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Full Length Paper

Development of a Software for Exergy Analysis of Carbon Monoxide Boiler

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Abstract

As a result of essential utilities of a carbon monoxide boiler, it is often difficult to embark on a manual method in analysing given parameter obtained from the plant. In order to minimize the effort and possible errors that may arise, the development of a software module that would effectively analyze the carbon monoxide boiler for performance evaluation is paramount. In this study, software was developed for analysing the exergy of carbon monoxide boiler. The boiler unit consists of the combustion chamber, boiler tube, economizer, super-heater, and air-preheater. In the development of the software, flowcharts and algorithm were developed. Visual basic.net programme tool was used as the programme language in coding the software. Data was collected from the external operator log sheet and panel operator log sheet of the boiler unit of the Power Plant and Utilities Department, Warri Refinery and Petrochemical Company, Ekpan-Warri, Nigeria. The software developed was verified through several test cases and the software was found to perform efficiently and correctly. An analysis was carried out using the software and the result shows that the super-heater has the highest exergetic efficiency (44.3%). However, the highest exergy destruction occurred at the combustion chamber (34869.7kJ/s).

Keywords: Boiler, Carbon Monoxide, Exergy, Software, Exergetic Efficiency, Exergy Destruction

INTRODUCTION

Energy availability and optimization is paramount in determining the level of civilization in any generation. Energy, being the ability or capacity to do work is a property of objects, transferable among them via fundamental interactions, which can be transformed but not created or destroyed. The utilization of energy is one of the most important signs showing the development stages of countries and living standards of communities. Besides, energy consumption and supply are important factors used for evaluating social Human Development Index Ranking (HDIR) and standard of living of any country [1-2]. Energy can be electrical, mechanical, chemical, thermal solar or nuclear. The most used form of energy is the electrical energy which is a clean form of energy. Studies of energy and exergy analyses for generation of power systems are of scientific interest and are highly needed for the efficient utilization of energy resources. For this reason, the exergy analysis has drawn much attention by researchers in recent years. Some devoted their studies to component exergy analyses [3-4] and improving its efficiency [5-6]. The exergy method of analysis is based on the second law of thermodynamics and the concept of irreversible production of entropy. The fundamentals of the exergy method were laid down by Carnot in 1824 and Clausius in 1865 [7-10]. The energy-related engineering systems are designed and their performance is evaluated primarily by using the energy balance deduced from the first law of thermodynamics. Engineers and scientists have been traditionally applying the first law of thermodynamics to calculate the enthalpy balances for more than a century to quantify the loss of efficiency in a process due to the loss of energy [11-12]. The exergy concept has gained considerable interest in the thermodynamic analysis of thermal processes and plant systems since it has been seen that the first law analysis has been insufficient from an energy performance stand point [13-15].

In recent years, exergy analysis has found increasingly acceptance as a useful tool in the design, assessment, optimization and improvement of energy systems. Determining exergy efficiencies for an overall system and/or the individual components making up the system constitutes a major part of exergy analysis. A comprehensive analysis of a thermodynamic system includes both energy and exergy analyses in order to obtain a more complete picture of system behaviour. To assist in improving the efficiencies of power plants, their thermodynamic characteristics and performances are usually investigated. Although, several works have been carried out on exergy and energy analysis of boiler and turbine but few attempts were made in developing software for evaluation of a boiler. Sarang [7] carried out a research work on exergy analysis of boiler in cogeneration thermal power plant. In his work, effective energy utilization and its management for minimizing irreversibility was made human to look for efficient energy consumption and conversion. He made an attempts to be find out amount and source of irreversibilities 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 which can help to re-design the system components. Krishan *et al.* [16] research on the performance and exergy analysis of the boiler. According to them, exergy analysis has sparked interest within the scientific community to require a more in-depth check up on the energy conversation devices and to develop new techniques to rise utilize the prevailing restricted resources. Exergy analysis gives entropy generation, irreversibility percentage exergy loss and second law efficiency. The exergy loss or irreversibility is maximum at the boiler. Thus, to know about actual flow of exergy in the cycle thermodynamic analysis based on second law is desirable. They simulated power plant boiler based on the measured operating data and the thermodynamic states of the plant components. They concluded that maximum exergy destruction occurs due to combustion process. Besides, exergy efficiency of boiler according to second law analysis and the best exergetic efficiency of the boiler is seen when bituminous coal is used. Aljundi [13] studied the exergy analysis of Al-Hussein power plant (396MW) in Jordan. The performance of the plant was estimated by a component wise modelling and a detailed break-up of energy and exergy losses for the considered plant has been presented. It was found that the exergy destruction rate of the boiler is dominant over all other irreversibility in the cycle. Besides, the exergy analysis provides the tool for a clear distinction between energy losses to the environment and internal irreversibility in the process. Therefore, there is need to develop a software for efficiently analysis of the boiler performance, thus this research work.

MATERIALS AND METHODS

2.1 Data Collection

The data used for this research work were collected from the external operator log sheet and panel operator log sheet of the gas turbine unit, Power Plant and Utilities Department, Warri Refinery and Petrochemical Company, Ekpan-Warri. The data collected contains the temperature of air, flue gases and exhaust gases, pressure of air, flue gases, exhaust gases, and mass flow rate of fuel, air and exhaust gases and this data spans from January to June 2016.

2.2 Specification of Boiler’s Streams

Table 1 shows the boiler feed-water and Table 2 shows the fuel oil parameter. Table 3 shows the combustion air parameter and the **s**team parameter is shown in Table 4.

Table 1: Boiler Feed-Water Parameter

Pressure (bar)	Temperature (^{0}C)	Enthalpy (kJ/kg)	Entropy (kJ/kgk)
67.10	152	640.83	1.8621
67.50	153	645.16	1.8722
67.40	153	645.16	1.8722
67.70	153	645.16	1.8722
67.90	153	645.16	1.8722
67.60	153	645.16	1.8722
67.80	150	623.18	1.8417
67.50	141	593.41	1.7494
67.00	142	597.71	1.7597
67.10	144	606.31	1.7803
67.10	146	614.92	1.8009
67.20	148	623.55	1.8213
67.20	152	640.83	1.8621
67.50	153	645.16	1.8722
67.60	152	640.83	1.8621
67.50	151	636.50	1.8519

Table 2: Fuel Oil Parameter

Pressure (bar)	Temperature (^{0}C)	Flow Rate (kg/s)	Entropy of kJ/kg.k)
6.78	114	0.978	2.1230
644	119	0.978	2.2034
6.55	115	1.000	2.2010
6.25	199	1.050	2.2034
6.76	120	0.990	2.2034
6.43	117	0.980	2.2000
6.15	115	0.950	2.2010
6.27	117	0.961	2.2000
6.78	118	0.990	2.2100
6.48	117	0.970	2.2100
6.49	116	0.899	2.1080
6.31	117	0.900	2.2000
6.50	115	0.900	2.2034
6.18	120	1.050	2.2034
6.32	118	1.050	2.2034
6.48	115	1.110	2.2000
617	118	1.080	2.2100
5.83	117	1.055	2.2000
6.06	155	1.020	2.2019
6.01	116	1.030	2.1980
6.03	117	0.980	2.2000
5.92	119	0.890	2.2034
6.42	115	0.899	2.2000
6.32	117	0.900	2.2000
6.30	118	0.930	2.2100

Table 3: Combustion Air Parameter

Pressure (bar)	Temperature (^{0}C)	Flow rate (kg/s)
0.0405	90.3	0.0212
0.0397	78.1	0.0213
0.0398	79.0	0.0212
0.0393	80.2	0.0211
0.0395	80.9	0.0211
0.0389	81.2	0.0211
0.0405	81.2	0.0211
0.0404	71.7	0.0214
0.0408	71.8	0.0214
0.0404	72.7	0.0214
0.0406	74.4	0.0213
0.0411	74.3	0.0213
0.0410	75.5	0.0213
0.0408	75.8	0.0211
0.0409	75.8	0.0211
0.0407	76.1	0.0216
0.0406	75.7	0.0211
0.0405	75.1	0.0217
0.047	74.3	0.0213
0.0407	77.2	0.0214
0.0401	76.6	0.0212
0.0398	76.7	0.0213
0.0401	76.6	0.0213
0.0401	76.6	0.0212
0.0399	76.9	0.0211
0.0401	76.8	0.0211
0.0403	76.4	0.0214
0.0403	76.1	0.0214
0.0405	75.9	0.0214

Table 4: Steam Parameter

Pressure (bar)	Temperature (^{0}C)
50.76	563
50.70	563
50.72	560
50.74	569
50.60	555
50.69	560
50.65	563
50.70	563
49.80	563
49.50	565
49.25	565
49.00	568
50.00	568
50.56	561
51.28	561
51.00	552
50.98	552
50.65	553
50.60	552
49.80	558
49.25	560
50.60	560
50.60	560
50.72	563
50.88	561
50.88	560
50.55	560
50.55	560
50.60	560

2.3 Data Analysis

The data presented in Table 1-Table 4 were analysed to determine the exergy and exergy efficiency of the combustion chamber and gas turbine, exergy destruction and exergy destruction efficiency of the air compressor, combustion chamber and gas turbine. Also the overall plant exergy, overall plant exergy efficiency, total exergy destroyed and overall plant exergy destruction efficiency using Equation (1) to Equation (37) for the period under consideration.

Combustion Chamber

The energy input to the combustor is given by Equation (1)

$$E_{in} = \left[\dot{m}\, fhf + \dot{m}\, aha \right] \quad \text{..... (1)}$$

The energy output in the combustor for reactant was calculated from Equation (2)

$$\dot{E}^{cc}_{out} \Rightarrow \Delta Q$$

$$\sum_R \left(n\bar{\bar{M}}\, hf \right) = \left(n_c \times m_c \times hf_c\right) + \left(n_H \times m_H \times hf_H\right)$$

$$+\left(n_S \times m_S \times hf_S\right) + \left(n_O \times m_O \times hf_O\right) + \left(n_N \times m_N \times hf_N\right) \quad \text{.... (2)}$$

The energy output in the combustor for product is given by Equation (3)

$$\sum_P \left(n\bar{\bar{M}}\, hf \right) = \left(n_{co2} \times m_{co2} \times hf_{co2}\right) + \left(n_{Ho2} \times m_{Ho2} \times hf_{Ho2}\right) + \left(n_{So2} \times m_{So2} \times hf_{So2}\right)$$

$$+\left(n_{O2} \times m_{O2} \times hf_{O2}\right) \quad \text{..... (3)}$$

Hence,

$$\Delta Q = \sum_P \left(n\bar{\bar{M}}\, hf \right) - \sum_R \left(n\bar{\bar{M}}\, hf \right) \quad \text{..... (4)}$$

The rate of heat of combustion of fuel is given by Equation (5)

$$\Delta\dot{Q} = \dot{m}\, f\Delta Q \quad \text{... (5)}$$

From first law of thermal efficiency of combustor

$$\eta_i^{cc} = \frac{\dot{E}^{cc}_{out}}{\dot{E}^{cc}_{in}} = \frac{\Delta\dot{Q}}{\dot{E}^{cc}_{in}} \times \frac{100}{1} \quad \text{... (6)}$$

To determine the energy destruction in the combustor, the following assumptions were made;

- The combustor operates at a steady state $\left(\Delta\dot{M}_{cr}, \Delta E_{cr} = 0 \right)$
- No work interaction
- Kinetic and potential energies are negligible

The exergy into the combustor is given by Equation (7)

$$\dot{\varphi}^{cc}_{in} = \dot{m}\, f\left(hf - ToSf\right) + \dot{m}\, a\left(Ha - ToSa\right)$$

$$\dot{\varphi}^{cc}_{out} \Rightarrow \dot{m}\, p\left(hf - ToSf\right) \quad \text{..... .. (7)}$$

From second law of thermodynamics, efficiency of combustor will become,

$$\eta_{ii} = \frac{\varphi^{cc}_{out}}{\varphi^{cc}_{in}} \quad \text{............. (8)}$$

The energy destruction in the combustion chamber is given by Equation (9)

$$\dot{E}^{cc}_{d} = \dot{E}^{cc}_{in} - \dot{E}^{cc}_{out} \quad \text{............. (9)}$$

Boiler Tube

With the application of steady flow exergy, net exergy carried by flue gas into boiler is given by Equation (10)

$$\frac{\dot{E}^{Bt}_{in}}{\dot{m}\, f} = \Delta Q$$

$$\dot{E}^{Bt}_{in} = \dot{m}\, f\Delta Q = \Delta\dot{Q} \quad \text{........... (10)}$$

Also, the net exergy carried by fluid stream into boiler was calculated from Equation (11)

$$\dot{E}^{Bt}_{in} = \dot{m}\, w\left(h_{s,o} - h_{w,in}\right) \quad \text{.......... (11)}$$

From first law, the efficiency of boiler tube is given by Equation (12)

$$\eta_i = \frac{\dot{E}^{Bt}_{out}}{\dot{E}^{Bt}_{in}} \quad \text{........... (12)}$$

The net exergy carried into boiler by flue gas is given by Equation (13)

$$\dot{\varphi}^{Bt}_{in} = \left(h_{w,i} - h_o\right) - T_o\left(S_{wi} - S_o\right) \quad \text{............ (13)}$$

Also, the net exergy carried out of boiler by fluid stream is given by Equation (14)

$$\dot{\varphi}^{Bt}_{out} = \left(h_{s,oi} - h_o\right) - T_o\left(S_{s,o} - S_o\right) \quad \text{........... (14)}$$

From second law, the efficiency of boiler tube is given by Equation (15)

$$\eta_{ii} = \frac{\dot{\varphi}^{Bt}_{out}}{\dot{\varphi}^{Bt}_{in}} \quad \text{.......... (15)}$$

The exergy destruction in boiler tube is given by Equation (16)

$$\dot{E}_d^{Bt} = \dot{E}_{in}^{Bt} - \dot{\varphi}_{out}^{Bt}$$

.... (16)

Super Heater

The net exergy carried out by flue gas in super heater is given by Equation (17)

$$\dot{E}_{in}^{Sup} = \dot{m}\,g\left(h_{gi} - h_{go}\right)kJ/s$$

.... (17)

The net exergy carried out by stream in super heater is given by Equation (18)

$$\dot{E}_{out}^{Sup} = \dot{m}_{Sup}\left(h_{Sup,o} - h_{Sup,i}\right)kJ/s$$

.... (18)

From the first law, efficiency of super heater is given by Equation (19)

$$\eta_i = \frac{\dot{E}_{out}^{Sup}}{\dot{E}_{in}^{Sup}}$$

.... (19)

The net exergy carried out by flue gas in super heater is given by Equation (20)

$$\dot{\varphi}_{in}^{Sup} \Rightarrow \dot{m}\left\{\left(h_{gi} - ToS_{gi}\right) - \left(h_{go} - ToS_{go}\right)\right\}$$

.... (20)

The net exergy carried out by steam in super heater is given by Equation (21)

$$\dot{\varphi}_{out}^{Sup} \Rightarrow \dot{m}_{Sup}\left[\left(h_{Sup,o} - ToS_{Sup,o}\right) - \left(h_{Sup,i} - ToS_{Sup,i}\right)\right]$$

....(21)

$$\eta_{ii} = \frac{\varphi_{out}^{Sup}}{\varphi_{in}^{Sup}}$$

.... (22)

The exergy destruction in super heater is given by Equation (23)

$$\dot{E}_d^{Sup} = \dot{E}_{in}^{Sup} - \dot{\varphi}\,Sup$$

.... (23)

Economizer

The net exergy carried out by flue gas in economizer is given by Equation (24)

$$E_{in} = \dot{m}\,g\left(h_{gi} - h_{go}\right)kJ/s$$

.... (24)

The net exergy carried out by flue stream is given by Equation (25)

$$\dot{E}_{out}^{eco} = \dot{m}\,w\left(h_{eco,o} - heco,i\right)$$

.... (25)

From the first law, efficiency of economizer is given by Equation (26)

$$\eta_i = \frac{\dot{E}_{out}^{eco}}{\dot{E}_{in}^{eco}}$$

.... (26)

The net exergy carried out by flue gas in economizer is given by Equation (27)

$$\dot{\varphi}_{out}^{Sup} \Rightarrow \dot{m}_g\left[\left(h_{gi} - ToS_{gi}\right) - \left(h_{go} - ToS_{go}\right)\right]$$

......(27)

The net exergy carried out by fluid stream in economizer is given by Equation (28)

$$\dot{\varphi}_{out}^{eco} \Rightarrow \dot{m}_w\left[\left(hwo - To_{(swo)}\right) - \left(h_{wi} - To_{(swi)}\right)\right]$$

..... (28)

From second law, the efficiency was calculated from Equation (29)

$$\eta_{ii} = \frac{\varphi_{out}^{eco}}{\varphi_{in}^{eco}}$$

.... (29)

The exergy destruction in economizer is given by Equation (30)

$$\dot{E}_d^{eco} = \dot{E}_{in}^{eco} - \dot{\varphi}_{out}^{eco}$$

.... (30)

Air Pre-Heater

The net exergy carried out by flue gas in air-preheater is given by Equation (31)

$$E_{in}^{Air} \Rightarrow \dot{m}_g\left(h_{gi} - h_{go}\right)kJ/s = \dot{m}\left[cp_g \Delta T\right]$$

..... (31)

The net exergy carried out by air stream in air-preheater is given by Equation (32)

$$E_{out}^{Ap} = \dot{m}_a\left(h_{ao} - h_{ai}\right)$$

.... (32)

The first law of efficiency of air pre-heater is given by Equation (33)

$$\eta_i = \frac{\dot{E}_{out}^{Ap}}{\dot{E}_{in}^{Ap}}$$

.... (33)

The net exergy carried out by flue gas in air-preheater is given by Equation (34)

$$\dot{\varphi}_{in}^{Ap} \Rightarrow \dot{m}\left[\left(h_{gi} - ToS_{gi}\right) - \left(h_{go} - ToS_{go}\right)\right]$$

.... (34)

The net exergy carried out by hot air stream in air preheater is given by Equation (35)

$$\dot{\varphi}_{out}^{Ap} \Rightarrow \dot{m}_a\left[\left(h_{ao} - ToS_{ao}\right) - \left(h_{ai} - ToS_{ai}\right)\right]$$

.... (35)

From second law, efficiency of air pre-heater is calculated from Equation (36)

$$\eta_{ii} = \frac{\dot{\varphi}_{out}^{Ap}}{\dot{\varphi}_{in}^{Ap}}$$

.... (36)

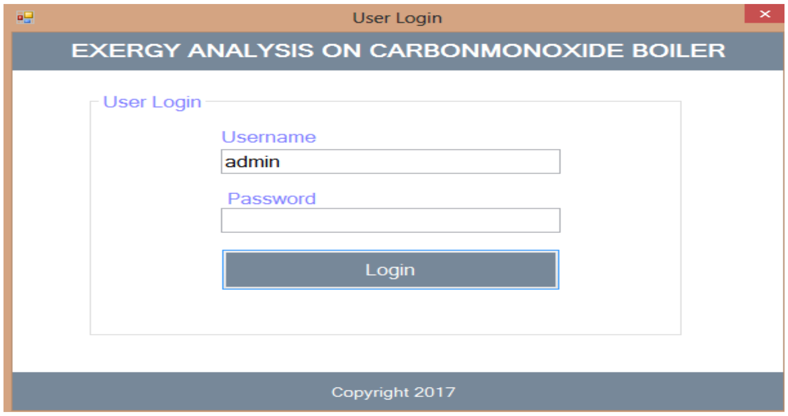
= 42.3%

The exergy destruction of air-preheater is given by Equation (37)

$$E_d^{Ap} = \dot{E}_{in}^{Ap} - \varphi_{out}^{Ap} \tag{37}$$

2.4 Development of Software

The software used was developed using Visual basic.net and the data saved into test file. This was done to enable the system support good interface facilities with external programs and systems. The SWEACB was designed in a way that the interaction with the system is through series of input and dialogue forms. These forms however, allow the user to select the required parameters from a predefined list. The user enters only the values of the parameters and the system automatically generates the required result in the user interface. It also provides a user friendly interface consisting of menu bars and buttons to help user during data input to the system and facilitates to explicitly display results. In addition, background colours, font sizes and font colours are carefully chosen to enhance the visual effect of the interfaces. The software developed is achieved by the following steps; Development of flowchart, development of algorithm and coding of the software. A flowchart was developed to analyse, documents and also to manage the process of the program in various fields. An algorithm is a specific set of instruction for carrying out a procedure of solving problem, usually with the requirement that the procedure terminate at some point. The algorithm developed for the analysis for the carbon monoxide boiler was based on the flowchart and consists of the sequence of the operational result. The software was coded using the appropriate programming tool such as Visual basic.net. This is because of the unique characteristics of the programming language such as flexibility and ease of use through the adaption of modular approach. The screenshots of the various interfaces of the developed software are presented in Fig.1 to Fig. 9.



Username: admin

Fig 1: Screenshot of User Login

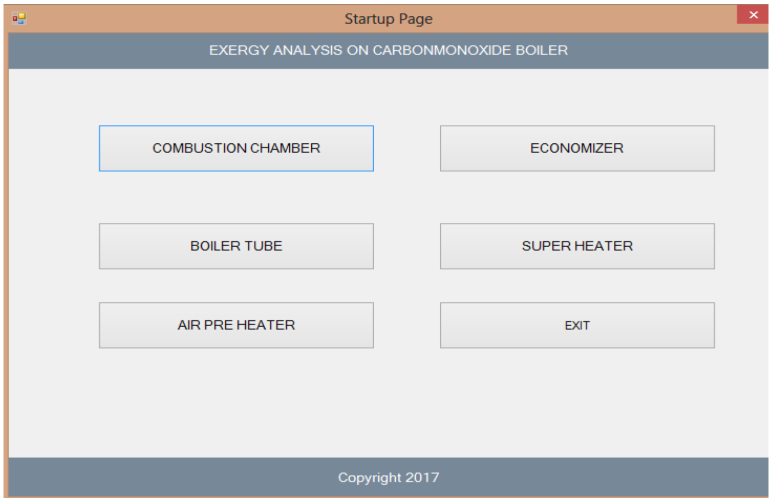
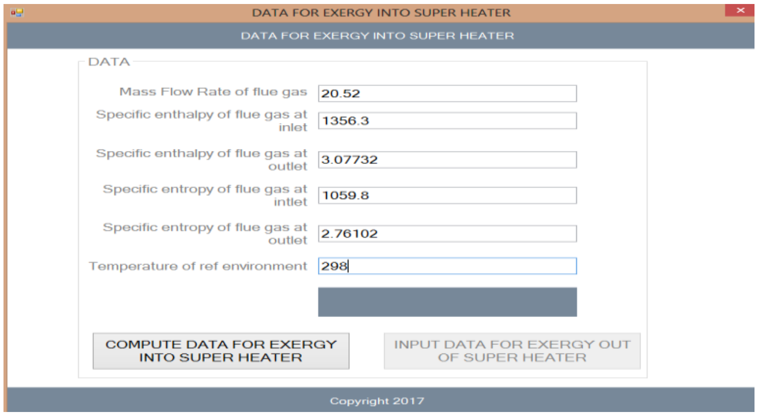
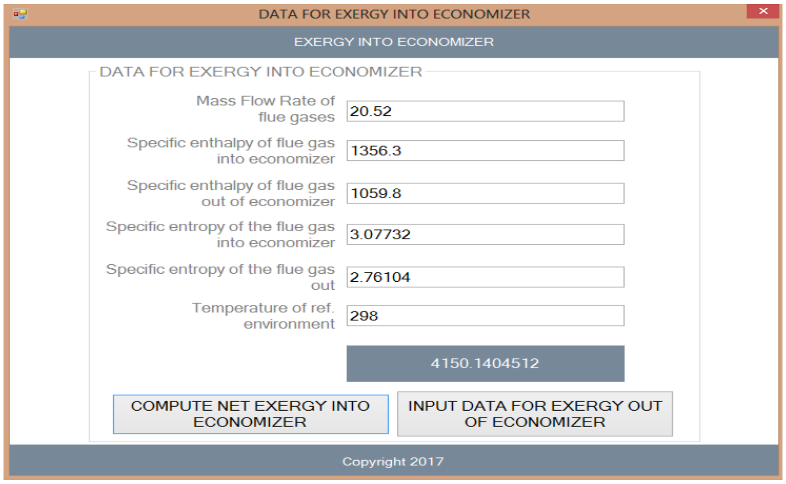


Fig 2: Screenshot of Main menu



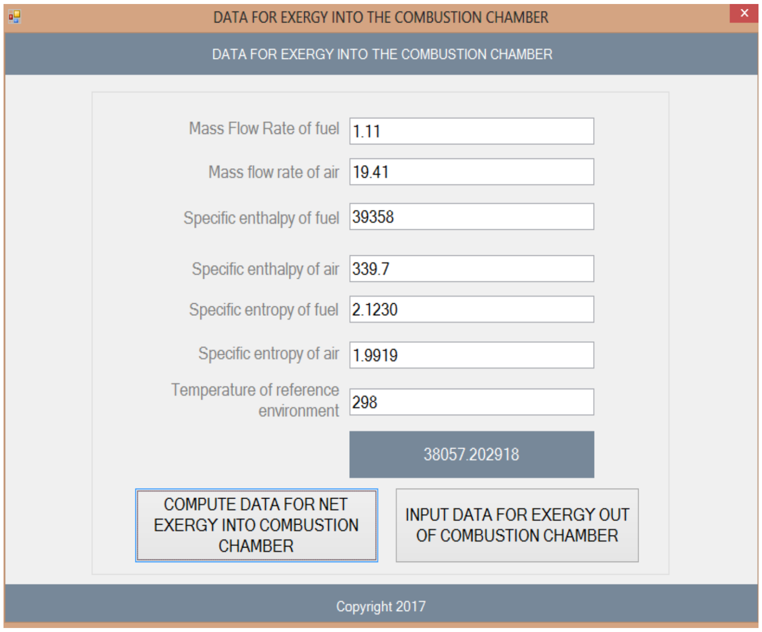
Mass Flow Rate of flue gas: 20.52
Specific enthalpy of flue gas at inlet: 1356.3
Specific enthalpy of flue gas at outlet: 3.07732
Specific entropy of flue gas at intlet: 1059.8
Specific entropy of flue gas at outlet: 2.76102
Temperature of ref environment: 298

Fig 3: Screenshot for Super Heater Exergy Computation Interface



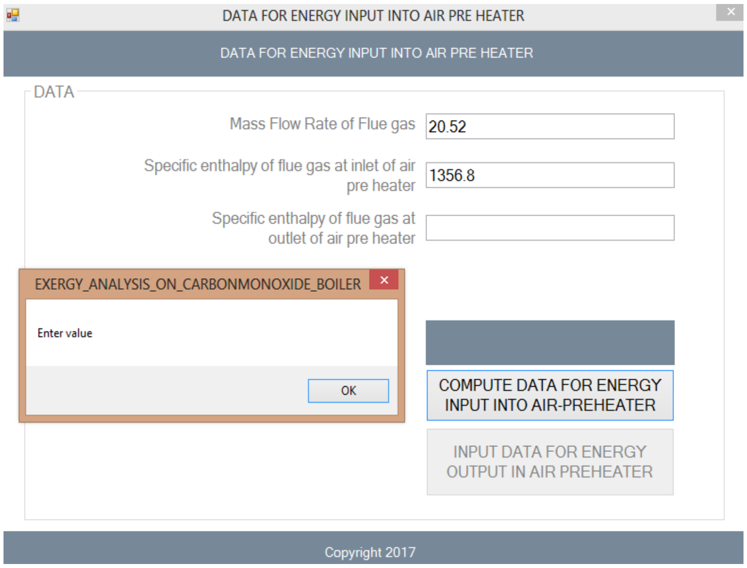
Mass Flow Rate of flue gases: 20.52
Specific enthalpy of flue gas into economizer: 1356.3
Specific enthalpy of flue gas out of economizer: 1059.8
Specific entropy of the flue gas into economizer: 3.07732
Specific entropy of the flue gas out: 2.76104
Temperature of ref. environment: 298
4150.1404512

Fig 4: Screenshot for Economizer Exergy Computation Interface



Mass Flow Rate of fuel: 1.11
Mass flow rate of air: 19.41
Specific enthalpy of fuel: 39358
Specific enthalpy of air: 339.7
Specific entropy of fuel: 2.1230
Specific entropy of air: 1.9919
Temperature of reference environment: 298
38057.202918

Fig 5: Screenshot for Combustion Chamber Exergy Computation Interface



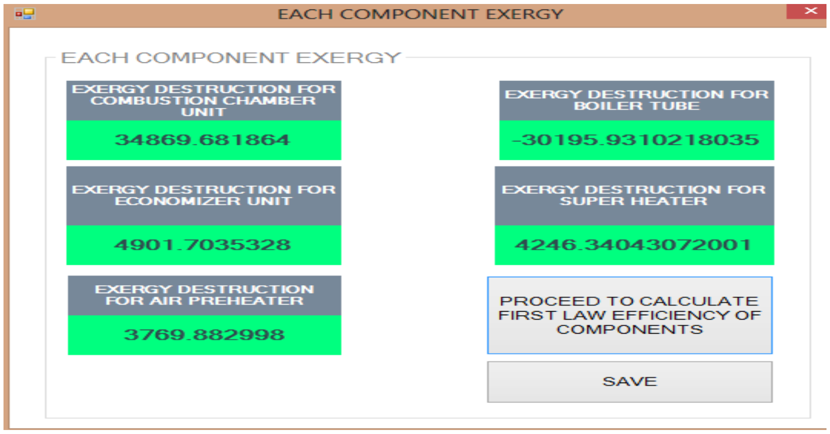
Mass Flow Rate of Flue gas: 20.52

Specific enthalpy of flue gas at inlet of air pre heater: 1356.8

Specific enthalpy of flue gas at outlet of air pre heater:

Enter value

Fig 6: Screenshot for Error message of Incomplete Data Input



EXERGY DESTRUCTION FOR COMBUSTION CHAMBER UNIT: 34869.681864

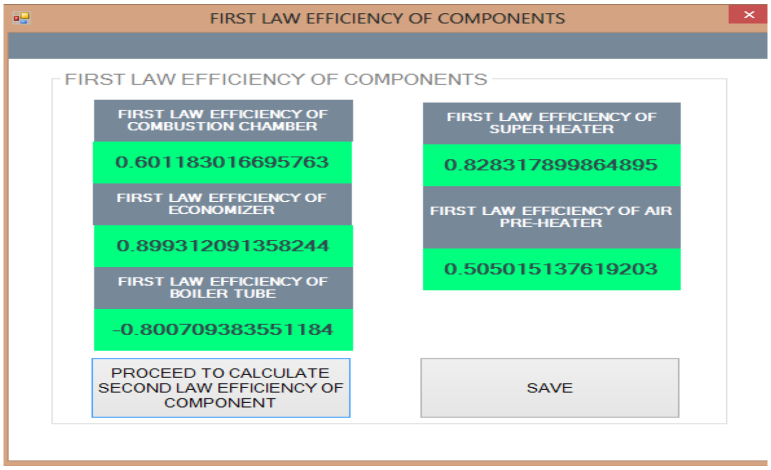
EXERGY DESTRUCTION FOR BOILER TUBE: -30195.9310218035

EXERGY DESTRUCTION FOR ECONOMIZER UNIT: 4901.7035328

EXERGY DESTRUCTION FOR SUPER HEATER: 4246.34043072001

EXERGY DESTRUCTION FOR AIR PREHEATER: 3769.882998

Fig 7 Screenshot for Exergy Destruction of the various Components of the Boiler Plant



FIRST LAW EFFICIENCY OF COMBUSTION CHAMBER: 0.601183016695763

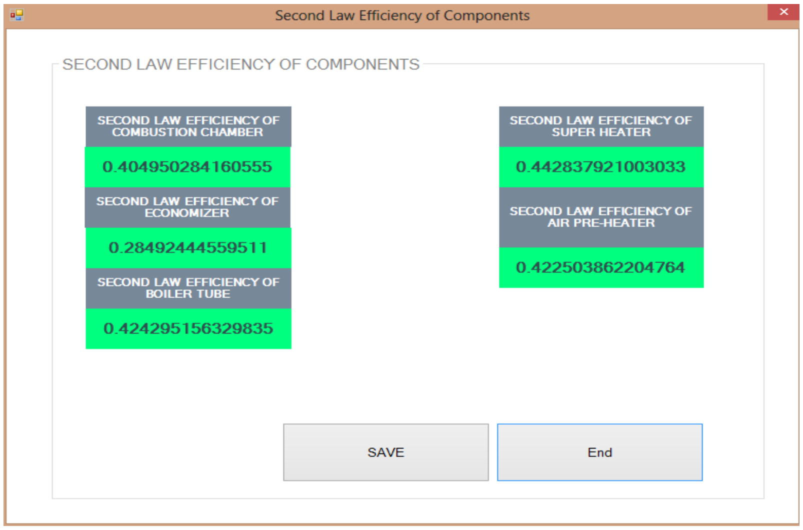
FIRST LAW EFFICIENCY OF SUPER HEATER: 0.828317899864895

FIRST LAW EFFICIENCY OF ECONOMIZER: 0.899312091358244

FIRST LAW EFFICIENCY OF AIR PRE-HEATER: 0.505015137619203

FIRST LAW EFFICIENCY OF BOILER TUBE: -0.800709383551184

Fig 8 Screenshot for Energetic Efficiency of the various Components of the Boiler Plant



SECOND LAW EFFICIENCY OF COMPONENTS

SECOND LAW EFFICIENCY OF COMBUSTION CHAMBER
0.404950284160555

SECOND LAW EFFICIENCY OF ECONOMIZER
0.28492444559511

SECOND LAW EFFICIENCY OF BOILER TUBE
0.424295156329835

SECOND LAW EFFICIENCY OF SUPER HEATER
0.442837921003033

SECOND LAW EFFICIENCY OF AIR PRE-HEATER
0.422503862204764

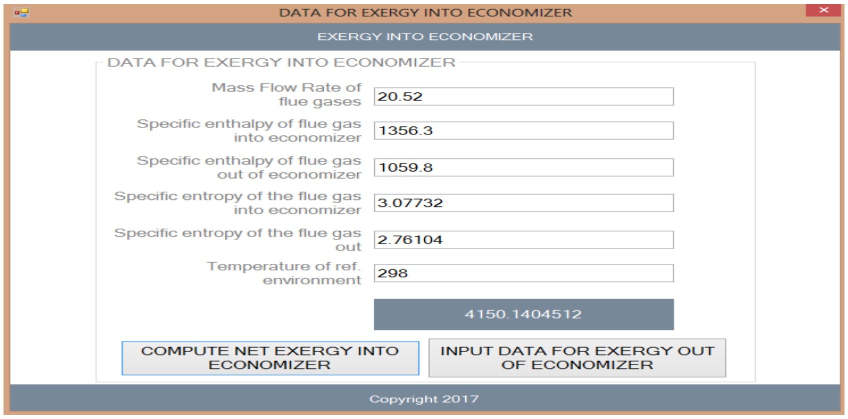
Fig 9: Screenshot for Exergetic Efficiency of the various Components of the Boiler Plant

RESULTS AND DISCUSSION

A software was developed for analysing the exergy of carbon monoxide boiler and named SWEACB. The software was validated using data collected from Warri Refinery and Petrochemical Company (WRPC). The results of net exergy carried out by flue gases in the economizer were determined as follow;

Mass flow rate of flue gas= 20.52
Specific enthalpy of flue gas at economizer inlet = 1356.3
Specific enthalpy of flue gas at economizer outlet = 1059.8
Entropy of flue gas at inlet of economizer = 3.07732
Entropy of flue gas at inlet of economizer = 2.76104
Temperature of reference environment = 298
Output (net exergy carried out by flue gases in economizer) = 4149.9

Fig 10: shows the screenshot of software result for net exergy carried by flue gas in economizer



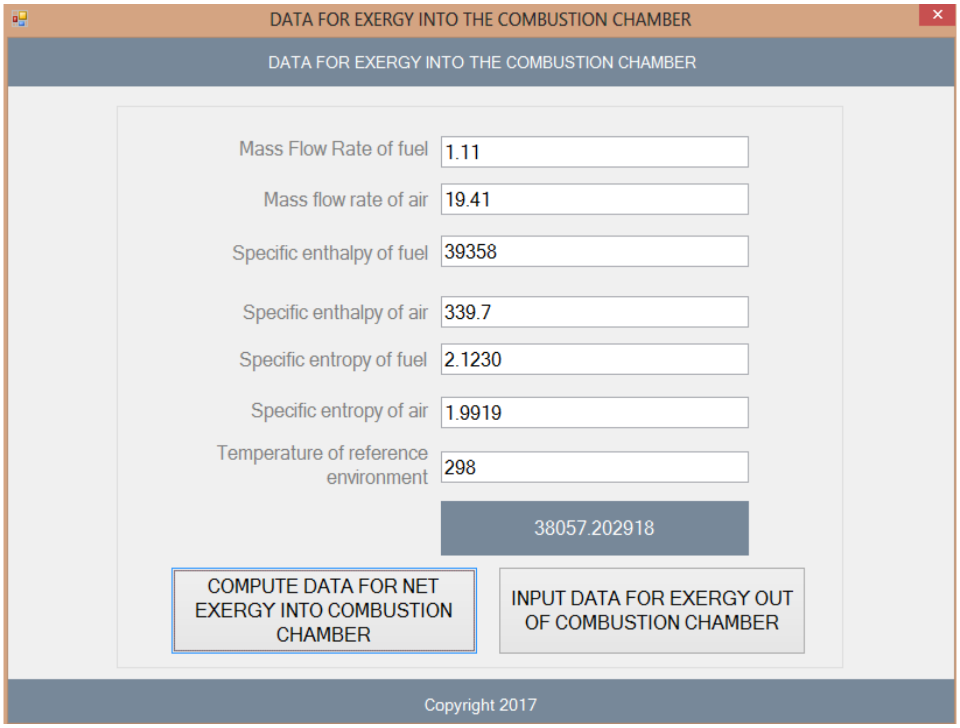
DATA FOR EXERGY INTO ECONOMIZER

Mass Flow Rate of flue gases: 20.52
Specific enthalpy of flue gas into economizer: 1356.3
Specific enthalpy of flue gas out of economizer: 1059.8
Specific entropy of the flue gas into economizer: 3.07732
Specific entropy of the flue gas out: 2.76104
Temperature of ref. environment: 298
4150.1404512

Fig 10 Screenshot of Software Result for Net Exergy carried by Flue Gas in Economizer

The results of net exergy into combustion chamber are as follow;
Mass flow rate of fuel=1.110
Specific enthalpy of fuel=39358
Specific enthalpy of air=339.7
Specific entropy of fuel =2.1230
Specific entropy of air =1.9919
Temperature of reference environment=298
Output (exergy into the combustion chamber) =38057.19

Fig. 11 shows the screenshot of software result for exergy into combustion chamber



Mass Flow Rate of fuel: 1.11
Mass flow rate of air: 19.41
Specific enthalpy of fuel: 39358
Specific enthalpy of air: 339.7
Specific entropy of fuel: 2.1230
Specific entropy of air: 1.9919
Temperature of reference environment: 298
38057.202918

Fig. 11 Screenshot of Software Result for Exergy into Combustion Chamber

A total of fifteen cases were examined during the software verification and a summary of the results obtained is shown in Table 5. As shown in Table 5, from the result obtained for manual computation and software computation of the energy destruction and efficiencies of the various components of the boiler, it is obvious that there is no significant difference between both means of computation. However, the software computation is very fast. Besides, it aids reduction and simplification of the computation process. Thus, organizational performance can be improve with the use of this software as it eliminates the arithmetic process involved in computing inventory parameters

.

Table 5: The result for Efficiencies and Destruction of various Components in the Boiler Unit

S/N	Components of Boiler	Manual Computation	Software Computation
1	Energetic efficiency of combustion chamber	60.1%	60.118%
2	Exergetic efficiency of combustion chamber	40.5%	40.495%
3	Exergy destruction of combustion chamber	34869.7kj/s	34869.682kj/s
4	Energetic efficiency of boiler tube	72.1%	72.437%
5	Exergetic efficiency of boiler tube	42.4%	42.429%
6	Exergy destruction of boiler tube	27275.87kj/s	27275.872kj/s
7	Energetic efficiency of economizer	89.9%	89.931%
8	Exergetic efficiency of economizer	28.5%	28.492%
9	Exergy destruction of economizer	4901.7kj/s	4901.704kj/s
10	Energetic efficiency of superheater	82.8%	82.831%
11	Exergetic efficiency of superheater	44.3%	44.284%
12	Exergy destruction of superheater	4246.4kj/s	4246.340kj/s
13	Energetic efficiency of air-preheater	50.5%	50.502%
14	Exergetic efficiency of air-preheater	42.3%	42.250%
15	Exergy destruction of air-preheater	3769.6kj/s	3769.883kj/s

The statistical analysis result of t-test carried out on the software and manual means is shown in Table 6. The test was carried out in succession at 95% confidence level to ascertain if there is/are significant difference(s) in both means. The null hypothesis is that there is no significant difference in the means of using manual computation and software computation. While the alternative hypothesis is that, there is a significant difference in both means. The significance level (α) is the probability of rejecting the null hypothesis when it is true, if the t-test valuesis outside the range of confidence level, the assumption that the null hypothesis is true is rejected and the alternate hypothesis is accepted. The table below shows the result of the t-test analysis.

Table 6: Result of t-test Analysis

X_1	X_2	X_1^2	X_2^2	$\overline{X_1}$	$\overline{X_2}$	S_1^2	S_2^2	σ	t_{cal}
60.1	60.118	3612.01	3614.17	4789.82	10281183.4	10281183.4	10281446.4	3327.48	0.000016
40.5	40.495	1640.25	1639.85						
34869.7	34869.682	1215895978	1215894723						
72.1	72.437	5198.41	5247.12						
42.4	42.429	1797.76	1800.22						
27275.87	27275.872	743973084.3	743973193.4						
89.9	89.931	8082.01	8087.58						
28.5	28.492	812.25	811.79						
4901.7	4901.704	240266.6	240790.4						
82.8	82.831	6855.84	6860.97						
44.3	44.284	1962.49	1961.07						
4246.4	4246.340	18031910.3	18031403.4						
50.5	50.502	2550.25	2550.45						
42.3	42.250	1789.29	1785.06						
$\sum X_1 =$	$\sum X_2 = 7$	$\sum X_1^2 = 20$	$\sum X_2^2 = 200$						

$\sum X_1 = 71847.07$, $\sum X_2 = 71847.385$, $\sum X_1^2 = 2001961939$, $\sum X_2^2 = 2001961939$

$$\overline{X_1} = \frac{\sum x_1}{n_1},\ \overline{X_2} = \frac{\sum x_2}{n_2}$$

$$S_1^2 = \frac{1}{n_1-1}\left[\sum X_1^2 - \frac{(\sum x_1)^2}{n_1}\right], \quad S_2^2 = \frac{1}{n_2-1}\left[\sum X_2^2 - \frac{(\sum x_2)^2}{n_2}\right]$$

$$\sigma = \sqrt{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2}}, \quad t_{cal} = \frac{\overline{X_1} - \overline{X_2}}{\sigma\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}}$$

$\overline{X_1}$ = Mean of manual results
$\overline{X_2}$ = Mean of software oresults
S_1^2 = Variance of $\overline{X_1}$ variables
S_2^2 = Variance of $\overline{X_2}$ variables
$\alpha = 0.05$
Confidence interval of the difference
Low ($t_{28,0.025}$) = -2.056
Upper ($t_{28,0.975}$) = 2.056

Since the value of t-calculated fall within the confidence level, the null hypothesis is accepted and the alternative rejected affirming the superiority of the software means over the manual means.

Furthermore, the exergy destruction and efficiencies of the various components of the gas boiler was carried out using the software developed as shown in Fig. 12. It was observed from the results obtained, that the super-heater has the highest exergetic efficiency (44.3%) and the economizer, the lowest exergetic efficiency (28.5%). This implies that there is adequate transfer of heat from the flue gas to the saturated steam at the super-heater. Also from the exergetic efficiency of the economizer, it shows that the heat transfer from flue gas to the feed water is not complete due to irreversibility and needs appropriate lagging.

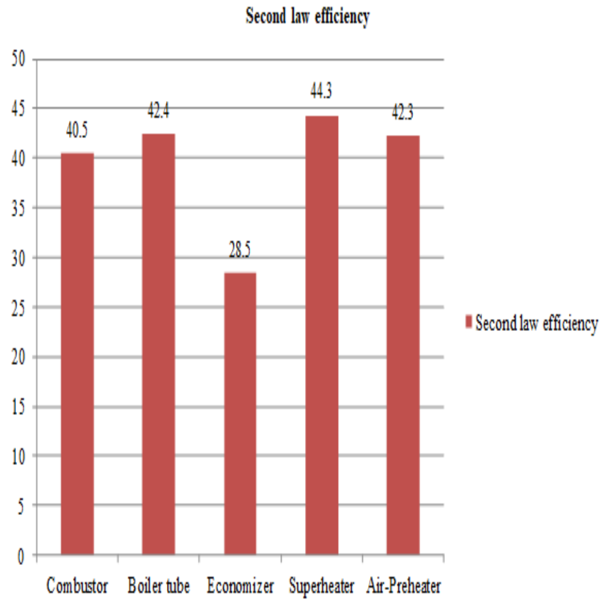


Fig 12: Exergy Destruction and Efficiencies of the various Components of the Gas Boiler

Moreover, the highest exergy destruction occurred in the combustion chamber (34869.682kJ/s) and the lowest exergy destruction in the air-preheater (3769.6kJ/s) as shown in Fig. 13. This is as a result of incomplete combustion of fuel due to improper air-fuel mixture. Therefore to prevent such from occurring consistently, the maintenance team of the boiler plant should ensure that the boiler is properly lagged. Also the low exergy destruction at the air-preheater shows that the energy supplied to the air-preheater by the flue gas from the combustion chamber was well utilized. The results of the comparison chart for energy and exergy is shown in Fig 14. The outcome of the results revealed that higher efficiency was obtained with first law.

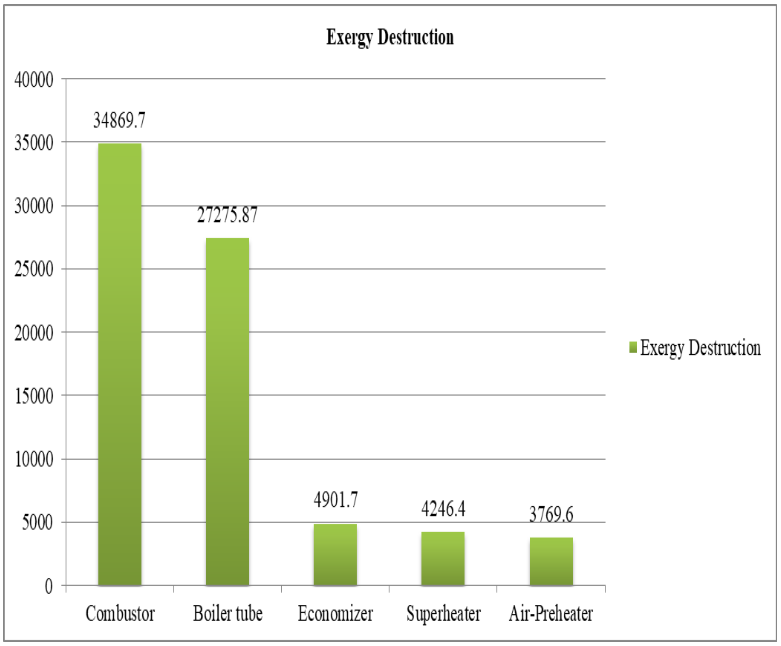


Fig 13: Exergy Destruction of Various Components

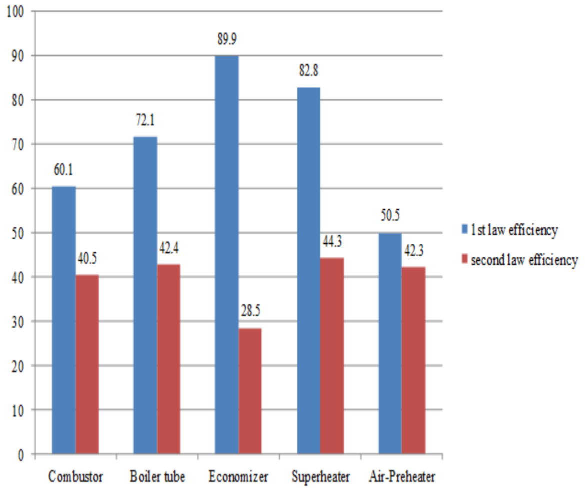


Fig 14: Results of the Comparison Chart for Energy and Exergy

CONCLUSION

This research work which focused on the exergy analysis of carbon monoxide boiler turns out to be successful, since the set-out aim and objectives were met. The results obtained from the software shows that the super-heater has the highest exergetic efficiency (44.3%) and the air-preheater the lowest exergetic efficiency (42.3%). This implies that there is adequate transfer of heat from the flue gas to the saturated steam at the super-heater. Also to increase the exergetic efficiency of the economizer which is lowest, modification should be done by using refractory (insulation) to reduce heat loss. The highest exergy destruction occurred at the combustion chamber (34869.7kJ/s) and the lowest exergy destruction at the air-preheater (3769.8kJ/s). Therefore, attention should be given to the combustion chamber to minimize exergy losses as a result of irreversibility.

RECOMMENDATION

Based the analysis carried out, it is recommended that;

i. Necessary modification like refractory (insulation) should be used for the combustion chamber to reduce exergy destructions thereby improving boiler performance.

ii. The major exergy destruction occurs in the heat recovery system i.e., Super-heater, Economizer, Boiler tube and Air-pre-heater which leads to inefficient heat transfer between hot stream (flue gas) and cold stream (water & air).It indicates heat exchanger system need to be carefully inspected.

iii. Students should be encouraged to carry out research on project work in the area of software application in solving engineering problems in industrial plant.

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