International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 8, Issue 8, pp 252-263, August-2024

https://doi.org/10.47001/IRJIET/2024.808029

Energy, Exergy and Economic Analysis of Boiler Systems

[1]*Ebieto, C. E., [2]Odoemenem, B. C.

[1]Department of Mechanical Engineering, University of Port Harcourt Port Harcourt, Rivers State, Nigeria
[2]Masters of Engineering Management (MEM), University of Port Harcourt, Rivers State, Nigeria
*Corresponding Author's E-mail: celestine.ebieto@uniport.edu.ng

***Abstract* - This paper presents a framework for energy, exergy utilization, and economic analysis of industrial steam boiler system in Nigerian Bottling Company (NBC), Enugu, Nigeria. The study was carried out by an investigative approach in which all other parameters were kept constant, and a particular one was varied, and the desired quantity measured. The results of the effects of burner rotary cup speed and fuel nozzle sizes on emissions show that for boiler having liquid fuel nozzle sizes 3mm, 4mm and 6mm and with constant fuel inlet temperature of 82°C were analysed. Nozzle size of 4mm diameter with burner rotary cup operating at speed of 2920rev/min to 3200rev/min generated minimum emission while burning fuel oil of 82°C with excess air of 12.36%. Similarly, nozzle size of 6mm with rotary cup burner operating between 3950rev/min to 4400rev/min at 12.36 % excess air generated no emission of CO and NOx. It was concluded that the combustor yielded the highest energy efficiency of 99.8% while the heat exchanger gave the lowest energy efficiency of 94% when run on both fuel oil and natural gas. This improved efficiency translates to a savings of approximately 89 million naira annually for a boiler operating at 46% availability yearly.**

Keywords: Exergy, Energy, Boiler, CO, NOx, Excess air, Fuel, Savings.

I. INTRODUCTION

Energy has a significant role in every area of the economy of any nation. The per capita energy consumption of a nation can be closely correlated with its standard of living. Per capita energy consumption serves as a gauge for both national prosperity and per capita income [1]. Several nations, including Nigeria heavily rely on fossil fuels for their primary sources of energy and foreign exchange earnings, fossil fuels have long been the mainstay of the global energy supply and it is a particular contributor of greenhouse gas (GHG) emissions, that is acknowledged to be unsustainable worldwide, is the use of fossil fuels [2]. Currently, fossil fuels like coal, oil, fuel oil, and natural gas are used to power thermal power plants in the world to generate about 80% of the electricity needed; the remaining 20% is generated by nuclear, hydraulic, solar, geothermal, and biogas power plants [3].

Significant amounts of fossil fuel are used to produce steam by all of the major industrial energy consumers: primary metals (10%), petroleum refining (23%), chemicals (42%), food processing (57%), pulp and paper (81%). Industrial systems are extremely distinct; however they frequently share considerable similar steam systems, which make them a good target for energy-savings initiatives [4]. Energy Information Administration [5] says that coal is responsible for about 45%, natural gas and nuclear energy are responsible for about 20% and 15% of the world's electricity production respectively. Since these energy sources generally use boiler systems, steam turbine to convert its chemical potential energy to electricity generation, one can only imagine the possible way of savings derivable from improving the efficiency of a steam boiler by just a small fraction. As a result, it is critical to limit the energy consumption of any given process and regulate both the amount and rate of energy deterioration, that is, to reduce heat loss in the boiler and increase the transfer of heat to the water. Boiler systems are enclosed spaces where fuel is burned to produce steam from water [6]. Boilers can lose heat in a number of ways, such as hot flue gas losses, radiation losses, and blow-down losses in the case of steam boilers [7]. Regretfully, energy analysis based on the first law of thermodynamics fails to identify any deterioration in energy quality. An essential thermodynamic concept, exergy is defined as the utmost possible useful work that a system can produce during a reversible process from its initial state to the dead state of its environment [8]. Exergy, a term derived from the second law of thermodynamics, provides a means of quantifying both the energy transformation and the energy destruction that occurs when energy quality is lost [9]. The second law of thermodynamics, on which exergy analysis is based, is a helpful technique for assessing, optimizing, and improving the steam power plant and heat generation systems. The weakness of energy analysis, which measures irreversibility by creating entropy throughout a process, is addressed by exergy. The quantity and character of energy are evaluated using exergy. The total quantity of exergy is not conserved in a process or system; rather, it is lost as a result of heat transfer and internal irreversibilities that cross the system boundaries. The exergy loss is directly proportional to the entropy generated as a result of the irreversibility inherent in the process.

Exergy analysis has generated scientific interest [10] in the need for a more comprehensive examination of energy conversation devices and the development of novel methods to increase utilization of existing limited resources. Failure to account for the quality of available energy renders the energy analysis insufficient for a comprehensive understanding of all critical aspects of energy utilization processes. At times, it fails to notice critical elements that require enhancement. The environment influences the exergy of a system [11]. According to [12], this would subsequently cause future energy-related issues to become more severe. According to [13], energy that cannot be transformed into another kind of energy is referred to as an energy, or worthless energy. In order to further the objective of more effectively using steam boiler energy resources, [14] raised the issue of the influence of steam boiler energy resource use on the environment. As a result, energy analysis seems to be a significant instrument in addressing this impact. It is imperative to conduct exergy analysis at the process plant level as opposed to extrapolating findings from various environmental sites.

This paper will help reduce the major problems facing the production companies in using high thermal energy consumption, which has resulted in high cost of production and reduce profit margin as evidence seen in company's energy cost records, e.g., Beverage companies. From the research, it was established that exergy analysis of power is more realistic than its energy analysis, also note that exergy is consumed due to irreversibility, and consumption is proportional to entropy as creation is conserved, while exergy, as an evaluation of energy quality or work potential can be measured. The exergy efficiency must always be greater than the energy efficiency. This paper offers a framework for assessing the effects of boiler rotary burner cup speed, emissions of CO and NO_x, fuel nozzle size on emission oil, excess air and fuel types on its performance and emissions with a view to optimize, identify and quantify components having greatest losses of energy and exergy efficiencies in the NBC, Enugu, Nigeria boiler plant.

II. METHODOLOGY

The study was carried out by an investigative approach in which all other parameters were kept constant, and a particular one was varied, and the desired quantity measured. In each case, enthalpy, entropy, pressure, temperature, and the flow rate of each node were measured or calculated and tabulated. The energy and exergy efficiencies of the components were calculated for each of the experiments. The influence of some operating conditions (excess air, rotary burner cup speed, fuel nozzle size) on the boiler was also investigated. For the experiments, the following apparatus were used; temperature and pressure gauges, tachometer, infra-red thermometer, fluid flow meters, exhaust gas analyser, stop watches, frequency converters, and data-recording system. Having analysed all the process plants components, the readings or values obtained when the air inlet values and other thermodynamic variables are changed will be obtained. For each component, the effects of varying the parameters above are plotted against the energy and exergy efficiencies. This helped in the analysis for the optimization of the system. For each system or component, the values of the stream properties are recorded- mass, temperature, pressure, enthalpy, entropy, exergy, and heat values obtained from the calculations using their respective formulae. The energy and exergy efficiencies of the components were plotted on one graph and their values compared for a particular condition. This helped to pin- point the component with the highest exergetic loss.

System Description

A 15/10 Ton three-pass fire tube boiler that is horizontally oriented. The outside dimensions,3 metres diameter and is 7.5 metres long. It is adequately lagged to minimise heat loss to the environment. On the inside, the combustion chamber runs approximately 90% of its entire length with a diameter of 1 metre. For the experiment, the draft fan motor which brings in air into the boiler was equipped with a frequency converter. The frequency converter is responsible for the regulation of the speed either upward or downward depending on the amount of air needed in the boiler. Similarly, the burner which is located right at the inlet of the combustion chamber is a rotating cup type which is driven by a motor equipped with frequency converter for the regulation of the speed of the burner cup.

The fire tubes collect into a chimney at the reverse side of the boiler and towers above the boiler. Its diameter is about 60cm and high enough to protrude through the roof of the building. Just at the inlet of the chimney is a hole for the exhaust gas analysis. It is through this hole that the exhaust gas analyser is dipped to measure the contents of the flue gas. The boiler is intermittently purged to get rid of Total Dissolved Oxygen. The boiler burners used for the experiments were made by SAACKE.

III. MATHEMATICAL MODELLING

Modelling Adiabatic Temperature of Combustion

The boiler is used for actual production; no permission was secured for its retrofit for direct temperature measurement. As a result, an indirect procedure was employed. Here, subscripts a, f and h stand for air, fuel and combustion gases and R, T and P stand for reactants, temperature, and pressure respectively. For a reaction to occur, the reactants will follow the process as outlined in

Figure 1. The reactants at temperatures, T_a and T_f are assumed to combine at a reference temperature, T_o and still form products at the same reference temperature prior to attaining a final temperature, T_a is the adiabatic flame temperature in the combustion chamber.

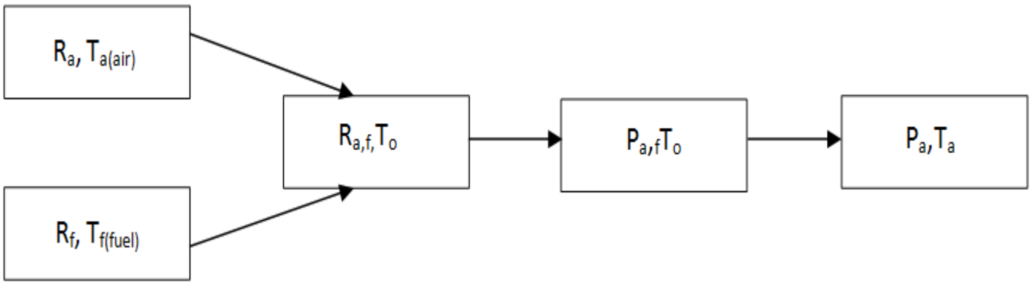


Figure 1: Combustion Reaction Process

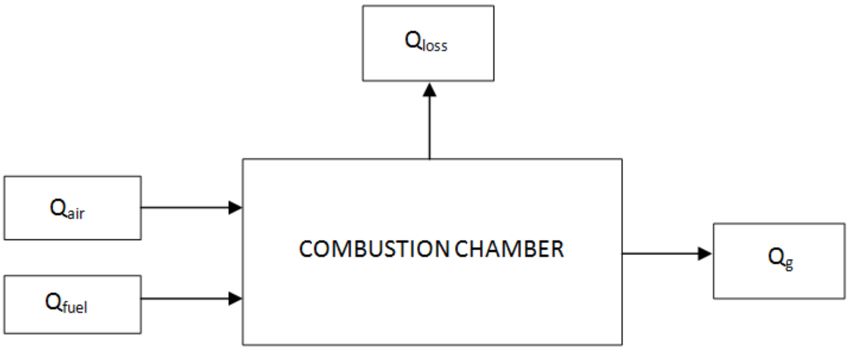


Figure 2: Energy Balance around Combustion Chamber

From Figure 2 above, the energy balance of the system is given as:

$$Q_f + Q_a = Q_l + Q_g \qquad (1)$$

Here, Q_f is the total energy of the fuel, Q_a is the sensible energy of the air, Q_l is the heat loss in the combustion chamber and Q_g is the heat content of the combustion gases. Q_f is a combination of sensible heat of the fuel, Q_{fs} (heat content of the fuel due to the difference in temperature between it and the reference environment) and the calorific value, C_v. Thus

$$Q_f = Q_{fs} + C_v$$

This gives;

$$Q_{fs} + C_v + Q_a = Q_l + Q_g$$

$$m_f C_{pf} (T_f - T_o) + C_v + m_a C_{pa} (T_a - T_o) = Q_l + m_g C_{pg} (T_g - T_o) \qquad (2)$$

Where m_f is the mass flow rate; C_p is the specific heat capacity at constant pressure. $Q_l = 0$ Since the combustion is assumed to be adiabatic knowing full well that it is adequately lagged.

The equation reduces to:

$$m_f C_{pf} (T_f - T_o) + C_v + m_a C_{pa} (T_a - T_o) = m_g C_{pg} (T_g - T_o)$$

If the water in the combustion product is in vapour phase, C_v is lower heating value (LHV), if not; it is the higher heating value. The term on the right hand of the equation is the combustion product, which is a mixture of CO_2, N_2, O_2, H_2O at times CO, NO_x.

Thus,

$$m_g Cp_g\left(T_g - T_0\right) = (m_g O_2 Cp_g\left(T_g - T_0\right))O_2 + \left(m_g N_2 Cp_g\left(T_g - T_0\right)\right) N_2 + (m_g CO_2 Cp_g\left(T_g - T_0\right)CO_2 + \left(m_g H_2O Cp_g\left(T_g - T0H2O+(mgCOCpgTg-T0)CO \qquad (3)$$

This can be simplified to:

$$(T_g - T_0)(m_g O_2 Cp_g O_2 + m_g N_2 Cp_g N_2 + m_g CO_2 Cp_g CO_2 m_g H_2O Cp_g H_2O + m_g COCp_g CO)$$

The adiabatic temperature, T_g is given as:

$$T_g = T_0 + \frac{m_f Cp_f (T_f - T_0) + m_a Cp_a (T_a - T_0) + LHV}{(m_g O_2 Cp_g O_2 + m_g N_2 Cp_g N_2 + m_g CO_2 Cp_g CO_2 + m_g H_2O Cp_g H_2O + m_g COCp_g)} \qquad (4)$$

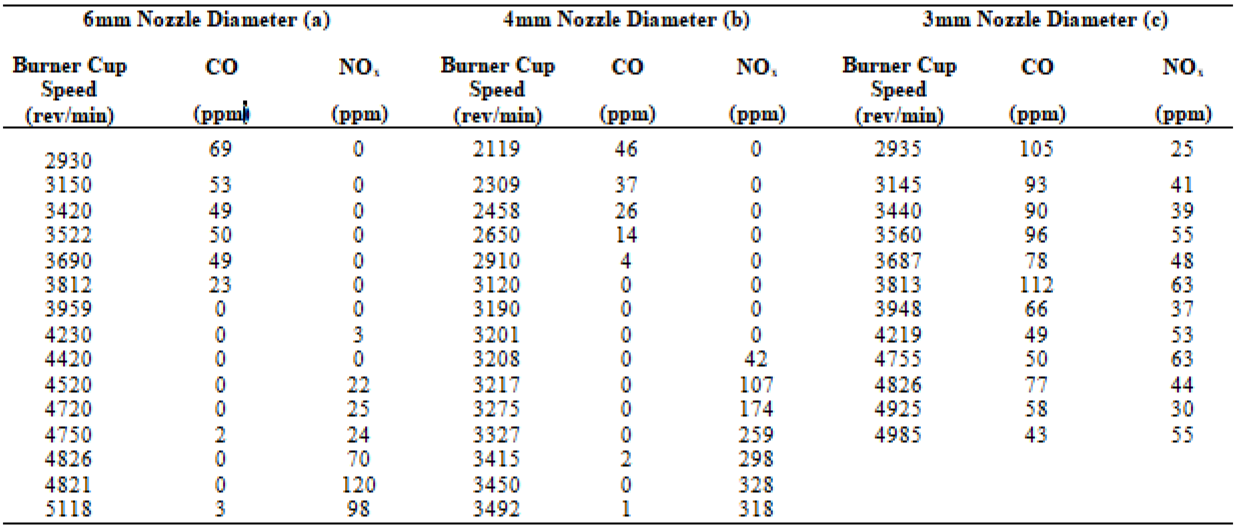
Since the C_p varies with the temperature, T_g is obtained by first guessing a value, T_{ass} and the mean temperature above T_0 is calculated as 0.5 (T_{ass} +T_g). The corresponding Cp_g at a temperature, 0.5 (T_{ass} + T_0) is read from the property table for each of the gases. With this, the T_{g1} is calculated. If the Tg1 calculated is not close to Tass, a new mean temperature is assumed this time it is given as; 0.5(T_{g1}+T_0) and the C_p corresponding to this value is read from the property table again and a new $T_{g2}$is obtained. This new T_{g2} is compared with the previous T_{g1} and if their values are close, T_g then becomes T_{g2} if not, another mean temperature is calculated, and the process continues until T_{gn} is close to $T_{gn-1}$and the value for T_{gn} becomes the adiabatic flame temperature. With T_g evaluated, the thermodynamic properties of combustion gases at T_g will now be found for the h_g, s_g in Equations 1 to 2 which will then enable the calculation of the efficiencies.

IV. RESULTS AND DISCUSSIONS

Plant Normal Operating Condition

At the beginning of the experiment, the operating condition of the boiler was measured and noted. This was done several times to ensure consistency in the result. Having carried out the energy and exergy analysis of the different components of the boiler at the initial operating conditions, only the air flow rate was varied at first instance to compare the energy and exergy efficiencies of the boiler.

Table 1: Variation of CO and NO$_x$ Emissions with Rotary Cup Speed



6mm Nozzle Diameter (a)			4mm Nozzle Diameter (b)			3mm Nozzle Diameter (c)		
Burner Cup Speed (rev/min)	CO (ppm)	NO$_x$ (ppm)	Burner Cup Speed (rev/min)	CO (ppm)	NO$_x$ (ppm)	Burner Cup Speed (rev/min)	CO (ppm)	NO$_x$ (ppm)
2930	69	0	2119	46	0	2935	105	25
3150	53	0	2309	37	0	3145	93	41
3420	49	0	2458	26	0	3440	90	39
3522	50	0	2650	14	0	3560	96	55
3690	49	0	2910	4	0	3687	78	48
3812	23	0	3120	0	0	3813	112	63
3959	0	0	3190	0	0	3948	66	37
4230	0	3	3201	0	0	4219	49	53
4420	0	0	3208	0	42	4755	50	63
4520	0	22	3217	0	107	4826	77	44
4720	0	25	3275	0	174	4925	58	30
4750	2	24	3327	0	259	4985	43	55
4826	0	70	3415	2	298			
4821	0	120	3450	0	328			
5118	3	98	3492	1	318			

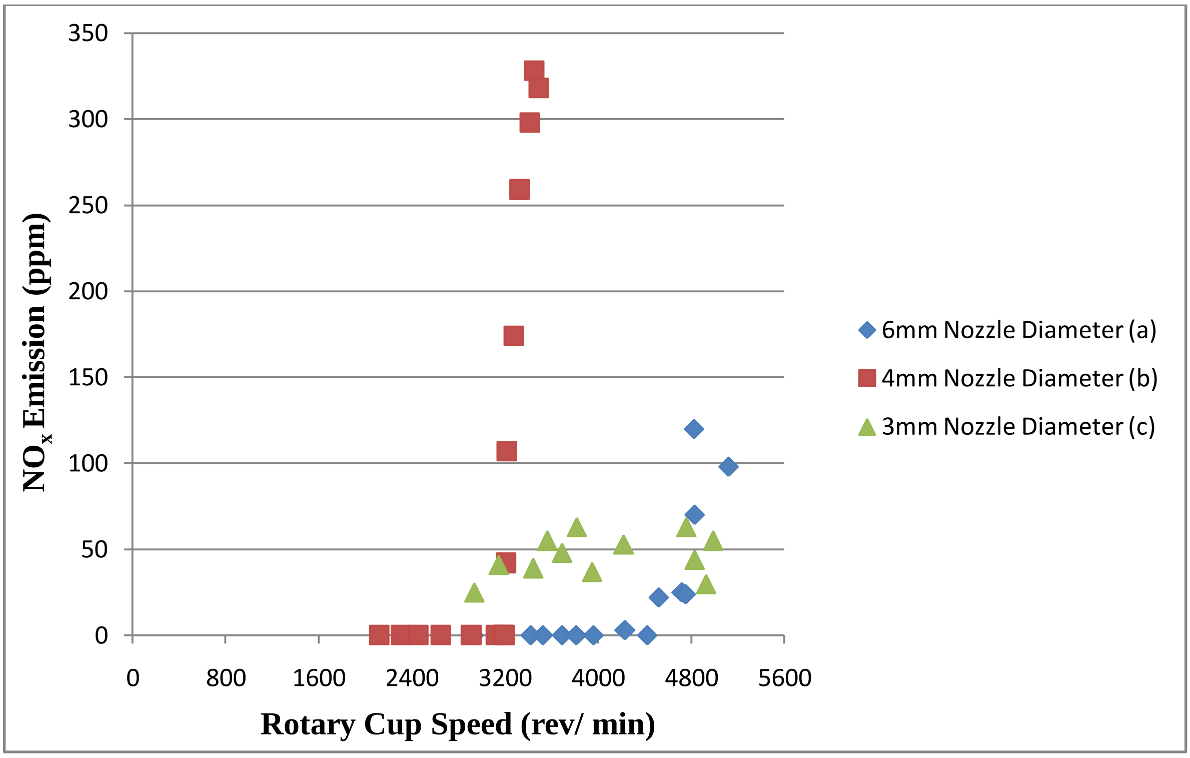


Figure 3: Variation Of No_x Emissions with Rotary Cup Speed for 3mm, 4mm and 6mm Nozzle Size

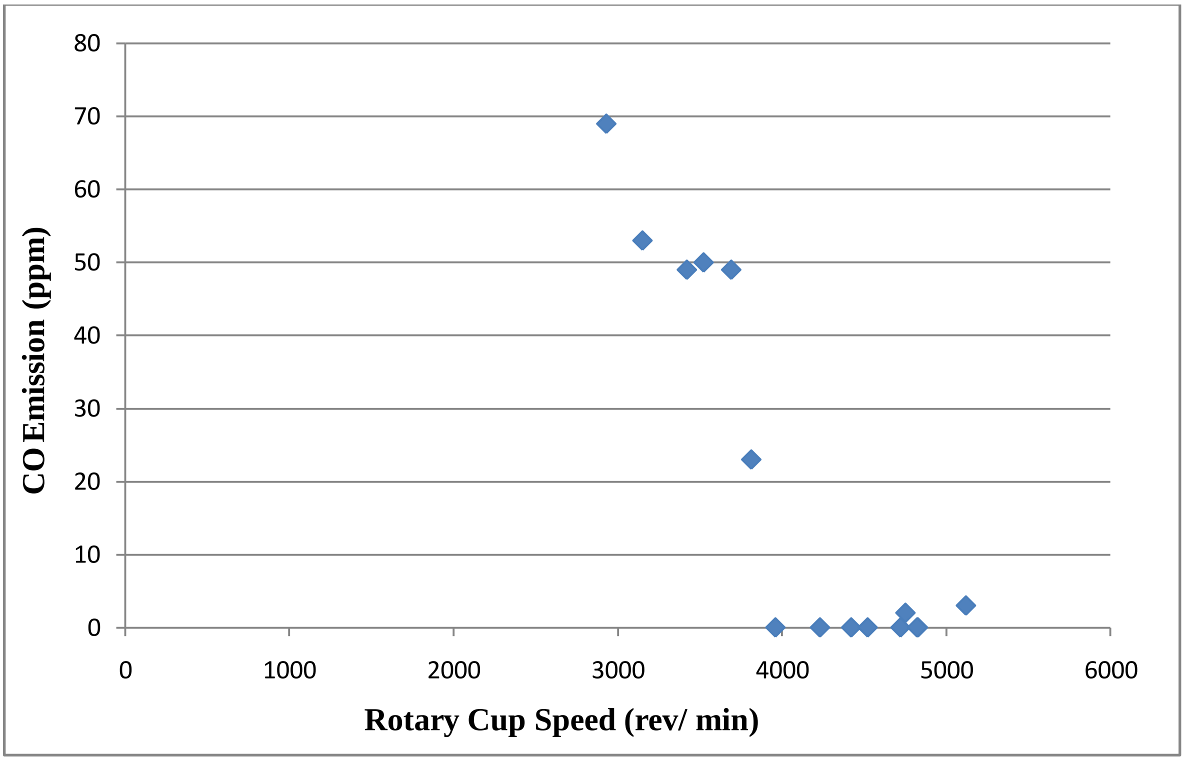


Figure 4: Variation of CO Emissions with Rotary Cup Speed for 6mm Nozzle Size

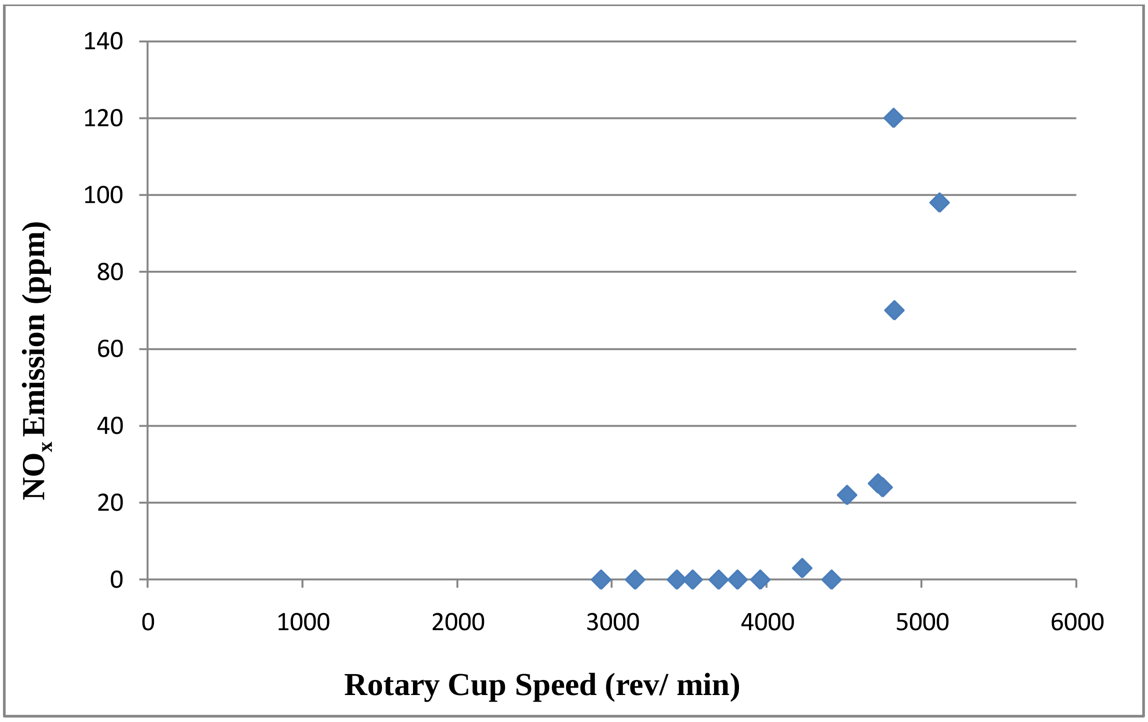


Figure 5: Variation of NO$_x$ Emissions with Rotary Cup Speed for 6mm Nozzle Size

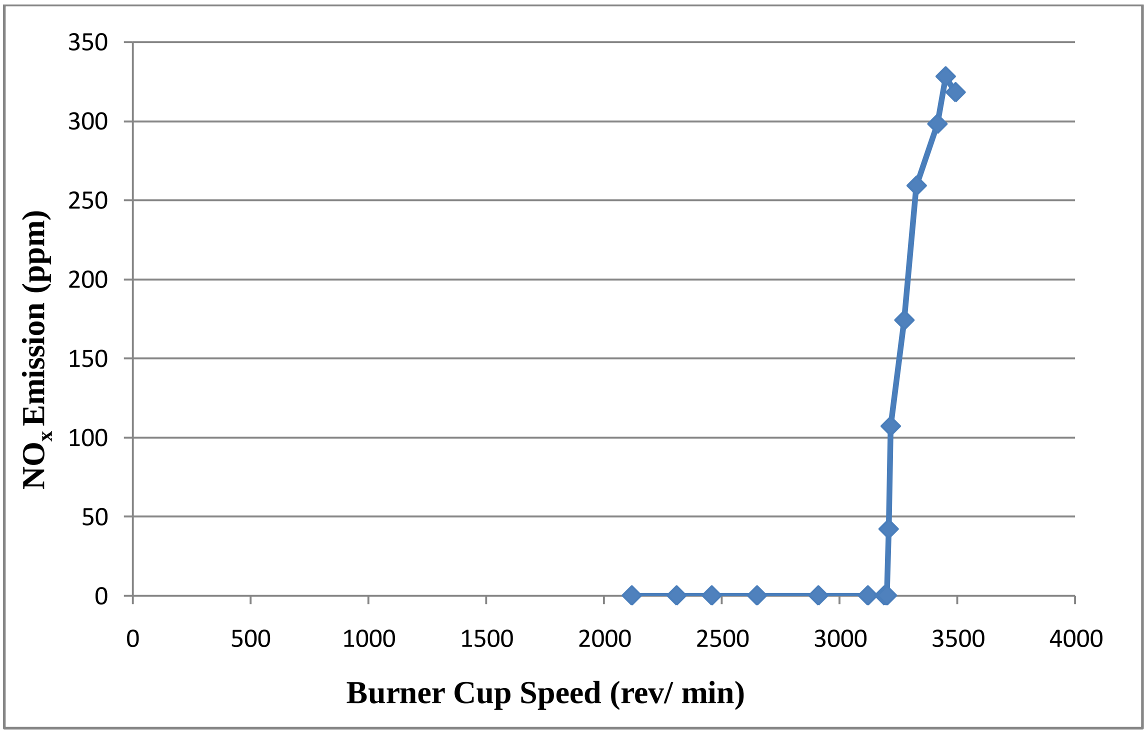


Figure 6: Variation of NO$_x$ Generation with Burner Cup Speed for 4mm Nozzle Size

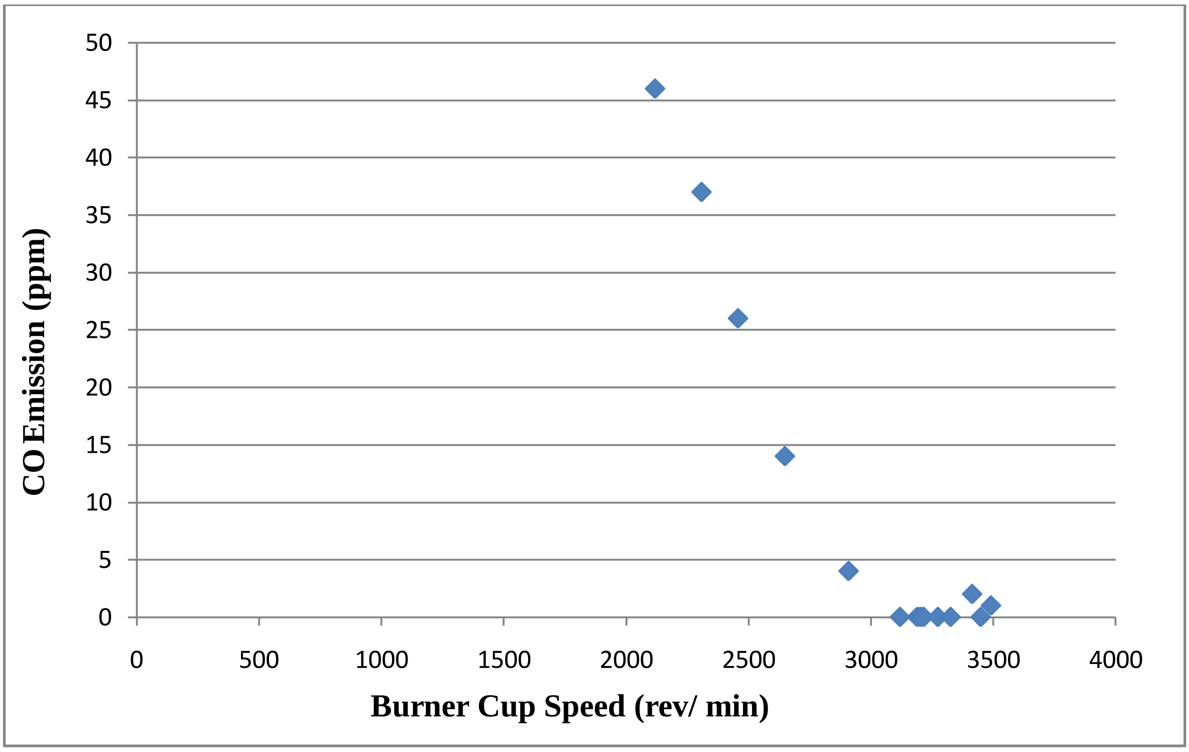


Figure 7: Variation of CO Emission with Burner Cup Speed for 4mm Nozzle Size

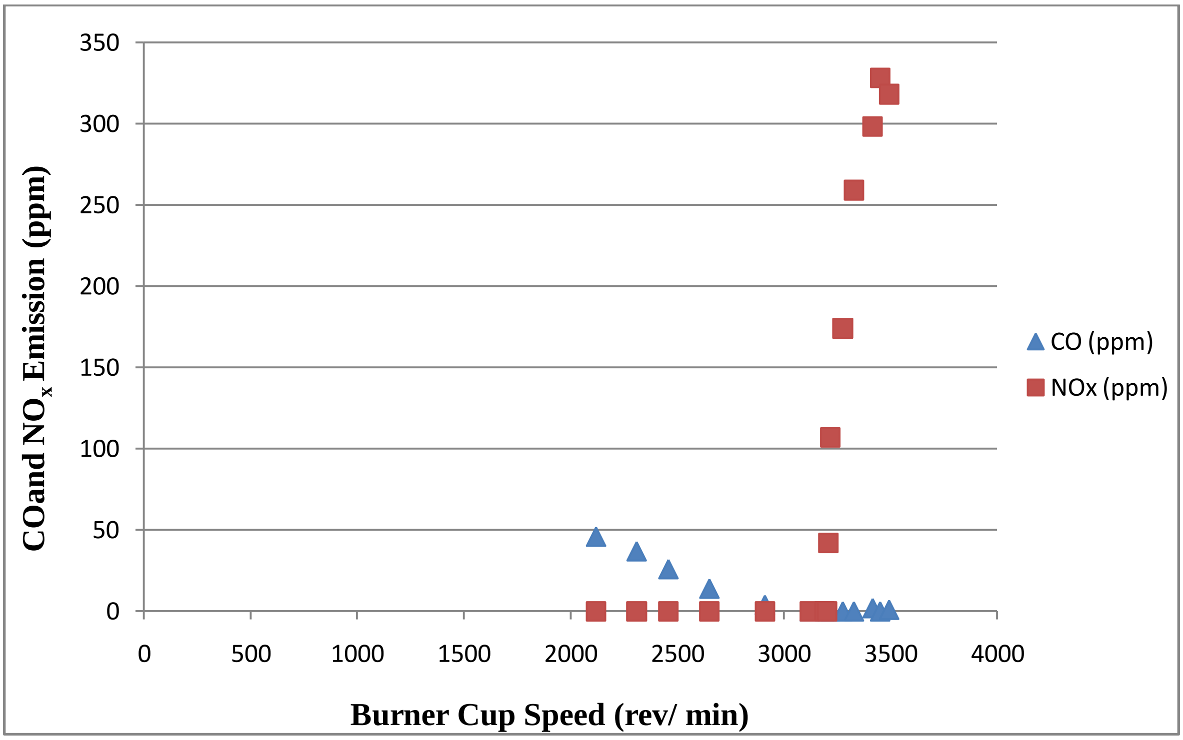


Figure 8: Variation of CO and NO$_x$ Generation with Burner Cup Speed for 4mm Nozzle Size

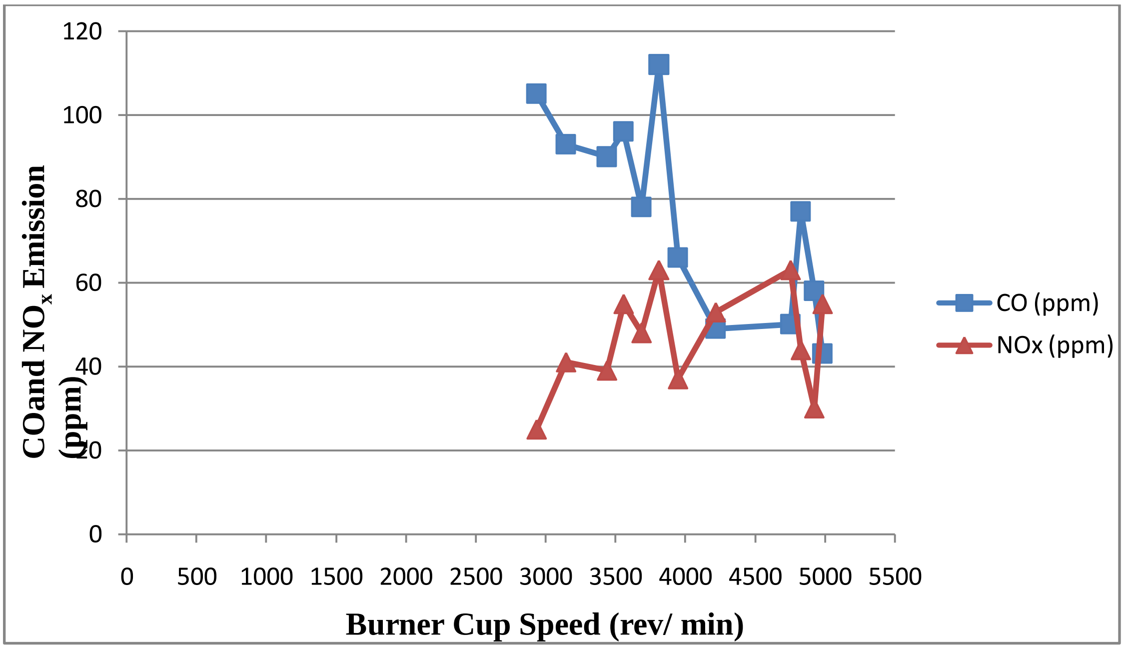


Figure 9: Variation of CO and NO$_x$ Generation with Burner Cup Speed for 3mm Diameter at 0.23kg of Fuel Flow Rate

The variation of CO and NO$_x$ emission as can be seen from Figures 7 and 8 above shows that fuel atomization in a fire-tube boiler is heavily dependent on the rotational speed of the rotary cup burner. As the speed of the rotary cup burner is reduced, the degree to which the fuel is broken down into smaller sizes (atomization) is decreased and thus fuel tends to come as lump rather than in finer sizes. This of course introduces incomplete combustion in the combustion chamber which results in more CO emission. On the other hand, as the speed of the burner cup is increased, fuel is broken down into smaller and smaller sizes which of course creates more surface area for combustion and thus increases the combustion temperature which ultimately increases the amount NOx (thermal NO$_x$) as is picked up by the exhaust gas analyser. By properly altering the rotary cup speed in each case, a region is observed where both CO and NOx production tend to zero. This is the "**NOCONOX" (this means no CO, no NO$_x$)** equilibrium point where for a constant nozzle size, constant air- fuel ratio and constant fuel viscosity, it is safe to operate the boiler with very minimal emissions. This phenomenon was observed for nozzle sizes between 4mm and 6mm.

From Figure 9 above, operating with fuel nozzle size of 3mm and same conditions with those of 4mm and 6mm nozzle sizes, the "NOCONOX" point did not occur but when the fuel flow rate (exit velocity) was lowered, the "NOCONOX" point was achieved. This of course shows the dependence of combustion on the exit velocity of fuel from the rotary cup burner. The smaller the nozzle size, the higher the fuel exit velocity which of course would be kept within a specified value (with 4mm and 6mm nozzles) for a good combustion to occur and for high heat energy to be released.

Table 2: Summary of the Boilers Normal/ Initial Operating Conditions before the Experiment

Streams	Flow Rate (kg/s)	Temp. (°C)	H (kJ/kg)	h at Stream Temp. (kJ/kg)	s at stream Temp. (kJ/Kg K)	ho at Ref Condition (kJ/kg)	so at ref Condition (kJ/kg k)	Total Physical Exergy (kJ/kg)	Total Chemical Exergy (kJ/kg)	Total Exergy (kJ/Kg)	Total Specific Exergy (kJ/s)
Fuel In	0.234	80	41795	41872.27	2.3	41795	2.1	15.865	44107.4	44123.265	10324.84401
Air In	4.2592	34	305.3	305.3	1.72	305.3	1.72	0.00	0.00	0	0
Hot Comb. Gas	4.4932	1762	2170.36	2170.368	8.87713	312	6.721289	1196.53	0.00	196.526	5376.29
Water In	2.51	90	430	430	1.32	130	0.47	39.9	0.00	39.9	100.149
Steam Out	2.51	160	2759	2759	6.77	130	0.47	701.2	0.00	701.2	1760.012
Flue Gas	4.4932	265	567.021	567.022	7.32018	312	6.721289	71.1626	0.00	1.162597	319.75

Table 3: Summary of the Boilers Normal and Operating Conditions on Experiment Fuel Oil

Experiments Fuel Oil	Excess Air (%)	Combustor Energy Efficiency (%)	Combustor Exergy Efficiency (%)	Heat Exchanger Energy Efficiency (%)	Heat Exchanger Exergy Efficiency (%)	Overall Boiler Energy Efficiency (%)	Overall Boiler Exergy Efficiency (%)
Normal Boiler Operating Condition	26.66	99.71	52.07	81.14	32.83	59.77	16.08
Boiler at Optimal Operating Condition	10.58	99.90	57.35	94.80	37.26	73.82	19.86

The optimized boiler is that which has the highest energy and exergy efficiencies while operating at a region where CO and NO_x emission is minimal.

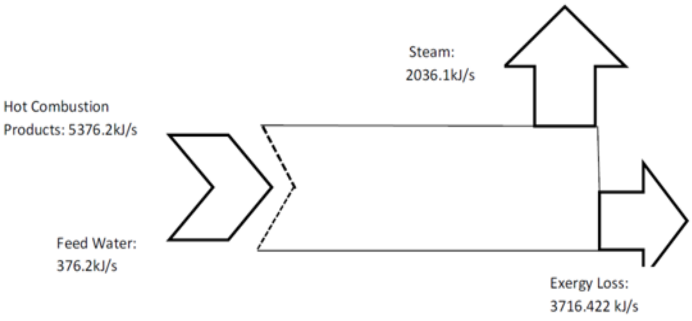


Figure 10: Grassman Diagram for Flow of Energy in Heat Exchanger: Initial Conditions

Table 4: Boiler Optimal Operating Conditions

Streams	Flow Rate (kg/s)	Temp. (°C)	H (kJ/kg)	h at Stream Temp. (kJ/kg)	s at stream Temp. (kJ/Kg K)	ho at Ref Condition (kJ/kg)	so at ref Condition (kJ/kg k)	Total Physical Exergy (kJ/kg)	Total Chemical Exergy (kJ/kg)	Total Exergy (kJ/Kg)
Fuel In	0.234	80	41795	41872.27	2.3	41795	2.1	15.865	44107.4	44123.27
Air In	3.7183	34	305.3	305.3	1.72	305.3	1.72	0	0	0.00
Hot Comb. Gas	3.9523	2002.21	2472.066	2472.066	8.877	312	6.721	1498.22	-13	1485.22
Water In	3.1	90	430	430	1.32	130	0.47	39.9	110	149.90
Steam Out	3.1	160	2759	2759	6.77	130	0.47	701.2	110	811.20
Flue Gas	3.9523	265	545.152	545.152	7.275	312.000	6.721	106.00	-13	93.00

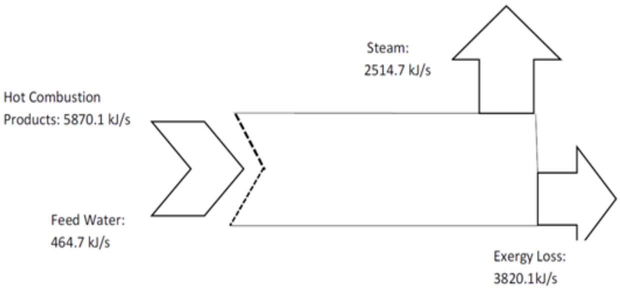


Figure 11: Grassman Diagram for Flow of Exergy in Heat Exchanger: Optimised Conditions

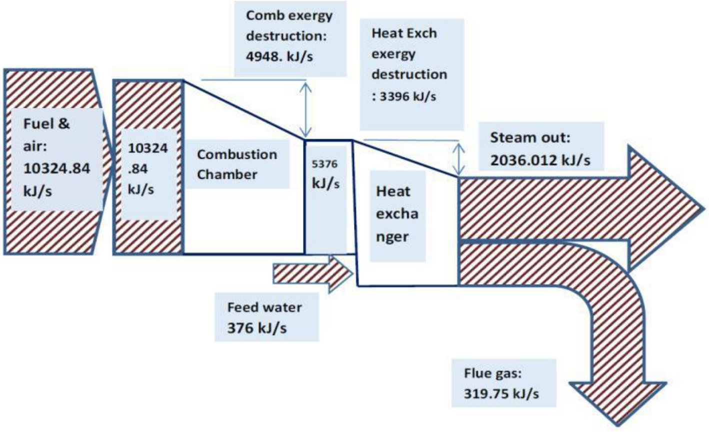


Figure 12: Grassman Diagram for Overall Boiler for Initial Conditions

The mass flow rate, mw, of water in (kg/s) as generated by the boiler after optimization, mf is the mass flow rate of fuel (kg/s) and h_s and hw are the specific enthalpies of steam and water at the generated and supplied conditions respectively in (kJ/kg).

Also, η, LHV and k are the efficiency of the boiler at the initial operating condition (before optimization), the fuel Lower Heating Value (J/kg) and the percentage utilization of the boiler in a year respectively.

The amount of money saved, assuming a litre of heavy fuel oil is 105 Naira is given as:

$$\frac{((m_w(h_s - h_w) - m_f)*60*60*24*365}{\rho} \times 1000 \times 10 \qquad (4)$$

This gives an approximate savings of 797918.5951kg/ year.

Since the density of the fuel oil is 935.5kg/m^3, converting to cubic meter, the yearly savings becomes 852.93276 m^{3}or 852932.76 litres. Assuming, 1itre of fuel oil costs 105 naira. This gives a total saving of 89,557,940 Naira per annum.

The combustor yielded the highest energy efficiency of 99.8% while the heat exchanger gave the lowest energy efficiency of 94% when run on both fuel oil and natural gas. These values are also within the ranges of results published in the literature.

At a constant fuel flow rate, burner rotary cup speed and ambient temperature, the energy and exergy efficiencies of the combustor, heat exchanger and over all boiler energy and exergy efficiencies decreased with increase in the excess air level supplied to the burner.

A reduction of excess air level from 26.67% to 12.36% eliminates the presence of CO and NO_x and improves the boiler overall energy efficiency by 11.67% and its overall exergy efficiency by 3.14% This improved efficiency translates to a savings of approximately 89 million naira annually for a boiler operating at 46% availability yearly.

The results of the effects of burner rotary cup speed and fuel nozzle sizes on emissions show that for boiler having liquid fuel nozzle sizes between 4mm and 6mm and with constant fuel inlet temperature of 82°C, air and fuel flow rates of 4.01 kg/s and 0.234 kg/s respectively, fuel atomization increases with increase in the speed of the rotary cup burner. This was observed for the nozzle sizes within the range of 4mm to 6mm but produced a strange result for a 3mm nozzle size. With burner of nozzle size of 3mm, the fuel analysis showed a mixture of both CO and NO_x emissions. However, for the burner of nozzle size of 3mm, regulating the air flow rate or the rotary cup speed below 3100 rev/min reduces (to a large extent) or eliminates the presence of NO_x but not CO. On the other hand, it was found that a reduction in the fuel flow rate with same level of air flows greatly reduced the level of formation of CO. A small proportion of NO_x (less than 23 ppm) was obtained. This suggests a great deal of influence of fuel jet velocity on the degree of atomization and hence complete combustion of the fuel as evidenced by the reduced CO formation.

Optimized boiler uses 0.234kg/s fuel to generate 3.1kg/s of steam at the initial condition, the boiler uses 0.234kg/s fuel to generate 2.51kg/s steam. Thus, at initial condition, for the boiler to generate 3.1kg/s steam, it would require:

$$m_f = m_w \times (h_s - h_w)/(\eta \times LHV)$$

$$m_f = 0.2879\ kg/s$$

But with optimised boiler, the fuel savings is (0.2879-0.234) which 0.053909kg/s. Thus, in one day, the savings will be: 0.053909 × 60 × 60 × 24 = 4657.758kg or 5.98 metre cubed. This implies 4980 litres and a litre = 105 naira. In one year, the savings is 191381400 naira. But the boiler availability is about 46.6%. Thus, yearly savings = 89m naira.

V. CONCLUSIONS

The following are conclusions drawn from this study:

1. The experiment results demonstrate a consistent improvement in both energy efficiency and exergy efficiency across various parameters as the excess air percentage decreases. The combustion and overall boiler performance exhibit notable enhancements, with the overall boiler exergy efficiency reaching 18.939% in the last experiment compared to 12.840% in the initial one.
2. The reduction in excess air percentage contributes to increased combustion efficiency, leading to higher energy and exergy efficiencies in the combustion process. Moreover, improvements are observed in heat exchange efficiency, as evidenced by the rise in energy and exergy efficiencies in the heat exchange.
3. The primary components that contributed to the energy loss were the heat exchanger and the combustor.
4. One of the most efficient ways to reduce boiler energy consumption is to use the flue gas heat recovery technique.
5. A nozzle size of 4mm diameter, with a burner rotary cup operating at speed of 2920 rev/min to 3200 rev/min generated minimum emission while burning fuel oil of 82^{o}C temperature with excess air of 12.36%. Similarly, nozzle size of 6mm, with rotary cup burner operating between 3950rev/min to 4400 rev/min at 12.36 % excess air generated emission without CO and NO_x, with fuel oil supplied at 82^{o}C.
6. Optimized boiler uses 0.234kg/s fuel to generate 3.1kg/s of steam at the initial condition, the boiler uses 0.234kg/s fuel to generate 2.51kg/s steam. Optimised boiler fuel saving was 0.053909kg/s.
7. Thus, in one day, the savings was 5.98 metre cube, which implies 4980 litres, assuming a litre = ₦105. In one year, the savings will be₦191,381,400 naira. But the boiler availability is about 46.6%. Thus, yearly savings = 89m naira. The research calculated an approximate savings of 797918.5951kg/ year of heavy fuel oil on the assumption that aitre of fuel oil costs 105 naira, then the total cost savings of ₦89, 557, 940 per annum was realised.

REFERENCES

[1] Rai G.D. (2004): Non- Conventional Energy Sources. Khanna Publishers, Delhi; 2004.

[2] Oniemola, P. and Sanusi, G. (2007). “The Nigerian Bio-fuel Policy and Incentives: A need to follow the Brazilian Pathway”. Energy, Economy, Environment: the Global View: Proceedings of the 32nd IAEE International Conference.

[3] Kaushik, S. C., Siva, R. K., & Tyagi, S. (2011). Energy and exergy analyses of thermal power plants. Renewable and Sustainable Energy review, 1857-72.

[4] Einstein D., Worrell E., Khrushch M., 2001. Steam Systems in Industry: Energy Use and Energy Efficiency Improvement Potentials, Lawrence Berkeley National Laboratory, Available at: /http://www.osti.gov/bridge/servlets/purl/789187-uTGqsP/native/S, 6/09/09.

[5] Energy Information Administration (EIA), 2007. International energy annual, online, retrieved 3rd January 2009 from /www.eia.doe.gov/ieaS.

[6] Rajput, R. K. (2006), Thermal Engineering, Laxmi Publications (P) Ltd., New Delhi.

[7] ERC, 2004. In: How to Save Energy and Money in Boilers and Furnace Systems. Energy Research Centre (ERC), University of Cape Town, South Africa.

[8] Mahmood, M., Bhutta, A., Hayat, N., Bhatti, A. A., Ahmad, M. A., & Uzair, A. (2016). Exergy Analysis : A New Way Of Analyzing The Engineering Processes. 28(4), 3989–3992.

[9] Sanober, H. K., Richard, G., & Neil, B. (2012). Suitability of exergy analysis for industrial energy efficiency, manufacturing and energy management. ECEEE Summer Study on Energy efficiency in industry, 237-4.

[10] Kumar, K., Patel, D., Sehravat, V., & Gupta, T. (2015). Performance and Exergy Analysis of the Boiler. 4(6), 3011–3015.

[11] Tony, Suryo U. M. S. K., Yohana, E., Priyanto, S. D., Ignatius Apryando, M., &Tauviqirrahman. (2019). Energy and Exergy Analysis of Steam Power Plant 3rd Unit PT PLN (PERSERO) Centre Unit Generation Tanjung Jati B Use BFP-T Modification Cycle. E3S Web of Conferences, 125(201 9). https://doi.org/10.1051/e3sconf/201912513003.

[12] Tonon, S., Brown, M. T., Luchic, F., Mirandola, A., Stoppato, A., and Ulgiati, S. (2006), An Integrated Assessment of Energy Conversion Processes By Means of Thermodynamic, Economic And Environmental Parameters, Energy Vol. 31, pp149-163.

[13] Ayhan, B. and Demirtas, C. (2001), Investigation of Turbulators for Fire Tube Boilers Using Exergy Analysis, Turk J Engin Environ Sci, TUBITAK Vol. 25, pp249-258.

[14] Dincer, I. Hussain, M. M. and Al-Zaharnah, I. (2003), Energy and Exergy Use in the Industrial Sector of Saudi Arabia, Proc. Instn. Mech. Engrs., Vol. 217, pp481-492. Part A: J. Power and Energy, A02603 IMechE.

Citation of this Article:

Ebieto, C. E., & Odoemenem, B. C. (2024). Energy, Exergy and Economic Analysis of Boiler Systems. *International Research Journal of Innovations in Engineering and Technology - IRJIET*, 8(8), 252-263. Article DOI https://doi.org/10.47001/IRJIET/2024.808029

****