

EXERGY DESTRUCTION AND OPTIMIZATION OF INDUSTRIAL BOILER AT BPCL

¹Abin Babu, ²Abuthahir K.A., ³Rohith P.M., ⁴Rahul Unnikrishnan

^{1,2,3}Post Graduate Student, Universal Engineering College, Thrissur, kerala, India

²Assistant Professor, Universal Engineering College, Thrissur, kerala, India

Abstract: Economizer is an integral part of a boiler. It recovers some of the waste heat of hot flue gases going to chimney and thus helps in improving the boiler efficiency. The failure in the economizer tubes affects the performance of the boiler and hence its efficiency. The cause of failure may associated with water side corrosion, fire side corrosion over hearing , etc. Sulphuric acid dew point corrosion has been a quite common and important defect occurring in boilers running on fuel oils. The cause of sulphuric acid corrosion is found out and is rectified by giving suggestions. This project was carried out at BPCL Cochin refinery in order to find out the root cause of failure of utility boiler economizer tubes. Sulphuric acid corrosion was found to be the main reason for the failure of tubes. Remedial methods were recommended and the efficiency improvement using economizer was also calculated. The efficiency before and after failure are calculated.

Keywords: Economizer, waste heat, flue gas, dew point corrosion.

I. INTRODUCTION

Steam is required at BPCL Refinery for various applications such as heating medium, motive ore in turbines, in ejectors, as tripping medium in process and atomizing agent for liquid fuel in furnaces. Requirement of steam is met from dedicated utility boilers, CO boilers, Heat recovery steam generators and waste heat steam generators. UB is one of the high capacity utility boilers in power generating and steam utility station in BPCL-KR. It delivers steam at a pressure of 53 kg/cm² at 374°C. Steam flow rate is 105 metric ton per hour.

Studies of energy and exergy analyses for power generation systems are of scientific interest and also essential for the efficient utilization of energy resources. For this reason, the exergy analysis has drawn much attention by scientists and system designers in recent years. Some devoted their studies to component exergy analyses and efficiency improvement. Dincer *et al.*^[10] discussed that exergy appears to be a key concept, since it is a linkage between the physical and engineering world and the surrounding environment, and expresses the true efficiency of engineering systems, which makes it a useful concept to find improvements. The expression for energy (η) and exergy (ψ) efficiencies for the principal type of processes considered in the present study are based on the following definitions

$$\eta = \frac{\text{energy in products}}{\text{total energy input}}$$

$$\psi = \frac{\text{exergy in products}}{\text{total exergy input}}$$

Kanoglu *et al.*^[16] reported that an exergy analysis is usually aimed to determine the maximum performance of the system and/or identify the sites of exergy destruction. Identifying the main sites of exergy destruction, causes of destruction, true

magnitude of destructions, shows the direction for potential improvements for the system and components, it also reported the relation between energy and exergy, exergy and the environment, energy and sustainable development, and energy policy making in details. So from the above discussions and literatures it is obvious that analysis of exergy is crucial for energy planning, resource optimization and global environmental, regional, and national pollution reduction.

Datta *et al.* It is important to note that exergy destructions are due to irreversibilities in the turbine, pump and condenser. The primary way of keeping the exergy destruction in a combustion process within a reasonable limit is to reduce the irreversibility in heat conduction through proper control of physical processes and chemical reactions resulting in a high value of flame temperature but lower values of temperature gradients within the system. The optimum operating condition in this context can be determined from the parametric studies on combustion irreversibilities with operating parameters in different types of flames. The most efficient performance is achieved when the exergy loss in the process is the minimum. These can be done by optimizing heat exchangers, fins, thermal insulation and combustion process. Rashad *et al.*^[9] Conducted an energy and exergy analysis of Shobra El-Khima power plant in Cairo, Egypt is presented. The primary objectives of this paper are to analyze the system components separately and to identify and quantify the sites having largest energy and exergy losses at different loads. Sarang *et al.*^[7] Here the aim of this paper is to find out amount and source of irreversibility generated in boiler of 35 TPH boiler in 6 MW captive power plant so that any process in the system that having largest energy destruction can be identified that help designer to re-design the system components. Here the project is to carry out energetic and exergetic performance analyses, at the design conditions, for the existing coal and gas-fired thermal power plants in order to identify the needed improvement. For performing this aim, they summarized thermodynamic models for the considered power plants on the basis of mass, energy and exergy balance equations. The thermodynamic model simulation results are compared and based on the analysis the requirements for performance improvements were evaluated. Osueke *et al.*^[5] This research deals with Energy and Exergy analysis of steam power plant in Nigeria. The main aim this paper is to identify areas where energy losses are occurring and develop a model that will ensure efficient and effective improvement in a thermal power station. This was accomplished by conducting energy analysis of the overall plant and determination of the efficiencies and energy losses of all the major parts on the power plant in light of experimental data collected from Sapele power plant in Nigeria. At the beginning, areas where energy losses are being experienced in the plant were pinpointed. It was deduced that energy losses occurred fundamentally in the boiler where 105KW was lost to the surrounding while just 15.7 KW was lost from the condenser system. The rate proportion of the exergy destruction was discovered to be greatest in the boiler system (105.9%) trailed by the turbine (86.53%), and after that the condenser (62.5%). Moreover, the exergy efficiency of the power plant was 11.003% for boiler, 30.315% for turbine and 59.8% for condenser.

II. METHODOLOGY

The framework for the methodology of this study was classified into two major categories as shown in Fig.1. These include determination of operational variables and performance variables of steam boilers [19]. Then found out the critical component having highest exergy loss. Then the modifications were given.

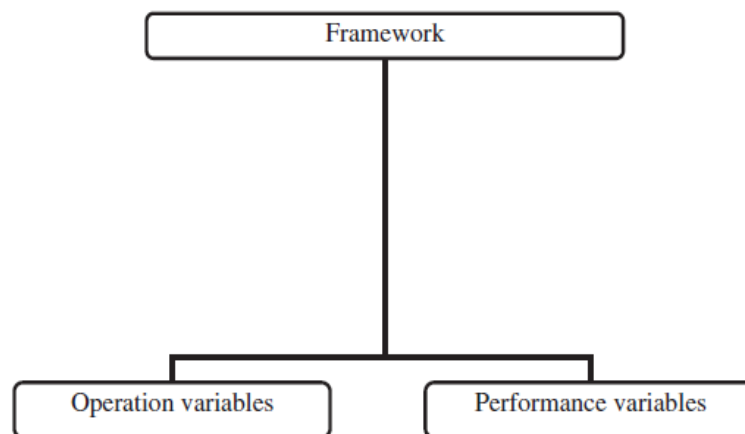


Fig.1 Methodological framework

Operation Variables

These are parameters concerned with the functioning of the boilers. They indicate measurable (direct operational variables) and computable (indirect operational variables) properties which describe the generic thermodynamic activities taking place in a boiler. Overviews of these properties are outlined in Fig.2.

(I) MEASURABLE PROPERTIES

These are usually monitored and recorded directly from in built or attached boiler measurement indicators over a specified period of time. An inventory data collection process is normally used to comprehensively collect boiler information.

(ii) COMPUTABLE PROPERTIES

These properties are those that are not usually read directly from indicators, and as such would have to be computed through the use of appropriate energy tables or charts; thermodynamic formulae, such as conservation of mass and energy, and exergy balance equations.

Standard Environmental Reference State

Typical reference state temperature, T_0 and pressure, P_0 of 25 °C (298.15 K) and 101.323 kPa and zero values for the height z_0 and velocity v_0 of the earth surface are used for most analyses. This often involves the use of the natural environment-subsystem model described in Table 1 for the following condensed phases at T_0 and P_0 : Water (H_2O), Limestone ($CaCO_3$), and Gypsum ($CaSO_4 \cdot 2H_2O$). A unique variance between exergy and other thermodynamic properties is that the reference state for exergy is determined by the surroundings.

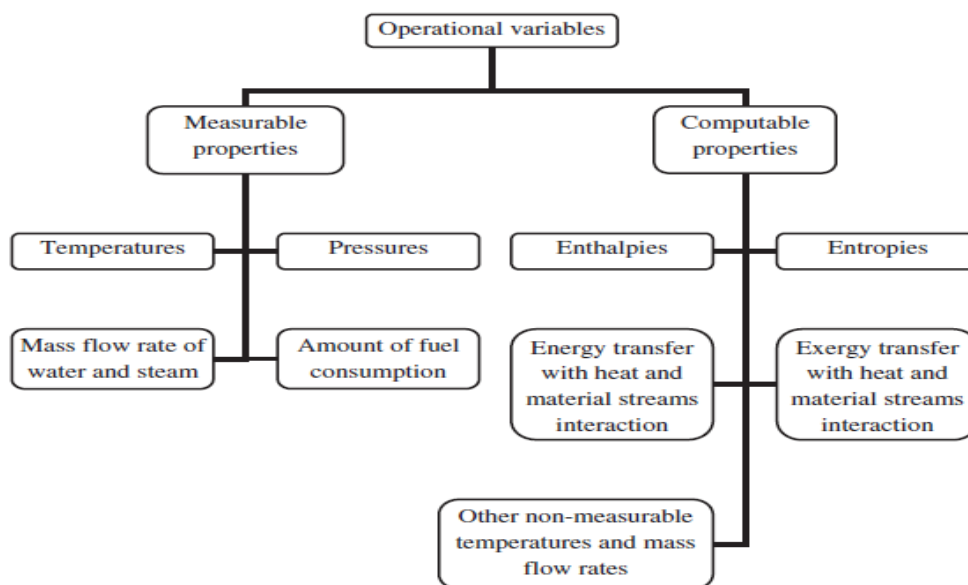


Fig.2. Operational variable framework.

Table 1: Composition of a reference-environmental model

Air constituents	Mole fraction
N ₂	0.7565
O ₂	0.2035
H ₂ O	0.0303
Ar	0.0091
CO ₂	0.0003
H ₂	0.0001

Physical And Chemical Exergies

The total exergy transfer associated with material streams for a flow process comprises of the physical and chemical exergies[20,21]. The flow exergy of a substance is the theoretically obtainable work when the substance is brought into total equilibrium with the local environment. It can be split into chemical exergy and thermo mechanical (physical) flow exergy which is represented by [20]:

$$\epsilon = \epsilon^{ph} + \epsilon^{ch} \tag{1}$$

The specific physical flow exergy is given by

$$\epsilon^{ph} = h - h_0 - T_0(s - s_0) \tag{2}$$

Where, $h_0 = h(T_0, P_0)$ = enthalpy at reference state; $s_0 = s(T_0, P_0)$ = entropy at reference state; and T_0, P_0 = reference state temperature and pressure.

The Schematic Of The Boiler Plants

The schematic diagrams shown in Fig. 3 can be used to analyse the mass flow rate, energy and exergy balances and exergetic efficiencies of boilers [1]. The schematic diagrams of the combustion and heat exchanging units, respectively, shown in Fig. 3 may be separately analyzed to establish the mass flow rate of the material streams in the boilers. Combustion of fuel takes place in the combustion unit of the boiler, while the heat carried by the hot flue gas from the combustion unit is used to transform liquid water to steam in the heat exchanging unit.

Thermodynamic And Exergetic Analysis Determination

An exergetic analysis involves mass, energy and exergy balance for each plant unit. The mass, energy and exergy balances at steady state for the material flows in a boiler system with negligible potential and kinetic energy changes can be expressed, respectively, by Eqs. (3.3)-(3.5)[1].

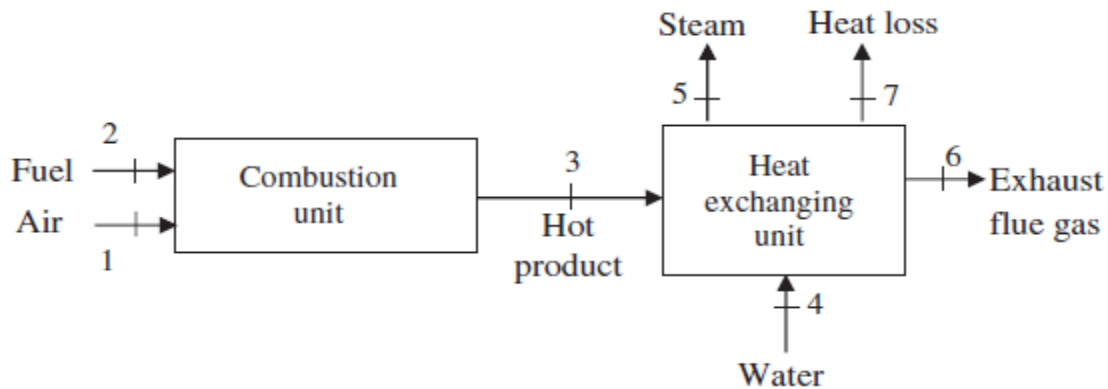


Fig. 3: Schematic diagram of combustion and heat exchanging units in a boiler

Mass Balance of Material Streams

Appropriate mass and energy balance as stated by equation (13) and equation (14) may be applied to a boiler system with the evaporation ratio and air fuel ratio and may be used to determine masses of substances of all material streams in the boiler, such as; air (m_a), fuel (m_f), hot products (m_p), feed water (m_w), steam (m_s) and exhaust flue gases (m_g), respectively.

$$m_a + m_f = m_p \tag{3}$$

$$m_p = m_g \tag{4}$$

$$m_w = m_s \tag{5}$$

Temperature, Enthalpy and Entropy of Feed Water and Steam

The enthalpy and entropy of feed water may be determined at a saturation temperature of 100°C or at other appropriate temperatures, while the saturation temperatures corresponding to their respective steam pressures may be obtained from saturated water and steam tables [3]. Superheated temperatures at the given steam pressures may be used where applicable for superheated steams.

Combustion Temperatures

From an energy balance analysis of a combustion process, the combustion temperature can be calculated as follows [22],

$$T_c = T_a + \frac{h_r}{[c_p \times (1 + AAF)]} \quad (6)$$

where, T_c =combustion temperature; T_a = temperature of the combustion air before entering the burner; h_r =heat of reaction (h_r =LHV, if exhaust gas streams is above 60°C, [31] c_p =specific heat of fuel at ambient temperature of products of combustion.

Enthalpy and Entropy of Inlet Air

The enthalpy and entropy of inlet air can be evaluated for inlet air temperature, T_a for different boilers operation from the ideal gas properties of air tables [3]. These are denoted by h_a and s_a .

Enthalpy of Hot Products

Applying the energy balance to the combustion unit shown in Fig. 3.3 and assuming heat was transferred adiabatically[1], the enthalpy of the hot products can be determined using

$$m_f h_f + m_a h_a = m_p h_p \quad (7)$$

Temperature of Exhaust Flue Gases

The exhaust flue gas temperature is given from the direct measurement as 172 °C.

Enthalpy of Exhaust Flue Gases

Enthalpies of most gases used in combustion calculations can be curve-fitted by the simple second order equation :

$$h = aT^2 + bT + c \quad (8)$$

where h =enthalpy in Btu/lb; T = temperature in degrees, °F; a , b and c are coefficients with the following values for T (0-500 °F) given as: $a = 1.683 \times 10^{-5}$; $b = 0.233$; and $c = -18.03$.

Eq. (8) can be used to evaluate the enthalpy of the exhaust flue gases. It should be noted that the constants a , b and c are stated only for the quoted temperature range given in °F.

Entropy of Combustion Fuel Gases

The entropy generated from a source can be expressed as follows [3]:

$$S_{gen} = \frac{q_{source}}{T_{source}} \quad (9)$$

where, S_{gen} = entropy generated from the source, kJ/kg K; q_{source} = heat transfer from a source to a sink, kJ/kg; and T_{source} = temperature of the source, K.

A study of the thermodynamic processes taking place between the combustion and the heat exchanging units shows that: the entropy generated from the combustion unit is the entropy of the combustion fuel gas, s_f , the heat transfer from the combustion unit to the heat exchanging unit equals the energy value of the hot products, h_p and the temperature of the source is the combustion fuel temperature, T_f .

$$S_f = \frac{h_p}{T_f} \quad (10)$$

The entropy of the combustion fuel gases can be determined by Eq. (10).

Entropy of Hot Products

The entropy of the hot products can be determined by Eq. (11), where T_p is the temperature of the hot products [3],

$$S_p = \frac{h_p}{T_p} \quad (11)$$

Entropy of Exhaust Flue Gases

The change in entropy of an ideal gas can be expressed by [3],

$$S_g = s_a + c_p \ln \frac{T_g}{T_a} \tag{12}$$

Chemical Exergy of Fuels

The chemical exergy of fuel is given by the eq.(13) it is given by T.J kottas [25],

$$\epsilon_{fuel}^{ch} = 1.06 \times LHV \tag{13}$$

Chemical Exergy of Air

The chemical exergy of atmospheric air can be determined from Eq. (3.15) and the mole fractions of the elements in a standard environment presented in Table 3.2 with their respective chemical exergies given by Ertesvag [24].

$$\epsilon^{ch} = \frac{e^{ch}}{M} \tag{14}$$

$$e_{air}^{ch} = \sum (n_i e_{xi}^{ch})_{air} \tag{15}$$

The molar mass of air is given as $M_{air} = 28.96$ kg/kmol [3].

Analysis of the Combustion Unit

Applying the energy balance Eq. (16) to the combustion unit as shown in Fig. 3, the energy input in the combustion unit can be determined by

$$E_{in} = m_f h_f + m_a h_a \tag{16}$$

Where h_f and h_a are the specific enthalpies of combustion fuel and air. The combustion efficiency of an adiabatic combustor is usually equal to unity [1], and may be represented by the first law efficiency given by

$$T_g = T_c - \frac{HHV \times \eta_{comb}}{(1 + AAF) C_p} \tag{17}$$

Where, HHV= high or gross heating value of fuel.

Applying the exergy balance equation to the combustion unit, the exergy destruction in the combustion unit can be determined by [1,2,14]

$$\dot{I}_c = \dot{m}_a [\epsilon_{a_1}^{ph} + \epsilon_{a_1}^{ch}] - \dot{m}_p \epsilon_p^{ph} + \dot{m}_f [\epsilon_f^{ph} + \epsilon_f^{ch}] \tag{18}$$

Where, $\epsilon_{a_1}^{ph}$, $\epsilon_{p_3}^{ph}$ are the specific physical exergies of air at inlet and that of hot products at exit, while $\epsilon_{a_1}^{ch}$, ϵ_f^{ch} are the specific chemical exergies of air and the combustion flue at inlet, and $\epsilon_{f_3}^{ch}$ is the specific chemical exergy of the combustion fuel at exit. The exergy efficiency of the combustion unit can be determined by,

$$\psi_c = \frac{\dot{m}_p \epsilon_p^{ph}}{\dot{m}_f [\epsilon_f^{ph} + \epsilon_f^{ch}]} \tag{19}$$

Table 2. Chemical exergies of components in air

Components	Chemical exergies
Nitrogen, N ₂	0.6681
Oxygen, O ₂	3.9305
Carbon dioxide, CO ₂	19.610
Argon, Ar	11.640
Water, H ₂ O (g)	9.474
Water, H ₂ O (liq)	0.8842
Hydrogen, H ₂	236.098
Carbon monoxide, CO	274.87

Analysis of the Heat Exchanging Unit

Performing an energy balance on the heat exchanging unit as shown in Fig. 3.3, and noting that $\dot{m}_p = \dot{m}_g$ and $\dot{m}_w = \dot{m}_s$ the heat loss can be determined by[3]

$$Q_{H(loss)} = \dot{m}_p(h_p - h_g) - \dot{m}_w(h_{w.out} - h_{w.in}) \tag{20}$$

where, h_g , h_s and h_w are the specific enthalpies of exhaust flue gas, steam and feed water.

The first law efficiency of the heat exchanging unit can be determined by [1]

$$\eta_H = \frac{\dot{m}_w(h_{t.out} - h_{t.in})}{\dot{m}_p(h_p - h_g)} \tag{21}$$

The exergy destruction in the heat exchanging unit can be determined by,eq. (22)

$$\dot{I}_H = \dot{m}_p \varepsilon_p^{ph} + \dot{m}_w [\varepsilon_{w.in}^{ph} + \varepsilon_{w.in}^{ch}] - \dot{m}_s [\varepsilon_{s.out}^{ph} + \varepsilon_{s.out}^{ch}] - \dot{m}_g [\varepsilon_g^{ph} + \varepsilon_g^{ch}]$$

The exergy efficiency of the heat exchanging unit can be determined by

$$\psi_H = \frac{\dot{m}_s [\varepsilon_{s.out}^{ph} + \varepsilon_{s.out}^{ch}] - \dot{m}_w [\varepsilon_{w.in}^{ph} + \varepsilon_{w.in}^{ch}]}{\dot{m}_p \varepsilon_p^{ph} - \dot{m}_g [\varepsilon_g^{ph} + \varepsilon_g^{ch}]} \tag{23}$$

Analysis of the Entire Heater

The overall boiler energy efficiency can be determined by [1]

$$\eta_H = \frac{\dot{m}_s(h_{s.out} - h_{s.in})}{\dot{m}_f h_f} \tag{24}$$

The overall exergy destruction of the heater was obtained as the sum of exergy destruction in the combustion chamber and the heat exchanger. That is,

$$\dot{I}_B = \dot{I}_C + \dot{I}_H \tag{25}$$

The overall heater exergy efficiency can be determined as the rational efficiency of the entire boiler which is the ratio of the desired exergy output, $\dot{E}_{desired\ output}$ to the exergy used, \dot{E}_{used} . The $\dot{E}_{desired\ output}$ was the net exergy for the heating of thermic fluid and \dot{E}_{used} is the net energy input into the system. The exergy efficiency of the boiler can therefore be determined by

$$\psi_B = \frac{\dot{E}_{desired\ output}}{\dot{E}_{used}} \tag{26}$$

$$\psi_B = \frac{\dot{m}_s [\varepsilon_{s.out}^{ph} + \varepsilon_{s.out}^{ch}] - \dot{m}_s [\varepsilon_{s.in}^{ph} + \varepsilon_{s.in}^{ch}]}{\dot{m}_f [\varepsilon_f^{ph} + \varepsilon_f^{ch}]} \tag{27}$$

III. CONCLUSION

Table 3: Exergic efficiencies of combustor unit

Exergetic equation	Exergetic values and efficiencies
$\eta_{comb} = \frac{(T_C - T_g) \times (1 + AAF) C_p}{HHV}$	87.05%
$I_c = \dot{m}_a [(h_a - T_{oSa}) + \varepsilon_a^{ch}] - \dot{m}_p [h_f - T_{oS_p}] + \dot{m}_f [(h_f - T_{oS_f}) + \varepsilon_f^{ch}]$	68107.56 KJ/s
$\Psi_c = \frac{\dot{m}_p (h_p - T_{oS_p})}{\dot{m}_f [(h_f - T_{oS_p}) + \varepsilon_f^{ch}]}$	43.66%

Table 4: secondary superheater

Exergetic equation	Exergetic values and efficiencies
$\eta_{SSH} = \frac{\dot{m}_s (h_{s.out} - h_{s.in})}{\dot{m}_p (h_{g.in} - h_{g.out})}$	63.85 %

$I_{SSH} = m_p[(h_{g-in} - T_0 s_{g-in} - h_{g-out} + T_0 s_{g-out}) - m_s[h_{s-in} - h_{s-out} - T_0(s_{s-in} - s_{s-out})]$	6168.88 KJ/s
$\Psi_{SSH} = \frac{m_s[h_{s-in} - h_{s-out} - T_0(s_{s-in} - s_{s-out})]}{m_p[(h_{g-in} - T_0 s_{g-in} - h_{g-out} + T_0 s_{g-out})]}$	38.03 %

Table 5: Primary superheater

Exergetic equation	Exergetic values and efficiencies
$\eta_{PSH} = \frac{m_s(h_{s-out} - h_{s-out})}{m_p(h_{g-in} - h_{g-out})}$	63.21 %
$\Psi_{PSH} = \frac{m_s[h_{s-in} - h_{s-out} - T_0(s_{s-in} - s_{s-out})]}{m_p[(h_{g-in} - T_0 s_{g-in} - h_{g-out} + T_0 s_{g-out})]}$	35.69 %

Table 6: Economizer

Exergetic equation	Exergetic values and efficiencies
$\eta_{ECO} = \frac{m_s(h_{s-out} - h_{s-out})}{m_p(h_{g-in} - h_{g-out})}$	73.42 %
$I_{ECO} = m_p[(h_{g-in} - T_0 s_{g-in} - h_{g-out} + T_0 s_{g-out}) - m_s[h_{s-in} - h_{s-out} - T_0(s_{s-in} - s_{s-out})]$	7415.4 KJ/s
$\Psi_{ECO} = \frac{m_s[h_{s-in} - h_{s-out} - T_0(s_{s-in} - s_{s-out})]}{m_p[(h_{g-in} - T_0 s_{g-in} - h_{g-out} + T_0 s_{g-out})]}$	34.01 %

Table 7: Exergetic efficiencies

Component	Exergetic efficiency
Combustor	$\Psi_{CO} = 44\%$
Secondary superheater	$\Psi_{SSH} = 38\%$
Primary superheater	$\Psi_{PSH} = 35.64\%$
Economizer	$\Psi_{ECO} = 34.01\%$

Table 8: Analysis of entire boiler

Mass flow rate of steam, m_s	27.79 Kg/s
Mass flow rate of fuel, m	2.79 Kg/s
Temperature out	447 °C
Temperature in	138 °C
Enthalpy of steam in	583.8 KJ/Kg
Enthalpy of steam out	330.6 KJ/Kg

The thinning and perforation in the economizer tubes are due to H₂SO₄ dew point corrosion during the initial start-up process. The relatively low temperature of feed water caused the lowering of the tube metal temperature and promoted the condensation of H₂SO₄.

REFERENCES

- [1] Saidur R, Ahamed JU, Masjuki HH. Energy, exergy and economic analysis of industrial boilers. Energy Policy 2010;38:2188-97.
- [2] Ohijeagbon IO, Jekayinfa SO, Waheed MA. Cumulative exergetic assessment of LPFO utilized steam boilers. Int.J. Exergy 2012;11(1):119-35.
- [3] Cengel YA, Boles MA. Thermodynamics: an engineering approach. 5th ed. McGraw Hill; 2006.
- [4] R. Mahamud, M.M.K. Khan, M.G. Rasul and M.G. Leinster Exergy Analysis and Efficiency Improvement of a Coal Fired Thermal Power Plant in Queensland

International Journal of Novel Research in Engineering and Science

 Vol. 3, Issue 2, pp: (1-9), Month: September 2016 - February 2017, Available at: www.noveltyjournals.com

- [5] Christian O. Osueke, Anthony O. Onokwai, Adeyinka O. Adeoye. Energy and exergy analysis of a 75mw steam power plant in sapele (nigeria), 2015.
- [6] A.H.Rana, J.R.Mehta. Energy and Exergy Analysis of Extraction of Back Pressure Steam Turbine. 2013.
- [7] Sarang j gulhane, Prof.Amit kumar Thakur. Exergy Analysis of Boiler In cogeneration Thermal Power Plant, 2013
- [8] A. Rashad and A. El Maihy. Energy and Exergy Analysis of a Steam Power Plant in Egypt, 2009
- [9] Dincer I, Hussain MM, Al-Zaharnah I. Energy and exergy use in the industrial sector of Saudi Arabia. Proc Inst Mech Eng Part A: J Power Energy 2003;217: 481-92. A02603 IMechE. [11] Ahamed JU, Madlool NA, Saidur R, Shahinuddin MI, Kamyar A, Masjuki HH. Assessment of energy and exergy efficiencies of a grate clinker cooling system through the optimization of its operational parameters. Energy 2012;46:664-74.
- [10] Frontina Petrakopoulou, George Tsatsaronis, Tatiana Morosuk, Anna Carassai. Conventional and advanced exergetic analyses applied to a combined cycle power plant, 2011
- [11] P. Regulagadda, I. Dincer, G.F. Naterer, (2010), "Exergy analysis of a thermal power plant with measured boiler and turbine losses", Applied Thermal Engineering 30, 970–976
- [12] Isam H. Aljundi, (2009), "Energy and exergy analysis of a steam power plant in Jordan", Applied Thermal Engineering 29, 324–328
- [13] S.C. Kaushik, V. Siva Reddy, S.K. Tyagi (2011), "Energy and exergy analyses of thermal power plants: A review", Renewable and Sustainable Energy Reviews 15, 1857–1872
- [14] kanoglu, M. Dincer, I. Rosen, MA, 2007. Understating energy and exergy efficiencies for improved energy management in a power plant. Energy policy 35, 3967-3975
- [15] Pathmasiri MMR, Attalage RA. Exergy analysis of steam boilers in Sri Lanka, Department of mechanical engineering, university of Moratuwa, [online]. Available: [http://www.energy.gov.lk/research/attachments/Exergy Analysis of Steam Boilers in Sri Lanka.pdf](http://www.energy.gov.lk/research/attachments/Exergy%20Analysis%20of%20Steam%20Boilers%20in%20Sri%20Lanka.pdf). [accessed 03.10.01].
- [16] Jayamaha, Lal. Energy efficient building systems, Hardbook, Europe. 2008.
- [17] Osemene KP. Evaluation of herbal medicines research and development outputs in Nigeria; 2008
- [18] Dincer I, Rosen MA. Exerfy, energy environment and sustainable development. London: Elsevier; 2007
- [19] Chemical exergy [online]. Available: [www.oocities.org/pldhr/lecture 7-5.ppt](http://www.oocities.org/pldhr/lecture%207-5.ppt).
- [20] He M, Zhang X, Zeng K, Gao K. A combined thermodynamic cycle used for waste heat recovery of internal combustion engine. Energy 2011;36:6821-9.
- [21] Kitto JB, Stultz SC. steam: its generation and use. 41st ed. Barberton, Ohio, USA: The Babcock Wilcox Company; 2005
- [22] Ertesvag IS. Sensitivity of the chemical exergy for atmospheric gases and gaseous fuels to variations in ambient conditions. energy conserv manage 2007;48;1983-95