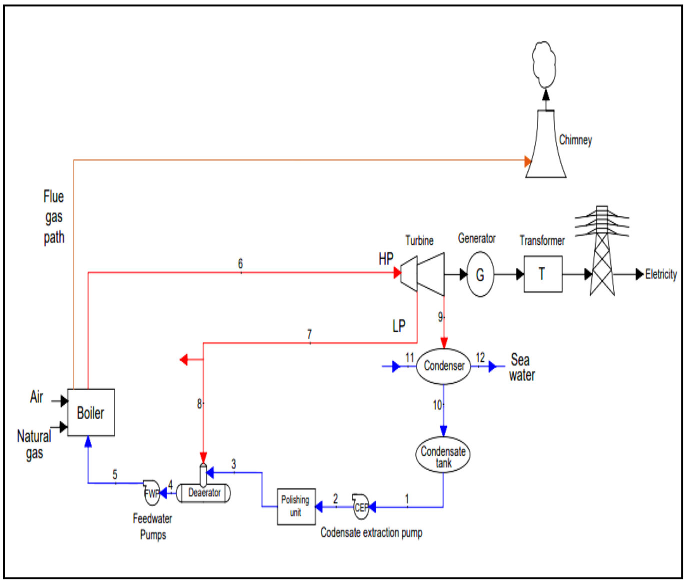

Fig 3.1 Schematic diagram of the thermal power plant.

Table 3.1: 1shows the present thermodynamic properties of the working fluid at each point on Schematic diagram of the thermal power plant at 100%.

Point	P (kPa)	T (°C)	ṁ (ton/hr)	h (kJ/kg)	State
1	400	48.8	76.23	204.66	Liquid
2	1200	49.2	76.23	207.02	Liquid
3	1100	50	76.23	210.27	Liquid
4	330	134	76.23	563.5	Liquid
5	6000	136	90.23	575.81	Liquid
6	4300	405	89.8	3221	Steam
7	470	187	42.8	2829.5	Steam
8	470	187	14	2829.5	Steam
9	14	52.548	47	2491.67	Steam
10	600	44	47	184.78	Liquid
11	450	27.6	3470	116.12	Liquid
12	430	37.4	3470	157.05	Liquid

Table 3.2. The Properties Present Of Natural Gas and Air at 100% Load.

Natural gas			
P (kPa)	T (°C)	q (m^3/hr)	GCV (kj/m^3)
40	25	6893	41957.152
Air			
P (kPa)	T (°C)	m· (ton/hr)	-
8.378	27	113	-

3.1 The Boiler

The type of boiler used in the thermal power plant is water tube boiler D-shape. The feed water flows through the tubes and is heated by the hot gases surrounding these tubes. These gases are produced by burning natural gas inside the furnace. The boiler design specifications are available in a Table 3.1.1. Major parts of this boiler are water wall tubes, steam drum, water (mud) drum, super heater, economizer and furnace.

Table 3.1.1 Boiler design specifications.

Parameter	Unit	Value
Type	-	water tube two drum (D-shape)
Steam generated	(ton/hr)	90
Steam temperature	(°C)	410
Steam pressure	(kPa)	4370
Feed water temperature	(°C)	138
Feed water pressure	(kPa)	6500
Efficiency of boiler	%	87

3.2 The Turbine

Steam turbine is one of the most important components of the power plant. It is a rotating mechanical device that produces mechanical work by converting thermal energy contained in the superheated steam to kinetic energy. This mechanical work rotates the shaft connected to the generator to produce electrical energy. The type of steam turbine installed in this power plant is a reaction turbine. It has two stages the high pressure and low pressure stage, where the each stage has one outlet at the end of the stage only.

The reaction turbine consists of a set of fixed and moving blades arranged in rows. Where steam flows over both blades (fixed and moving). The fixed blades act as a nozzle, so the pressure decreases and the velocity increases due to the expansion, then the kinetic energy increases, and a force is generated opposite to the direction of the steam flow so that the moving blades move in a reversal direction to the steam then the rotor rotates. This process is called a reaction according to Newton's third law, but during the moving blade decreases velocity and pressure. When steam exits from the moving blades in the first stage, it is directed from the fixed blades to enter the moving blades in the second stage, in this way the steam path continues in the turbine [6]. The turbine design specifications are presented in the Table 3.2.1.

Table 3.2.1. Turbine design specifications.

Parameter	Unit	Value
Type	-	extraction condensing steam turbine (Reaction)
No of stages	(N)	2 stages
Main steam temperature	(°C)	410
Main steam pressure	(kPa)	4370
Main steam flow	(ton/hr)	90
Extraction steam pressure	(bar)	4.3
Extraction steam temperature	(°C)	182
Exhaust steam pressure	(kPa)	15
Exhaust steam temperature	(°C)	53.97
Feed water enthalpy	(kJ/kg)	584.25376
Electric output of generator	(MW)	14.77
Turbine heat rate	(kJ/ kWh)	16119.165432
steam turbine generator efficiency	(%)	22.323
Isentropic efficiency	(%)	72.12

3.3 The condenser

The type of condenser installed in this plant is an indirect condenser type. Where it is knows as a heat exchanger tubes and water shell. Heat is transferred from steam to cooling water without mixing them with each other (indirectly), to convert exhaust steam to liquid state. At a pressure less than atmospheric pressure. Its main parts are inlet box of water, outlet box of water, tubes of water, shell is a cylindrical and closed at both ends, made of cast iron, tube sheet whose function is to install water tubes, hot well is installed at bottom of shell to ensure that the fluid transferred to the pump is liquid water. This part is not insulated in order to lose its heat to the atmosphere to obtain water is state a sub cooled, and there are air pipes installed at top the condenser that connect with ejector nozzle and ruptured disc that opens when the condenser pressure exceeds atmospheric pressure to balance them[6]. The condenser design specifications are available in a Table 3.3.1.

Table 3.3.1 Condenser design specifications.

Parameter	Unit	Value
Type	-	Indirect contact (surface condenser)
Number of water pass	(N)	2
Number of tubes	(Pieces)	3238
Cooling surface	(m^2)	793
Cool water inlet temperature	(°C)	28
Cool water outlet temperature	(°C)	39
Cool water velocity	(m/s)	1.8
Cool water rate	(ton/hr)	3145
Temperature of steam	(°C)	53.97
Condenser efficiency	(%)	42.36

3.4 Forced draft fan (FD)

It is a centrifugal fan that is installed near the boiler to supply the amount of air (oxygen) required for combustion to occur where the air pressure inside the boiler is higher than the atmospheric pressure, which operated by electric motor. The draft means that there is a difference between the pressure inside the furnace in the boiler and the atmospheric pressure [7]. The forced draft fan design specifications and present values are available in a Table 3.4.1.

Table 3.4.1. Forced draft fan (FD) design specifications.

Parameter	Unit	Design value
No of fans	(N)	1
flow	(ton/hr)	126
Density of air	(kg/m^3)	1.68
Total Static Pressure head	(mmWC)	869.57
Rotation speed	(rpm)	980
Motor input power	(kW)	235
Motor efficiency	(%)	92
Efficiency of fan	(%)	82.2

3.5 Boiler feed pumps (BFPs)

The main component in the power plant through which the Rankine cycle begins to operate, it supplies the boiler with the working fluid (water) in the required conditions. It is necessary that these pumps operate with a very high capacity and reliability, because any damage that occurs to them leads to a defect in the generation of steam. There are three horizontal centrifugal pump multistage (seven stages) in order to provide adequate of pressure and head, that work by electric motor. With regard to the boiler feed pumps design specifications and present value are available in a Table3.5.1.

Table 3.5.1 Boiler feed pumps (BFPs) design specifications.

Parameter	Unit	Design value
Water flow rate	(m^3/hr)	90.54
Total head ($H_d - H_{su}$)	(m)	640
Density of water	(kg/m^3)	939
Input kW of motor	(kw)	234
Motor efficiency	(%)	87
Number of stage	(Stage)	7
Numbers of pumps	-	3
Pump speed	(rpm)	2935
Discharge pressure	(kpa)	6500
Suction pressure	(kpa)	380
Hydraulic power	(kw)	148.3
Combined efficiency	(%)	63.4
Pump efficiency	(%)	72.9
Specific power consumption	(kwh/m^3)	2.6

3.6 Condensate extraction pump (CEP)

This type of pump is used to extract the water resulting from the condensation of steam in the condenser and the return of hot water. This power plant has single stage vertical condensate extraction pump. The main functions of this pump are extract water and transfer it to the deaerator through the polishing unit without an obvious increase in pressure. The condensate extraction pump design specifications and present values are presented in a Table 3.6.1.

Table3.6.1 Condensate extraction pump (CEP) design specifications.

3.7.Deaerator

Parameter	Unit	Design value
Water flow rate	(m^3/hr)	76.53
Total head $(H_d - H_{su})$	(m)	156
Density of water	(kg/m^3)	988.57
Input kW of motor	(kw)	43
Motor efficiency	(%)	92
Number of stage	(Stage)	1
Numbers of pumps	-	1
Pump speed	(rpm)	2147
Discharge pressure	(kpa)	1400
Suction pressure	(kpa)	570
Hydraulic power	(kw)	32.2
Combined efficiency	(%)	74.8
Pump efficiency	(%)	81.3
Specific power consumption	(kwh/m^3)	0.56

The objective of Deaerator are remove the dissolved gases (oxygen and carbon dioxide) and the gases that are not dissolved in the water, to prevent the occurrence of oxides on the walls of pipes and metal parts due to the presence of oxygen in the water and reduce the occurrence of corrosion due to carbonic acid resulting from the reaction of carbon dioxide with water. The type of deaerating device is the tray type, which consists of a vertical cylinder that includes the deaeration process and is mounted on a large horizontal cylinder as a feed water storage tank.

4. Theoretical Analysis

This section shows all the equations and calculations used to conduct the energy audit of the power plant according to the American Society of Mechanical Engineers (ASME). With the progress of time, this ASME has developed many standardized and consistent methods called performance test codes (PTC) to audit and test all the major parts in a power plant that could be a major cause of energy loss.

4.1. The Boiler

Based on ASME (PTC4- 1998), the direct method (input and output method) was adopted to evaluate the performance of the boiler. The formula of the direct method is:

$$\eta = \frac{\text{Energy output}}{\text{Energy input}} * 100\%$$

Or $$\eta = \frac{Q_g * (h_6 - h_5)}{q * GCV} * 100\%$$

4.2 The Turbine

Based on ASME (PTC 6 -1996), the turbine performance evaluate through:

- Heat rate, where it is the ratio between the heat entering the cycle and the electrical power produced by the generator, which shows how much heat energy is needed to generate 1 kWh of electricity. The heat rate inversely proportional to the efficiency of the turbine cycle. It is expressed mathematically as:

$$\text{Heat rate} = \frac{\text{Heat input to the cycle}}{\text{Gross Generator Output}}$$

$$\text{Or Heat rate} = \frac{Q_g * (h_6 - h_5)}{\text{Gross Generator Output}}$$

- Turbine cycle efficiency which is defined as efficiency of steam turbine generator is expressed as:

$$\eta = \frac{860}{\text{Turbine Heat Rate}} * 100\%$$

- The isentropic efficiency of steam turbine is imposing that the flow during turbine is isentropic to produce isentropic work, and then it defined the deviation actual work from isentropic work. Defined as:

$$\eta_s = \frac{\text{actual turbine work}}{\text{isentropic turbine work}}$$

Or $$\eta_s = \frac{W_a}{W_s} = \frac{h_6 - h_{9a}}{h_6 - h_{9s}} * 100\%$$

4.3 The Condenser

The thermal efficiency of the condenser represents the ratio between the actual temperature rise of the cooling water and the maximum possible temperature rise. . To estimate this efficiency, the convenient standard according to ASME is PTC12.2 – 1998. It is expressed as follows:

$$\eta_{cond} = \frac{T_{12} - T_{11}}{T_9 - T_{11}} * 100\%$$

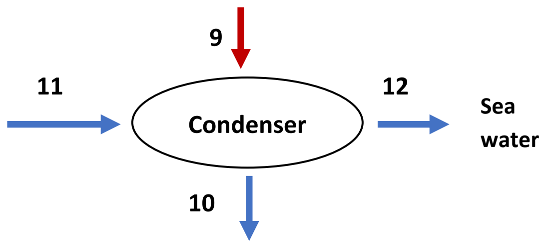

Fig 4.3.1 Schematic diagram of condenser.

4.4 Centrifugal Pumps (BFPs and CEP)

The present data needed to perform the energy audit for the performance of these pumps are shown in Tables (4.4.1 and 4.4.2) . The standard required to calculate the performance of centrifugal pumps is PTC8.2 – 1990. As follows:

$$\text{Hydraulic power (kW)} = \frac{m^{\cdot} \times (H_d - H_{su}) * \rho * g}{1000}$$

$$\text{Combined efficiency} = \frac{Hydraulic\ power}{Input\ kW\ of\ motor} * 100\%$$

$$\text{Pump efficiency} = \frac{Combined\ efficiency}{Motor\ efficiency} * 100\%$$

The formula for calculating the specific power consumption of pumps is as follows:

$$\text{Spec} = \frac{\text{Input motor kw}}{\text{Flow rate}}$$

Table 4.4.1 Present data of boiler feed pumps (BFPs).

Parameter	Unit	value
Water flow rate	(m^3/hr)	90.24
Total head $(H_d - H_{su})$	(m)	632
Density of water	(kg/m^3)	936
Input kW of motor	(kw)	247.8
Motor efficiency	(%)	86%
Discharge pressure	(kpa)	6000
Suction pressure	(kpa)	330

Table 4.4.2 Present data of Condensate extraction pump (CEP).

Parameter	Unit	value
Water flow rate	(m^3/hr)	76.23
Total head $(H_d - H_{su})$	(m)	152
Density of water	(kg/m^3)	987.51
Input kW of motor	(kw)	45
Motor efficiency	(%)	89
Discharge pressure	(kpa)	1200
Suction pressure	(kpa)	400

4.5. Forced draft fan (FD)

The performance of Forced draft fan has been evaluated, by the ASME (PTC 11-1984). The present data related to conducting an energy audit to forced draft fan is available in table (3.14.5.12) as follows:

$$\text{Fan air (kW)} = \frac{\text{Fan air flow} * \text{total head} * g}{3600 * \text{density of air}}$$

$$\text{FD fan efficiency} = \frac{\text{Fan air}}{\text{motor input power} * \text{motor efficiency}} * 100\%$$

Table4.5.1 Present data of FD fan.

Parameter	Unit	value
Suction pressure	mmWC	-6.68
discharge Pressure	mmWC	854.32
Total Static Pressure	mmWC	861
flow	ton/hor	117
motor input power	kW	240
Motor efficiency	%	90
Density of air	(kg/m^3)	1.62

4.6 Deaerator

The deaerator performance has been calculated by the terminal temperature difference (TTD), which is the difference between the saturation temperature (T_{sa}) of the interrupting pressure of steam flowing from the first stage of steam turbine and the temperature of the water leaving it (T_o).Through the ASME, the standard that shows deaerator performance is PTC 12.3 -1997. The terminal temperature difference is as follows:

$$\text{TTD} = T_{sa} - T_o$$

4.7. The overall and cycle efficiency of power plant

$$\eta_{overall} = \frac{\text{Generator output}}{q * \text{GCV}} * 100\%$$

$$\eta_{cycle} = \frac{\text{Generator output}}{Q_g * (h_6 - h_5)} * 100\%$$

5. Results and discussion

The results showed a deviation in the performance of all components of the power plant for which the energy audit was conducted from the design performance as shown in Table 5.1 and Figure 5.2. With respect the cycle efficiency, the efficiency slightly decreased from 22.2 % to 21.7 %. The overall efficiency was 17.9 %, but the design efficiency was not available. The boiler efficiency was 82.1 % while the design efficiency was 87 %. The reasons that reduce the performance of the boiler are poor quality of feed water and fuel, increased heat loss by flue gases and blow down, also heat loss due to poor insulation (loss by convection and radiation), as well as controlling the quantity and quality of air flowing into the boiler.

Regarding turbine performance, attention was paid to turbine heat rate, turbine generator efficiency, and isentropic efficiency. The results showed that the values are the following: 16530.8 kJ/ kWh, 21.8 % and 69.8 % respectively. Against the design values 16119.2 kJ/ kWh, 22.3 % and 72.1 % respectively. Turbine heat rate which inversely proportional to the efficiency of the turbine increased by 411.6 kJ/ kWh over the design value, which led to a decrease in the turbine efficiency as shown in the Figure 3. Where the main factor in turbine efficiency is the temperature of the steam flow. After analyzing the data, it was observed that there was a decrease in the steam flow temperature by an average of 5 °C from the design temperature. It has been proven that the turbine heat rate increases by 0.5 % when the steam flow temperature decreases by 10 °C. Also, the turbine blades must be maintained regularly to ensure the integrity of the seals and deposits on the blades, where stress corrosion and imbalance occur due to salt and silicon deposition. As well as the occurrence of roughness to the surface of the blades. The performance of the turbine becomes worse in terms of heat rate by 1% when the surface roughness of the blades is 10 µm [8].

The performance of BFPs in terms of hydraulic power, combined efficiency and pump efficiency were 145.5 kW, 58.7 % and 68.3 % respectively. But the design values were 148.3 kW, 63.38 % and 72.9 % respectively. Also, there was an increase in the specific power consumption by 0.2 kWh/m^3. BFPs are worked at a water flow rate close to their design but there is a gap in total head and discharge pressure. Concerning the performance of the condensate extraction pump, the hydraulic power was 31.18 kW, the combined efficiency was 69.3 % and the pump efficiency was 77.854 %. Whereas the design values 32.2 kW, 74.8% and 81.3 % respectively. Although there is an increase in the specific energy consumption of 0.04 kWh/m^3, it is satisfactory. Continuous operation of the pump leads to increased surface roughness and mechanical losses related to seals and bearings. In addition to impeller-related defects.

The condenser efficiency was found to be 39.3 %, but the design efficiency was 42.4 %. There was a difference in the temperature of the cooling water when entering and exiting the condenser compared to the design. It is possible that the condenser tubes are not clean, and then sea water that used for cooling is dirty and not treated properly. The performance of the FD fan decreased, where its efficiency was 78.4 %, in contrast, and the design efficiency was 82.2 %. There is a decline in airflow by the FD fan versus the design value.

The indicator used for the performance of the deaerator was the terminal temperature difference (TTD). Through [6] it was found that TTD is an indicator of heat transfer in the deaerator, as the relationship between them is inverse. If the TTD value increases, the heat transfer decreases, which is a negative indicator of deaerator performance. After analyzing the results, it appeared that there was an increase in the value of TTD. Where it reached to 15°C, while the design value was10.8 °C as in the Figure 4. There was an increase in steam pressure by 40 kPa, which led to an increase in T_{sa}, and a decrease in the pressure of cold water entering by 170 kPa, accompanied by a decrease in water temperature, which affected the properties of the water leaving the deaerator. Also, the reasons for the decrease in performance are vent of deaerator head not open enough because of calcification which leads to back pressure in deaerator so the mass flow rate of inlet steam decrease, and level of deaerator tank not accurate which causes to increase mass of water in tank so the temperature of water decrease.

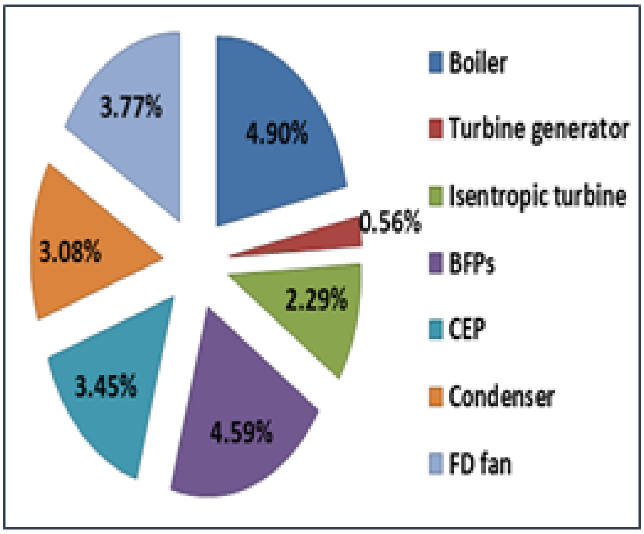

Fig 5.1 Percentages deviation of present efficiency from design efficiency of power plant components.

Table 5.1 Results of analyzed data.

Components	Parameter	Design	Present	Deviation
Boiler	Efficiency,(%)	87	82.1	-4.9
Turbine	Heat rate, (kJ/kWh)	16119.2	16530.8	411.6
	Generator efficiency, (%)	22.3	21.8	-0.5
	Isentropic efficiency, (%)	72.1	69.8	-2.3
Boiler feed pumps	Hydraulic power, (kW)	148.3	145.5	-2.8
	Combined efficiency, (%)	63.4	58.7	-4.7
	Pump efficiency, (%)	72.9	68.3	-4.6
	Specific power consumption, (kW.h/m^3)	2.6	2.8	0.2
Condensate extraction pump	Hydraulic power, (kW)	32.2	31.2	-1.0
	Combined efficiency, (%)	74.8	69.3	-5.5
	Pump efficiency, (%)	81.3	77.9	-3.4
	Specific power consumption, (kW.h/m^3)	0.56	0.6	0.04
Condenser	Efficiency, (%)	42.4	39.3	-3.1
FD fan	Efficiency, (%)	82.2	78.4	-3.8
Deaerator	TTD,(°C)	10.8	15.8	5.0
Cycle efficiency	Efficiency, (%)	22.2	21.7	-0.5
Overall efficiency	Efficiency, (%)	-	17.9	-

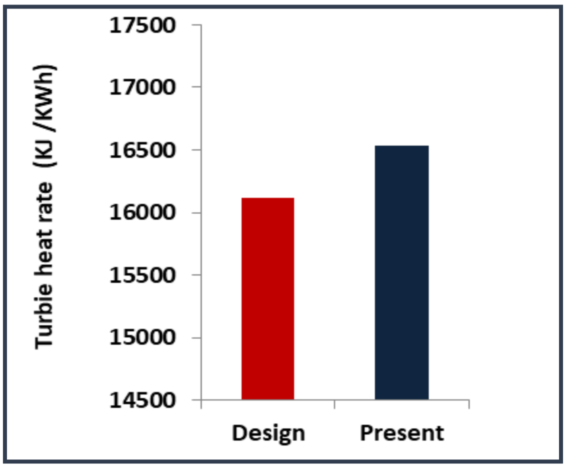

Fig 5.2 Heat rate of turbine in the case of design and the present.

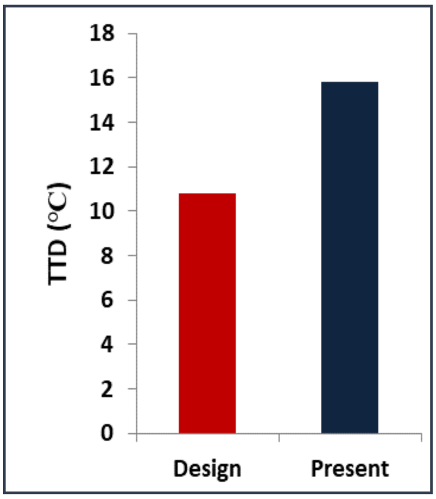

Fig 5.3 Terminal temperature difference (TTD) in°C for the deaerator in the case of design and the present.

After analyzing the results, there are many solutions that help to improve the performance of the power plant, as follows:

- Installation an air preheater at the boiler air inlet. It is a heat exchanger that heats the air entering the boiler by exchanging heat between the air and the hot flue gases, the temperature of which drops before it reaches the chimney. Preheating the air helps to speed up the combustion process inside the furnace so that an efficient combustion can be obtained. In addition, it reduces the cost of the steam generation process. When the air temperature rises by 4.4 °C, the boiler efficiency increases by 1 %. Also, each decrease in the temperature of the flue gases by 20 °C corresponds to an increase in boiler efficiency by 1% [9].
- To improve efficiency of the plant in general and the performance of the turbine in particular, it is necessary to increase the temperature of steam flowing to the turbine and reduce the temperature of the steam leaving the turbine, as possible. This is done by installing a feed water heater that reduces fuel consumption rate and heat rate, and thus reduces steam 65 generation cost and environmental influences[10]..Also, regular maintenance should be done to the turbine blades.
- Checking the quality of fuel (natural gas) and regulating the air flowing at the combustion chamber by controlling the quantity of excess air. To get a complete combustion and reduce emission.

6. Conclusions

The energy audit helps to know the performance of the power plant components and determine how much improvement they need based on the gap between present and design values that occur due to energy loss and also to learn about energy conservation methods. The thesis showed, by conducting an energy audit for this plant that after a period of time on the operation of plant, the performance of the main and auxiliary plant components decreases, so monitoring and periodic maintenance should be carried out to conserve energy and reduce the causes of loss. After analyzing the results, the main conclusions are as follows:

- The cycle efficiency slightly decreased from 22.2 % to 21.7 %, and the boiler efficiency was 82.1% while the design efficiency was 87 %.
- The turbine heat rate increased by 411.61 kJ/kWh more than the design value, which led to a decrease in turbine efficiency. Because of decrease in the steam flow temperature and occurrence of roughness on the surface of the blades.
- Regarding the performance of centrifugal pumps, the BFP efficiency decreased from 72.9 % to 68.3 % and the CEP efficiency reached 77.9% but the design value of 81.3 %.
- The condenser efficiency was found to be 39.3 %, but the design efficiency was 42.4 %.The FD fan had an efficiency of 78.4 %, whereas the design efficiency was 82.2 %.
- The results showed that the largest deviation between the present performances from the design performance of the power plant components that have been audited was the boiler by 4.9 %.
- When the boiler efficiency is increased by 2% then the natural gas saved at 2% equals 137.86 m^3/hr and the total natural gas saved per year equals 1207.7* 10^3 m^3. In addition to reducing the consumption of natural gas per year by 2415. 31*10^3 m^3 when applying the reheat system.

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