

ANALYSIS OF STEAM POWER PLANT AT KADUNA REFINING AND PETROCHEMICAL COMPANY FROM EXERGETIC PERSPECTIVE

ABSTRACT

This study presents the exergetic analysis of steam power plant at kaduna refining and petrochemical company limited. The aim of this research is to analyze the system components separately, and to identify and quantify the sites having the largest exergy losses. The performance of the plant was established and detailed break-up of exergy destruction of the considered plant has been presented. Computer softwares (ASPEN HYSYS, AUTOCAD and MICROSOFT EXCEL) were used for the simulation and calculation of properties that include stream enthalpy and entropy using the flow rate, working temperature and pressure of each equipment gotten from the company, at an assumed dead state temperature of 25°C at pressure of 101KPa. The analysis shows that The total exergy destroyed in the system is 209000kW, which makes about 18% of the total exergy entering the system The site having the largest exergy destruction was found to be in the boiler, having a 20000KW destroyed with a percentage performance loss of 36%, followed by the condenser, with 5880KW destroyed and percentage performance loss of 6%. Where as other equipments have total exergy efficiency of 2%. At end of this study, it can be suggested that the boilers should be properly lagged to avoid work loss.

Key Words – Steam power plant; Exergy; exergy destruction; temperature; pressure; enthalpy; entropy; energy.

Nomenclature

h Specific enthalpy (J/kg) s Specific entropy (J/kg.K)

I Exergy destruction rate (W) T Temperature (K)

$\dot{m}$ Mass flow rate (kg/s) $\dot{W}$ Work done rate or power done by the system (W)

P Pressure (Pa) $\dot{X}$ Total energy rate (W)

Q Heat transfer rate to the system (W)

ψ Specific exergy (J/kg)

Subscripts

e exit

i inlet

o Dead state condition

31

32 1. INTRODUCTION

33

34 Energy availability and optimization is paramount in determining the level of civilization of any generation.
35 Energy, being the ability or capacity to do work is a property of objects, transferable among them via
36 fundamental interactions, which can be transformed but not created or destroyed. The utilization of
37 energy is one of the most important signs showing the development stages of countries and living
38 standards of communities. Population increment, urbanization, industrializing, and technological
39 development result directly in increasing energy consumption. This rapidly growing trend brings about
40 the crucial environmental problems such as contamination and greenhouse effect. (Suryvanshee and
41 Chaube, 2013).

42

43 Energy can be electrical, mechanical, thermal solar or nuclear. The most used form of energy is the
44 electrical energy which is a clean form of energy.

45

46 Steam power plant is one of the major sources of electricity and most industries use it to generate
47 electricity needed to run their equipments. To assist in improving the efficiencies of power plants, their
48 thermodynamic characteristics and performances are usually investigated. Power plants are normally
49 examined using energy analysis which deals with the quantity of energy and asserts that energy cannot
50 be created or destroyed. The law merely serves as a necessary tool for the bookkeeping of energy during
51 a process and offers no challenges to the engineer.

52

53 The second law (Exergy analysis), however, deals with the quality of energy. It is concerned with the
54 degradation of energy during a process, the entropy generation, and the lost opportunities to do work;
55 and it offers plenty of room for improvement. The second law of thermodynamics has proved to be a
56 powerful tool in the optimization of complex thermodynamic systems (Ganapathy *et al.*, 2009; Makinde,
57 2008; Cengel and Boles, 2008) cited by Mborah and Gbadam(2010).

58

59 Exergy investigations of the energy use were first introduced in USA (Reistad ,1975) cited by Saidur et
60 al.,(2009). It has been carried out for various countries such as Ghana (Mborah and Gbadam, 2010),
61 Cyprus (Hamidi,2012), Malaysia (Saidur et al.,(2009) Egypt (Rashad and El Maihy2009), Nigeria (Nuhu et
62 al., 2012).

63 1.1 Background of study

64 Kaduna Refining and petrochemical company (KRPC) was established to efficiently and profitably
65 process crude oil into refined petroleum products and manufacture linear Alkyl benzene (LAB), tin and
66 drums for domestic consumption and export.

67 The company was designed and constructed by CHIYODA Chemical Engineering and Construction co.,
68 Limited Yokohama, Japan . It was commissioned in 1980 as NNPC Refinery Kaduna. Its initial capacity
69 was 100,000 Barrels per stream day [BPSD]. As the third Refinery in the country, it was established to
70 cope with the growing demand for petroleum products, especially in the Northern part of the country. The
71 Refinery was designed to process both Nigerian and imported crude oils into fuels and lube products
72 (Nuhu et al., 2012).

73 The Power Plant and Utility Department (PPUD) complex of KRPC is saddled with the responsibility of
74 providing safe, reliable and secured electric power, steam, water (cooling, drinking, service, and boiler
75 feed), Air (instrument, plant), nitrogen etc. required for continuous operation of the Process Plants and
76 other facilities in the Refineries and Petrochemical Plants.

77 The aim of this research is to analyze the system components separately, identify and quantify the sites
78 having the largest exergy losses and suggest solution to the problem.

2. MATERIAL AND METHODS

2.1 Plant Analysis

The steam power plant and its main units that are described here, are in line with the descriptions given by CHIYODA Chemical Engineering and Construction Co. Ltd (1981)

The plant has a total installed capacity of (56) MW, designated in unit No. 70 in Kaduna Refining and petrochemical Company Limited (KRPC) located at 16km, Kachia road Kaduna, Nigeria. It is housed with Power Plant and Utility Main Control Room. The power house consists of (2) deaerators, feed water pumps, (5) boilers, (4) steam turbines units (4x14) MW at 100% load and condensers. The power plant uses fuel oil.

Feed water from the demineralizer unit goes to the deaerators where dissolved oxygen is being separated to the atmosphere from a value of 1.00ppm to 0.007ppm thereby increasing the temperature from 45 °C at 1atm pressure to 125 °C. The deaerated water goes to the heater through the pumps, undergoing another heating process where the temperature is further raised to 140°C which flows to the boilers. The boilers heat up the water to steam at 412°C temperature and a pressure of 42.6kg/cm³g. This steam is used to drive the prime mover of the turbo generators and other turbine pumps and exhausts to a water cooled condenser where the low pressure section steam is condensed to condensate under vacuum at a pressure of 660mmHg and the condensate flows back to the demineralizer unit and the process is recycled.

2.1.1 Main units of the steam power plant

The main units of the steam power plant consists of the following:

1 Feed water unit:

This comprises of :

(a) deaerators, where dissolved oxygen and other gases are removed to prevent corrosion damage in the steam system and increase the feed water temperature as well.

The design parameters of the deaerator are listed below:

Capacity	: Total 640 t/h
Dissolved Oxygen content	: Inlet 1.0 ppm
	: Outlet 0.007 ppm
Feed water temperature	: Inlet 45°C
	: Outlet 125°C

(b) feed water pumps, which transport feed water to the boiler. The system consist of three High Pressure (HP) boiler feed water pumps, two Low Pressure (LP) boiler feed water pumps and one start up boiler feed water pump

Below is the list of design parameters of boiler feed water pump:

For high pressured feed water

Capacity	:(480 t/h for boilers and 120 t/h for process water)
Suction pressure	: 2.5 kg/cm ² g
Discharge pressure	: 60.5 kg/cm ² g
FW temperature	: 125°C

(c) Water heater

The deaerated water is pumped to the heater (70E01A,B) which acts as a preheater of the feed water. It has the following design conditions:

Capacity	: Total 480 t/h
Feed water temperature	: Inlet 125°C
	: Outlet 140°C

(2) Boiler unit

All boilers are designed to be operated in parallel with equal load distribution and with fuel gas, fuel oil or both fuels firing.

Design Conditions

Types of Boilers : IHI-FW SD, two drums and natural circulation type

The steam generators serve to produce the steam needed for the functioning of the process plant of the refinery and of the turbo-alternators; they burn a fuel (gas or fuel oil) which develops the heat necessary for vaporize the water.

The fundamental parts of steam generator are:

The Combustion Chamber: where the fuel is burnt

The Boiler: where the heat produced by the combustion is transmitted to the water, vaporizing it.

The Economizer: where the feed water is preheated and brought to the conditions close to vaporization.

The Superheater: where the steam produced by the boiler, exposed to the action of the heat, is dried and superheated

The Air-Preheated: where by exploiting the heat still possessed by flue gases which leave the boiler to preheat the air needed for combustion.

Boiler, economizer, superheater and preheater have a tubular structure i.e. are made up of a bank of tubes with the aim of increasing the extension of the metal surface through which the heat is transmitted by the hot gases.

Design conditions

Type of boiler	: IHI-FWSD, two drums and natural circulation type.
Number	: Five sets
Evaporation of each boiler at MCR	: 120,000Kg/hr
Two hour peak load	: 138,000Kg/hr
Maximum allowable working pressure	: 43, Kg/cm ² g
Maximum steam pressure at superheater outlet at MCR:	42.6 Kg/hr
Working steam temperature at superheater outlet	: 412°C
Feed water temperature at economizer inlet	: 140°C
Air temperature at forced draft fan inlet	: 35°C
Draft system	: Forced draft system
Firing system	: Gas and or oil firing system.

(3) Turbine unit (condensing type)

The unit is made up of four turbine generators which can each generate 14MW at an output voltage of 11KiloVolts (AV), AC, 50Hz. The turbines are impulse, extraction and condensing type driven by steam of pressure 42kg/cm², 412°C at a speed of 6362 revolution per minute (rpm).

Design conditions:

Type	: Three phase and synchronous type
The turbine speed	: 6,362rpm
The generator shaft speed	: 1,500rpm
Steam temperature / pressure	: 412°C /42.5kg/cm ²

2.2 Thermodynamic Analysis

The cycle of the power plant is depicted in figure 1. This consists of four main components (steam generator, turbine, condenser and pump). Additional components were added to enhance cycle performance and to improve efficiency.

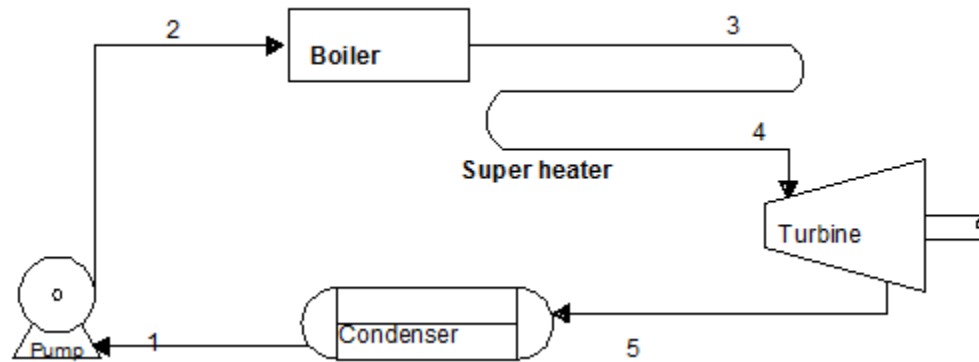


Figure 1: Schematic representation of the cycle

Exergy (also known as Work Potential) is defined as the maximum useful work that can be obtained from a system at a given state in a given environment; in other words, the most work you can get out of a system. Exergy destruction (I) is the measure of irreversibility that is the source of performance loss. Therefore, an exergy analysis assessing the magnitude of exergy destruction identifies the location, the magnitude and the source of thermodynamic inefficiencies in a thermal system. (Rashad and El Maihy, 2009). This can be represented mathematically as :

$$\Psi = (h - h_0) - T(s - s_0) \quad (2.1)$$

$$\dot{X} = \dot{m} \Psi_f = \dot{m} (h - h_0) - T(s - s_0) \quad (2.2)$$

$$I = \dot{X}_f - \dot{X}_o \quad (2.3)$$

The performance loss can be calculated as:

$$P_{\text{loss}} = \frac{I}{\dot{X}_{\text{in}}} \quad (2.4)$$

Mass and energy balance should be performed prior to exergy balance. This can ensure that all flows included are balance (Khalifa, 2009). Mass balance for steady state, steady flow process can be written as:

$$\sum \dot{m}_i = \sum \dot{m}_e \quad (2.5)$$

From first law of thermodynamic the energy balance can be written as:

$$\sum \dot{m}_i h_i = \sum \dot{m}_e h_e \quad (2.6)$$

According to Rashad and El Maihy(2009), the exergy destruction rate and the exergy efficiency for a steady state operation, and choosing each component as a control volume, are defined as shown in Table 1.

Table 1. Definitions of the exergy destruction rate and the exergy efficiency of the plant

	Exergy Destruction Rate
Pumps	$I_{\text{pump}} = \dot{X}_{\text{in}} - \dot{X}_{\text{out}} + \dot{W}_{\text{pump}}$
Heaters	$I_{\text{heater}} = \dot{X}_{\text{in}} - \dot{X}_{\text{out}}$
Turbine	$I_{\text{turbine}} = \dot{X}_{\text{in}} - \dot{X}_{\text{out}} - \dot{W}_{\text{el}}$
Condenser	$I_{\text{condenser}} = \dot{X}_{\text{in}} - \dot{X}_{\text{out}} + \dot{W}_f$

2.3 Assumptions

The following assumptions are adopted for the analysis:

1. The reference state for the steam and feed water is the water at a temperature of 25°C , pressure of 101KPa, enthalpy of -890000 kJ/kgmol-c and entropy of 894.6 kJ/kg-C.
2. All processes are steady-state and steady-flow with negligible potential and kinetic energy effect.

2.4 Modeling of the plant

Power plant consists mainly of deaeration section, pre-heating section (heat exchanger networks), boiler feed water pumps, boiler, superheaters, turbine, and condenser. The plant can be represented in block diagram as shown in Figure 2.

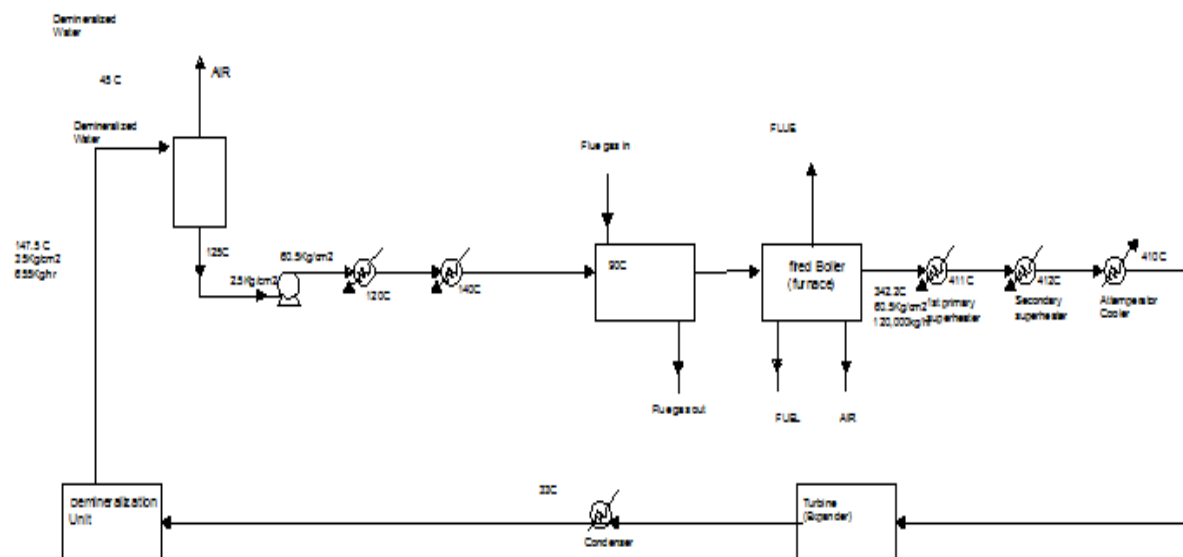


Figure 2 Block diagram of steam power plant

The simulation of the steam power plant was done using Aspen Hysis software version 8.0, with KRPC, PPU data log sheet (mass flow, temperature, and pressure readings) in line with the supervised work of Adam(2014). The temperature, pressure, molar flow rates, molar enthalpy, and molar entropy used for the exergy analysis was obtained from the simulation results..

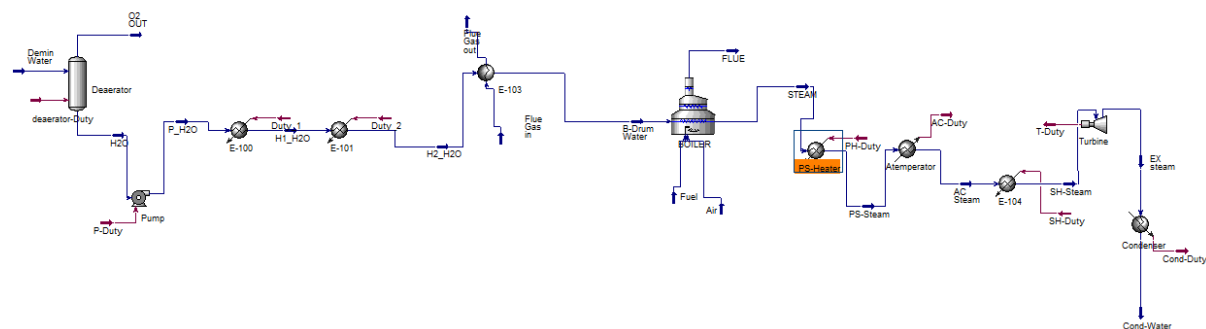


Figure 3 Aspen HYSYS V 8.0 Simulation of the steam power plant

3.0 RESULT AND DISCUSSION

3.1 RESULT.

The results of the analysis are tabulated in table 2, showing the stream exergy of each equipment.

Table 2 Analysis result of the unit.

Temperature: 25°C, Pressure: 101.3Kpa, Molar enthalpy:-890000kJ/Kgmol-c, Molar entropy: 894.6kJ/kg-C.

Components	Inlet streams KJ/h		Outlet streams KJ/h		Exergy(in) KJ/h	Exergy(out) KJ/h
Deaerator	5.69E+08	18971022.07	2.42E+08	3.45E+08	5.88E+08	5.87E+08
Pump	3.45E+08	630000	3.45E+08		3.46E+08	3.45E+08
Heater 1	3.45E+08		3.45E+08		3.45E+08	3.45E+08
Heater 2	3.45E+08		3.45E+08		3.45E+08	3.45E+08
Economizer	3.45E+08	8.86E+08	3.62E+08	8.69E+08	1.23E+09	1.23E+09
Boiler	3.62E+08	8.78E+08	7.27E+08	3.68E+08	8.86E+08	1.97E+09
Pri-S.H	3.68E+08	2349677	3.70E+08		3.70E+08	1.25E+09
Atemp.	3.70E+08		3.70E+08		3.70E+08	3.70E+08
Sec-S.H	3.70E+08		3.70E+08		3.70E+08	3.70E+08
TURBINE	3.70E+08		3.62E+08		3.70E+08	3.62E+08
Condenser	3.62E+08		3.41E+08		3.62E+08	3.41E+08

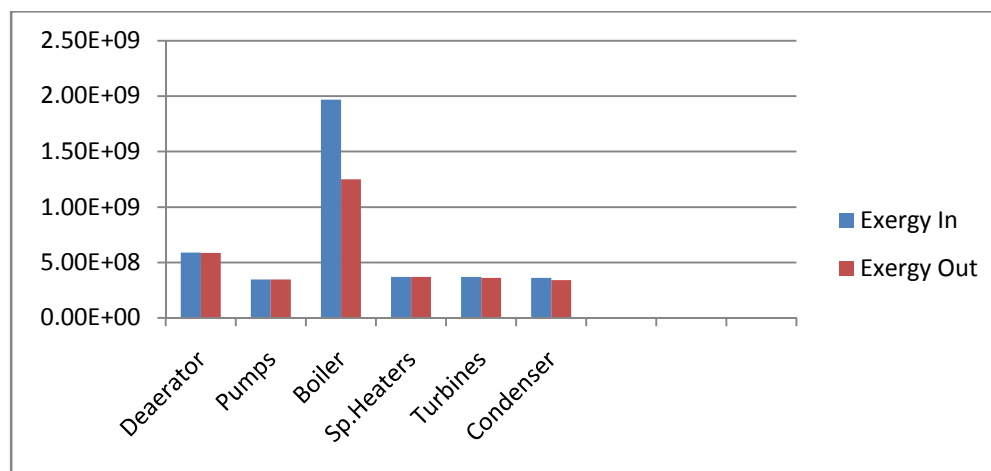


Figure 4 Exergy analysis of major equipment.

Table 3 Exergy destructed and percentage performance loss

Equipment	Exergy In KW	Exergy Out KW	Irrevers. KW	Perc.Loss %
Deaerator	1.65E+05	1.64E+05	2.72E+02	0.164848
Pump	9.68E+04	9.66E+04	1.76E+02	0.181818
Boiler	5.51E+05	3.51E+05	2.00E+05	36.29764
Pri-S.H	1.04E+05	1.39E+05	9.79E+01	0.094135
TURBINE	1.39E+05	1.02E+05	2.24E+03	1.611511
Condenser	1.02E+05	9.55E+04	5.88E+03	5.770363
Total	1.16E+06	9.48E+05	2.10E+05	18.1135

3.2 DISCUSSION

From figure 4, the inlet and outlet exergies were presented and it can be seen that the boiler has the largest inlet as well as outlet exergy, where as the heaters have the lowest exergy both inlet and outlet giving rise to low exergy destructed.

Table 3 shows the Exergy in KW, the destructed values as well as the percentage performance loss of the major equipments. The total exergy destroyed in the system is 209MW and can be seen that the boiler has the largest exergy destruction with a percentage performance loss of 36.3% , it counts alone for about 95% of the plant loss. This could be due to improper lagging of the boiler. The primary super heater has the least percentage performance loss of 0.09%. The turbine and the condenser have exergy destruction of 2240KW and 5880KW respectively.

4.0 CONCLUSIONS

In this study, an exergy analysis of PPU of KRPC has been presented. In the considered PPU, the maximum exergy destructed was found in the boilers where 36.3% of the input exergy was destructed to the environment. Next to it was the exergy destructed in the condensers where 5880KW of exergy was destructed which represent 5.77% of the input exergy, followed by the turbine having 1.61% and less than 1% for all other components.

From the research it can be suggested that the boilers should be properly lagged to avoid energy leak. The exergy analysis should be done periodically for each unit of the plant as a performance test; this will be helpful for maintenance and replacement decisions. The effect of varying the reference environment state on the exergy analysis is highly recommended for the next phase of study.

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