Evaluation of Energy and Exergy Efficiency of Steam Generation and Utilization in Nigerian Pharmaceutical Industries

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Abstract
The results of the evaluation of energy-exergy efficiency of pharmaceutical plants in Nigeria have been presented. Two pharmaceutical plants at JUHEL and DANA in Awka, Anambra state and Minna Niger state were considered. The energy and exergy analyses of these pharmaceutical industries were used to determine the utilization efficiency of the process heat at different operating conditions. The exergy of the component system was evaluated and analysed with an engineering equation software (EES). The JUHEL boiler energy and exergy efficiencies were found to be 30.4% and 17.5% while the distillation unit recoded 42.3% energy and 22.6% exergy efficiencies. Similarly, DANA boiler energy and exergy efficiencies were found to be 22.4% and 16.6% by the autoclave unit which recorded 37.3% and 34.3% efficiencies. Other components of the plants with low energy and exergy efficiencies include; the steam headers, condensers and preheaters. Total exergy destruction for JUHEL and DANA plants was found at 13532kJ/hr for JUHEL and 14086KJ for DANA. Exergy destruction in JUHEL and DANA boilers were found at 6778 kJ/hr and 7789.5kJ/hr which accounted for 38% and 42.3% of the plants total exergy destruction respectively. However, the condenser and autoclave recorded 16% and 5% of the total exergy destruction in JUHEL plant while the same components recorded 15% and 5% of total destruction in DANA plant. The study also showed that for a 1^{o}C increase in ambient temperature, the exergy destruction in both plants increased by about 0.9%. However, variations in boiler inlet pressure showed that the rate of exergy destruction reduced with increased in boiler inlet pressure. The result of evaluation of the effect of flue gas constituents on boiler combustion efficiency showed that at 3.4% oxygen in flue gas, an optimal value of 14% excess air was recorded which resulted in optimal combustion efficiencies of 75% and 78%% for JUHEL and DANA plants respectively. The study suggests a retrofitting of the existing pharmaceutical plants and a time series analysis will be necessary to show how the plant's irreversibilities change with time for proper optimization.
Keywords: Energy, Exergy, Exergy Destruction, Combustion efficiency.

1. INTRODUCTION

The nexus between energy conversion, energy efficiency, energy supply and ecological concerns requires an enhanced use of energy resources for better efficiency. To actualize the goal of judicious use of resources and improved environmental sustainability, advanced thermodynamic techniques are required. There exist difficulties in using the conventional first law of thermodynamics alone for analysing efficiencies of thermodynamic systems used for process heat generation (boilers). The reason being that it gives misleading information about the efficiency of an energy conversion system since it fails to provide a measure of how nearly the performance of a system approaches ideality. For this reason, the combined approach of the first and second laws of thermodynamics, a concept called exergy, becomes imperative. Exergy as a thermodynamic tool can describe energy resource utilization as well as material loss to the environment and other secondary components in pharmaceutical or manufacturing plants. This makes it possible to quantify material flow within the environment and level of environmental sustainability. Many Nigerian pharmaceutical, chemical and utility sectors use steam boilers as their means of energy conversion. In pharmaceutical industries, the generated heat is used in secondary applications like in the distillers and the autoclave. In these units, components losses exits during heat transfer. The assessment of the complex thermodynamic process of the entire system and the needed improvement cannot be achieved with first law of thermodynamics alone (Qun *et al*., 2012; Winit *et al*., 2014). Krishan *et al*., (2013) performed a complete exergy analysis of a coal fire boiler based component wise modelling. The combustion efficiency for the fired coal was examined based on the simulated working data and the state properties of the plant. The result shows that the highest irreversibility occurs in the combustion process. Akubue *et al*., (2014) evaluated the performance of a steam boiler in a brewery in Nigeria using energy and exergy analysis. The exergy losses in the different boiler subsystems: combustion chamber, mixing section and heat exchanger were estimated. The exergy losses of the secondary component occurred in the combustion chamber followed by the heat exchanger. The energy and exergy analysis of steam boiler and autoclave in fibre cement process was presented by Ankit, (2012). The result showed that high exergy destruction rates was due to exhaust steam, condensate, and autoclave shell heat loss. Further, in terms of economic analysis, Saidur *et al*., (2010) considered the cost of exergy stream for industrial boilers fired with different fuels. The study shows that the exergy destruction cost was dominant in the combustion chamber and the economizers. Also, the exergy destruction cost was marginal with different fuel. Other cost analysis of industrial turbines has be presented in ERC, (2004). Ankit, (2012) carried out an energy and exergy analysis of a boiler with different fuels. He compared different types of coal like Indian coal, imported coal, mixture of both (60% imported+40 % Indian) and LPO oil and conclude that the first law efficiency was 76.54%, 83.03%, 80.60%, and 88.20% respectively. Also the exergetic efficiency of the boiler plant were recorded as 37%, 37.7%, 37.8% and 40.1% respectively for the fuels. Idehai, (2013) established an approach for the physical and chemical exergy study of steam boilers**.** Energy and exergy efficiencies obtained for the entire boiler was 69.56% and 38.57% at standard reference state temperature of 25^0C for an evaporation ratio of 12. Similarly, Sarang and Amkit, (2013) performed an exergy analysis of a boiler in a cogeneration thermal plant and concluded that the exergy destruction of the boiler at a load of 1.1 MW was 83.35% and 76.33 % for load of 5.6 MW. It was finally concluded that the system efficiency decreases at higher load and thus the exergy destruction. Pambudia *et al*., (2017) evaluated and optimized a fluidized bed boiler in ethanol plant using irreversibility analysis. The results showed that the exergy efficiencies of the boiler, deaerator, and pre-heater were 25.82%, 40.13%, and 2.617%, respectively. Soufiyan *et al*., (2016) presented an exergy analysis of a commercial tomato paste plant. Similarly, in a phosphoric acid factory, Hafdhi *et al*., (2015) studied energetic and exergetic interaction for a steam turbine which powers the system. Bouapetch *et al*., (2014) performed both energy and exergy analysis of a steam boiler and an autoclave in fiber based cement processing. The result presents values of 72.04 and 69.98% respectively in terms of energy and exergy. Taner and Sivrioglu, (2015) presented results comprising data on energy and exergy optimization for a sugar factory. The results showed an efficiency of 72.2% and 37.4% in terms of energy and exergy, respectively for the plant. However, the application of exergy analysis in pharmaceutical plants in Nigeria is not in open literature. Consequently, this study examines detailed exergy and energy utilization efficiencies of steam in to pharmaceutical plants in Nigeria. The effective parameters based on the local operating conditions will be well understood with exergy application. The findings from such study will prove useful in the design and optimization of efficient pharmaceutical plants.

2.1 MATERIALS AND METHODS

2.1.1 PLANT DESCRIPTION

The process flow diagrams of the JUHEL and DANA pharmaceutical plants are presented in Fig. 1. The plants are similar in components and process flow but differ in operating conditions. The plant comprises: the fire tube boiler, distillers, condensers and the autoclaves, preheaters and Pumps. JUHEL plant uses a reverse osmosis unit for primary filtration of water, while DANA uses activated carbon filters. Water is fed into the three pass, fire-tube boiler which is basically composed of a combustor and a heat exchanger. The combustion chamber is the turbo-engine component of the boiler. Fuel is supplied by the feeding nozzles of an electric burner, mixes with air flow coming from a forced draft fan and burns, releasing a stream of high temperature combustion product into the heat exchanger pipes. As it flows through the pipes, the pipes get very hot and thus transfers heat to the water which surrounds them. The water then gets heated up and turns into steam. While the flue gas is exhausted from the system through the flue gas stack, the steam is distributed through the steam line to the various operation devices such as the autoclaves, distillation units and condensers.

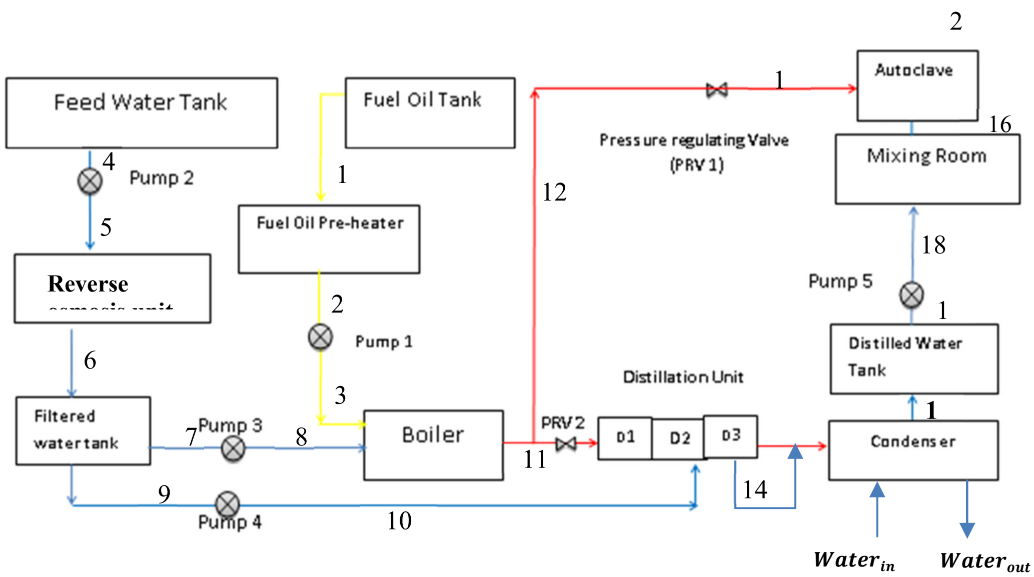

Fig. 1: Flow diagram of JUHEL/DANA pharmaceutical plants showing all the state points

Furthermore, a schematic diagram of the boiler with its accessories is shown in Fig. 2.

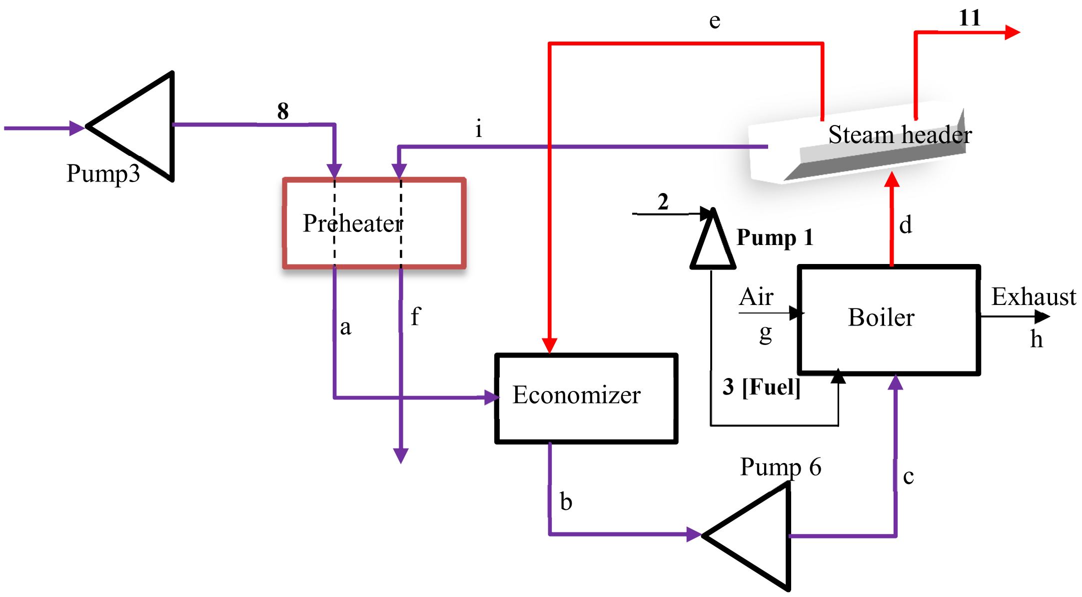

Fig. 2: Material flow of a fire tube boiler

2.1.2 DEVELOPED METHODS

Detailed exergy balance for the various components is presented in line with the general exergy balance for a control volume (Bejan and Tsatsaronis, 1995). The general exergy models for a control volume comprising exergy influx ex_{in}, efflux ex_{out}, heat input Q_{in} and work output W_{out} can be expressed under steady state conditions as:

$$\sum ex_{in} + ex_Q = \sum ex_{out} + ex_W + E_D \quad (1)$$

Where the specific exergy is expressed at a temperature $\boldsymbol{T}$ and pressure $\boldsymbol{P}$ all referenced at the ambient temperature $\boldsymbol{T_0}$ and pressure $\boldsymbol{P_0}$ as follows:

$$ex_{in,out} = [(h(T) - h(T_0)) - T_0\{(s(T) - s(T_0)\}] \quad (2)$$

In order to properly account for the properties of the system regarding the specific heat capacity at referenced temperatures, the pressure and other properties, the entropy change is here accounted for by employing the thermodynamic first law and necessary simplifications to obtain the expression for the entropy and enthalpy change below (Rajput, 2009):

$$\Delta s = c_p ln\left[\frac{T}{T_0}\right] - R * ln\left[\frac{P}{P_0}\right] \quad (3)$$

$$\Delta h = c_p[T - T_0] \quad (4)$$

Substituting these two expressions in equation 1, we obtain the term for calculating the physical exergy streams for the four structures as:

$$ex_{in,out} = \left\| c_p[T - T_0] - T_0\left\{c_p ln\left[\frac{T}{T_0}\right] - R * ln\left[\frac{P}{P_0}\right]\right\}\right\| \quad (5)$$

Additionally the exergy of heat and that due to work interaction is expressed as obtained in the expression below:

$$ex_Q = \left[1 - \frac{T_0}{T_Q}\right] Q_{in} \quad (6)$$

$$ex_W = W = c_p \Delta h \quad (7)$$

The developed expressions from equations 5 through 7 are necessary and sufficient to perform the component exergetic balance as follows:

The exergy at point 1 comprises the chemical exergy of fuel oil at standard temperature and pressure of 25°C and 1.013 bar, respectively. It is obtained using the following relationship:

$$\dot{E}_1 = \sum_i x_i E_{xi}^{CH} + RT_0 \sum x_i ln x_i \quad (8)$$

The mole fractions of constituents of the fuel are represented with the term $\boldsymbol{x_i}$ while the chemical exergy of the fuel is denoted by E_{xi}^{CH}.

The exergy at point 2 comprises the chemical exergy and slight physical which is added to the mass stream due to temperature variations at point 2. The exergy calculation is achieved using the following expression:

$$\dot{E}_2 = \sum_i x_i E_{xi}^{CH} + RT_0 \sum x_i ln x_i + h(T_2) - h(T_0) - T_0[s(T_2) - s(T_0)] \quad (9)$$

Equation 9 can be represented as:

$$\dot{E}_2 = \sum_i x_i E_{xi}^{CH} + RT_0 \sum x_i ln x_i + h(T_2) - h(T_0) - T_0\left[c_p ln\frac{T_2}{T_0} - R.ln\frac{P_2}{P_0}\right] \quad (10)$$

Following similar pressure conditions at point 2 and the ambient, the physical exergy term which comprises the pressure term is zero. Consequently, the exergy at point 2 can be written as:

$$\dot{E}_2 = \sum_i x_i E_{xi}^{CH} + RT_0 \sum x_i ln x_i + h(T_2) - h(T_0) - T_0 \left[c_p ln \frac{T_2}{T_0}\right] \quad (11)$$

Exergy balance around the fuel preheater is obtained as follows:

$$\dot{E}_1 = \dot{E}_2 + \dot{D}_{FPH} \quad (12)$$

Exergetic efficiency when applied to the fuel preheater is obtained with the relationship:

$$\psi_{FPH} = \frac{\sum_i x_i E_{xi}^{CH} + RT_0 \sum x_i ln x_i + h(T_2) - h(T_0) - T_0\left[c_p ln \frac{T_2}{T_0}\right]}{\sum_i x_i E_{xi}^{CH} + RT_0 \sum x_i ln x_i} \quad (13)$$

The exergy at point 3 is obtained by incorporating the pressure variation due to the pump with the relationship as:

$$\dot{E}_3 = \sum_i x_i E_{xi}^{CH} + RT_0 \sum x_i ln x_i + h(T_3) - h(T_0) - T_0 \left[c_p ln \frac{T_3}{T_0} - R. ln \frac{P_3}{P_0}\right] \quad (14)$$

Pump work can be expressed as:

$$\dot{W}_{Pump1} = v_{f@P_2}(P_3 - P_2) \quad (15)$$

Exergy balance around the pump therefore takes the form:

$$\dot{E}_2 + \dot{W}_{PUMP1} = \dot{E}_3 + \dot{D}_{P1} \quad (16)$$

The exergy efficiency for the pump is expressed with the relationship:

$$\psi_{P1} = \frac{\dot{E}_3 - \dot{E}_2}{\dot{W}_{PUMP1}} \quad (17)$$

The physical exergy at point 4 (for water) is negligibly small since its temperature is nearly ambient; and its pressure is same as the ambient pressure.

At point 5, the physical exergy following increased pressure by virtue of the pump can be expressed as:

$$\dot{E}_5 = [h(T_5) - h(T_0)] - T_0 \left[c_p ln \frac{T_5}{T_0} - R. ln \frac{P_5}{P_0}\right] \quad (18)$$

However, since the temperature at point 5 is nearly ambient, the physical exergy is merely obtained by the pressure variation of the water at pump inlet and outlet. Accordingly, the physical exergy at point 5 is reduced to:

$$\dot{E}_5 = T_0 \left[R. ln \frac{P_5}{P_0}\right] \quad (19)$$

Pump work is expressed as:

$$\dot{W}_{Pump2} = v_{f@P_4}(P_5 - P_4) \quad (20)$$

The exergy balance around the water pump and exergetic efficiency is written as:

$$\dot{E}_4 + \dot{W}_{PUMP2} = \dot{E}_5 + \dot{D}_{P2} \quad (21)$$

$$\psi_{P2} = \frac{\dot{E}_5 - \dot{E}_4}{\dot{W}_{PUMP2}} \quad (22)$$

Exergy at points 5 and 6 are same and expressed as:

$$\dot{E}_5 = \dot{E}_6 \quad (23)$$

$$\dot{E}_5 = \dot{E}_6 + \dot{D}_{ACF} \quad (24)$$

At the filtered water tank, exergetic conditions at inlet and outlet are similar. The expressions as well as the exergy balance is obtained as:

$$\dot{E}_6 = \dot{E}_7 = \dot{E}_9 \quad (25)$$

Exergy balance around the filtered water tank is expressed as:

$$\dot{E}_6 = \dot{E}_7 + \dot{E}_9 + \dot{D}_{FWT} \quad (26)$$

At point 8, the exergy is obtained with the expression:

$$\dot{E}_8 = [h(T_8) - h(T_0)] - T_0 \left[c_p ln \frac{T_8}{T_0} - R. ln \frac{P_8}{P_0}\right] \quad (27)$$

Exergy balance around pump 3, and its exergy efficiency is obtained as:

$$\dot{E}_7 + \dot{W}_{PUMP3} = \dot{E}_8 + \dot{D}_{PUMP3} \quad (28)$$

$$\psi_{PUMP3} = \frac{\dot{E}_8 - \dot{E}_7}{\dot{W}_{PUMP3}} \quad (29)$$

Where the pump work is obtained as follows:

$$\dot{W}_{Pump3} = v_{f@P_7}(P_8 - P_7) \quad (30)$$

Similarly, exergy balance around pump 4, and its exergy efficiency is obtained as foll)ows:

$$\dot{E}_9 + \dot{W}_{PUMP4} = \dot{E}_{10} + \dot{D}_{PUMP4} \quad (31)$$

$$\psi_{PUMP4} = \frac{\dot{E}_{10} - \dot{E}_9}{\dot{W}_{PUMP4}} \quad (32)$$

Where the pump work is obtained as:

$$\dot{W}_{Pump4} = v_{f@P_9}(P_{10} - P_9) \quad (33)$$

With respect to the operating temperature and pressure at point 10, the exergy at this point is obtained as:

$$\dot{E}_{10} = [h(T_{10}) - h(T_0)] - T_0 \left[c_p ln \frac{T_{10}}{T_0} - R. ln \frac{P_{10}}{P_0}\right] \quad (34)$$

Exergy balance around the preheater is obtained with the expression:

$$\dot{E}_8 + \dot{E}_i = \dot{E}_a + \dot{E}_f + \dot{D}_{Preheater} \quad (35)$$

Exergy computations at the state points ***i***, ***a***, and ***f*** is obtained with following expressions:

$$\dot{E}_i = [h(T_i, P_i) - h(T_0, P_0)] - T_0[s(T_i, P_i) - s(T_0, P_0)] \quad (36)$$
$$\dot{E}_a = [h(T_a, P_a) - h(T_0, P_0)] - T_0[s(T_a, P_a) - s(T_0, P_0)] \quad (37)$$
$$\dot{E}_f = [h(T_f, P_f) - h(T_0, P_0)] - T_0[s(T_f, P_f) - s(T_0, P_0)] \quad (38)$$

Exergetic efficiency for the preheater is obtained as:

$$\dot{\psi}_{Preheater} = \frac{\dot{E}_i - \dot{E}_f}{\dot{E}_a - \dot{E}_8} \quad (39)$$

At the economizer, exergy balance is expressed by:

$$\dot{E}_a + \dot{E}_e = \dot{E}_b + \dot{D}_{Economizer} \quad (40)$$

Streams at points ***a***, and ***e***, form the component fuel, while the stream at ***b*** forms the product. Accordingly, the exergetic efficiency for this component is expressed as:

$$\dot{\psi}_{Economizer} = \frac{\dot{E}_b}{\dot{E}_a + \dot{E}_e} \quad (41)$$

At state point ***e***, and ***b***, the exergy is a function of steam temperature and pressure and can be obtained with the following functions:

$$\dot{E}_b = [h(T_b, P_b) - h(T_0, P_0)] - T_0[s(T_b, P_b) - s(T_0, P_0)]_{Hot\,water} \quad (42)$$
$$\dot{E}_e = [h(T_e, P_e) - h(T_0, P_0)] - T_0[s(T_e, P_e) - s(T_0, P_0)]_{Steam} \quad (43)$$

Similarly, exergy balance around pump 6, and its exergy efficiency is obtained as follows:

$$\dot{E}_b + \dot{W}_{PUMP6} = \dot{E}_c + \dot{D}_{PUMP6} \quad (44)$$
$$\psi_{PUMP6} = \frac{\dot{E}_c - \dot{E}_b}{\dot{W}_{PUMP6}} \quad (45)$$

Where the pump work is obtained as:

$$\dot{W}_{Pump6} = v_{f@P_b}(P_c - P_b) \quad (46)$$

With respect to the operating temperature and pressure at point c, the exergy at this point is obtained as:

$$\dot{E}_c = [h(T_c, P_c) - h(T_0, P_0)] - T_0[s(T_c, P_c) - s(T_0, P_0)]_{Hot\,water} \quad (47)$$

At the boiler, the exergy balance is written as:

$$\dot{E}_g + \dot{E}_c + \dot{E}_Q = \dot{E}_d + \dot{E}_h + \dot{D}_{Boiler} \quad (48)$$

Where the term $\dot{E}_Q$ is the exergy of heat in the boiler, and $\dot{E}_h$ is the exergy associated with the exhaust. Terms of Equation 48 are expressed as follows:

$$\dot{E}_g = [h(T_g) - h(T_0)] - T_0\left[c_p ln\frac{T_g}{T_0} - R.\, ln\frac{P_g}{P_0}\right] \quad (49)$$

The expression above represents the exergy of air at inlet to the boiler. The exergy of heat in the boiler is obtained as:

$$\dot{E}_Q = \left[1 - \frac{T_0}{T_{Boiler}}\right]\dot{Q}_{Boiler} \quad (50)$$

With respect to the mass of oil burnt and its calorific value, Equ. 50 is written as:

$$\dot{E}_Q = \left[1 - \frac{T_0}{T_{Boiler}}\right] * \dot{m}_{Fuel\,Oil} * LHV_{Fuel\,Oil} \quad (51)$$

At the exhaust, approximated exergy at the exhaust is estimated with the relationship:

$$\dot{E}_h = [h(T_h) - h(T_0)] - T_0\left[c_p ln\frac{T_h}{T_0} - R.\, ln\frac{P_h}{P_0}\right] \quad (52)$$

Values for the specific heat are obtained based on the mass fractions of exhaust constituents.

The exergy of superheated steam at point ***d*** is obtained with the relationship:

$$\dot{E}_d = [h(T_d, P_d) - h(T_0, P_0)] - T_0[s(T_d, P_d) - s(T_0, P_0)]_{Steam} \quad (53)$$

Exergetic efficiency for the boiler takes the form:

$$\psi_{Boiler} = \frac{[h(T_d,P_d) - h(T_0,P_0)] - T_0[s(T_d,P_d) - s(T_0,P_0)]_{Steam}}{\dot{E}_Q = \left[1 - \frac{T_0}{T_{Boiler}}\right] * \dot{m}_{Fuel\,Oil} * LHV_{Fuel\,Oil} + [h(T_g) - h(T_0)] - T_0\left[c_p ln\frac{T_g}{T_0} - R.ln\frac{P_g}{P_0}\right]} \quad (54)$$

The exergy of steam delivered to the distillers at point 11 is obtained as:

$$\dot{E}_{11} = [h(T_{11}, P_{11}) - h(T_0, P_0)] - T_0[s(T_{11}, P_{11}) - s(T_0, P_0)]_{Steam} \quad (55)$$

Total exergy destruction in the boiler can be summed as:

$$\dot{D}_{TOTAL} = \dot{D}_{Preheater} + \dot{D}_{Economizer} + \dot{D}_{Boiler} + \dot{D}_{Pump6} \quad (56)$$

3.1 RESULTS AND DISCUSSION

3.1.1 Utilization Efficiency of JUHEL and DANA Plants Based on Energy and Exergy Efficiencies

The fuel utilization efficiency (FUE) is the ratio of all the useful energy extracted from the system to the energy of the fuel input at a particular condition.The fuel utilization efficieincy was considered at full load conditions of the system and components performances were expressed in terms of energy and exergy efficiencies.The fuel utilization efficiency varies from 30.4 to 67.2 % for energy efficiency and 17.5 to 55.6 % for exergy efficiency for JUHEL plant (Fig. 3a). Similarly, the FUE for DANA plant vary from 22.4 to 68.9 % for energy efficiency and 16.6 to 54.9 % for exergy efficiency (Fig.3b). Components with high utilization efficiency include the pumps, distilled water tank, distillation unit, and fuel preheater. The reason for the high FUE is attributed to low entropy generation which results in low exergy destruction. In the boiler system, the difference between the flame temperatures and the working fluid is responsible for the low FUE. However, the variations in components FUE and performance could be ascribed to large variations in operating parameters, faulty components and level of maintenance.

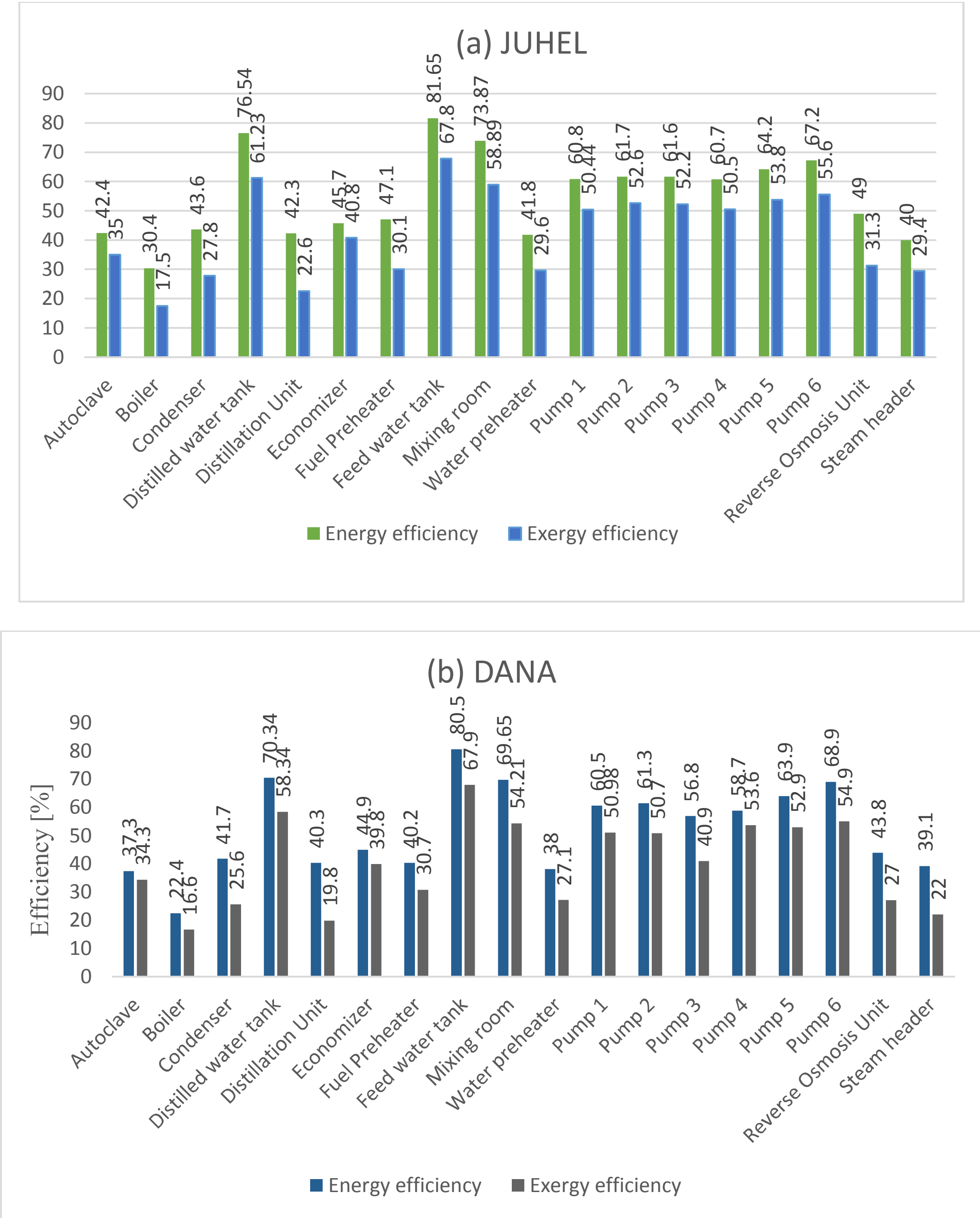

Fig. 3: Utilization efficiency of the plant components based on energy and exergy efficiencies (a) JUHEL plant and (b) DANA plant

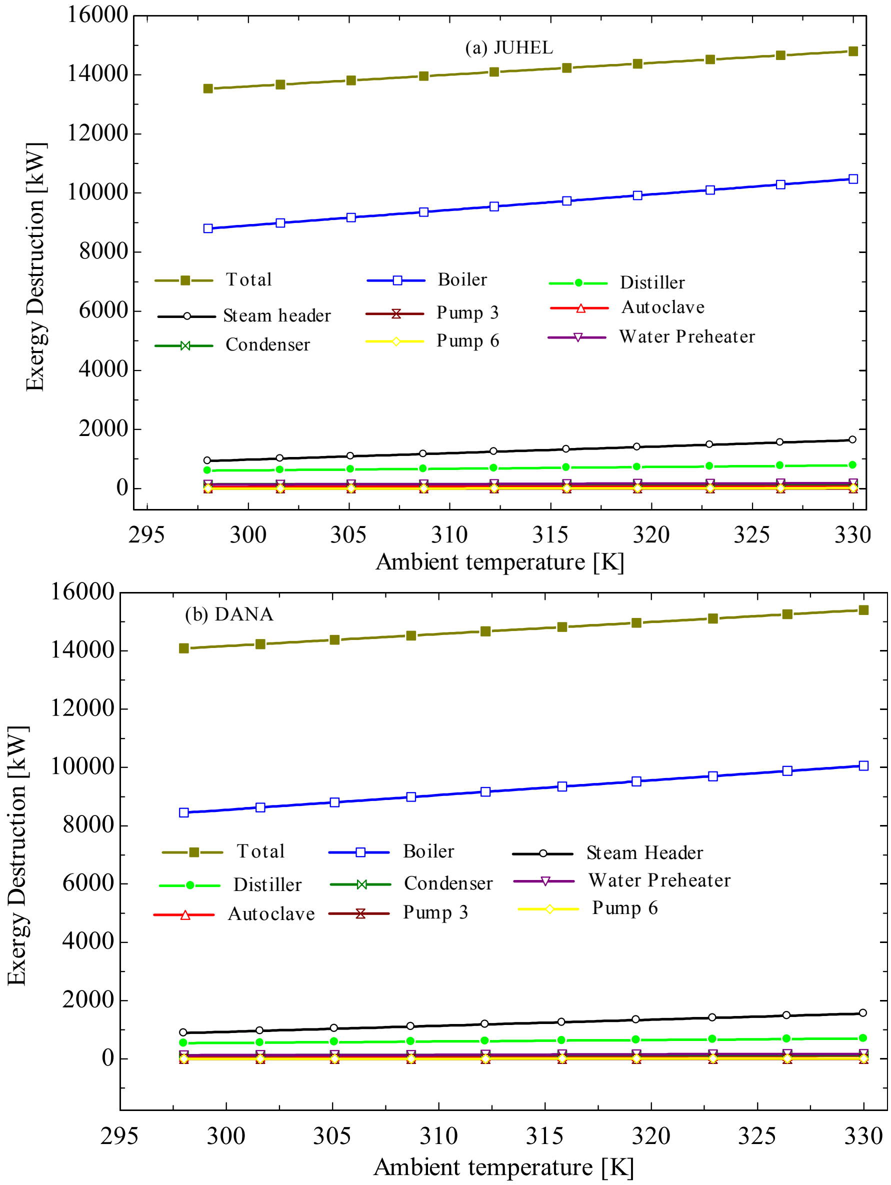

Fig. 4: The effect of ambient temperature on exergy destruction rate in (a) JUHEL plant and (b) DANA plant

3.1.2 The Effect Ambient temperature on the Exergy Destruction Rate

The effect of ambient temperature (AT) on the components performance and the entire plant is presented in Fig. 4a for JUHEL plant and Fig. 4b for DANA plant. Total exergy destruction for JUHEL and DANA plants was found at 13532KW for JUHEL and 14086KW for DANA. Exergy destruction in JUHEL and DANA boilers was found at 6778KW and 7789.5KW which accounted for 38% and 42.3% of the plants total exergy destruction respectively. However, the condenser and autoclave recorded 16% and 5% of the total exergy destruction in JUHEL plant while the same components recorded 15% and 5% of total destruction in DANA plant. The study also showed that for a 1°C increase in ambient temperature, the exergy destruction in both plants increased by about 0.9%. It is worth noting that operating the plants in environments of lower ambient air temperature will reduce the exergy destruction rate in the plant's components and the entire plant. Optimization of the actually temperature input required for proper combustion is necessary.

3.1.3The Effect of Inlet Boiler Pressure on the Exergy Destruction Rate

The effect of boiler inlet pressure was investigated for pressure range between 10 and 26 bars for JUHEL and DANA plants, Figs.5(a) and (b). The result showed that increase in boiler inlet pressure resulted in decreased exergy destruction and increased exergy efficiency. Moreover, for a pressure increase from 10 to 26bars, the total exergy destruction decreased from 15000KW to 13800KW in JUHEL and to 15400KW to 14000KW in DANA. This showed that exergy destructions in both plants decreased by about 1% for every 0.8% increase in pressure.

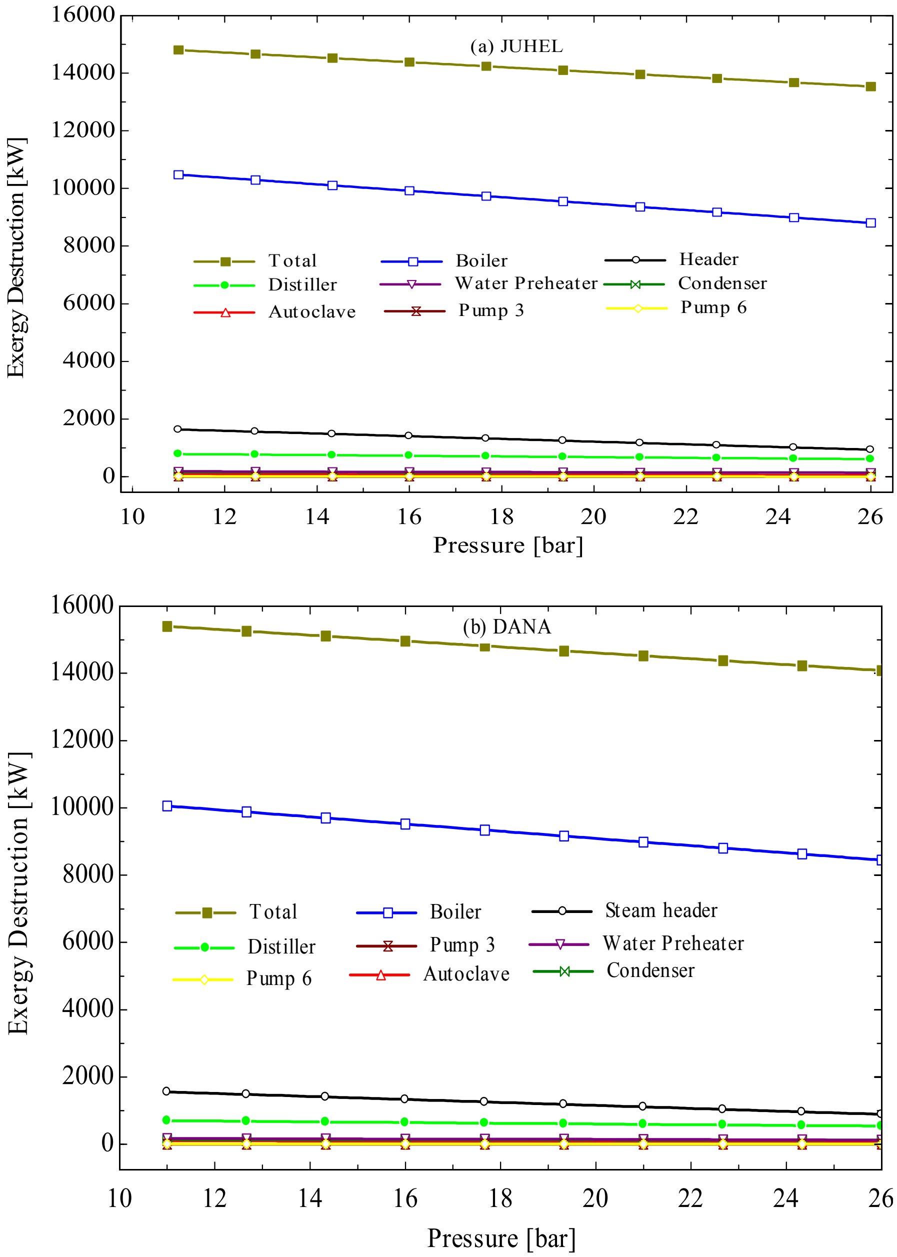

Fig. 5: The effect of boiler inlet pressure on exergy destruction rate (a) JUHEL plant and (b) DANA plant

3.1.4 The Effect of Excess Air on Flue Gas Temperature and Combustion Efficiency

Parametric effect of excess air on gas temperature is shown in Fig. 4a. for JUHEL and DANA plants. Excess air was varied between 5 and 23 % for both plants. The results showed that increasing the amount of excess air beyond 14% results in increase in flue gas temperature. Moreover, between 5 and 14 % excess air, gas temperatures increased slowly while at excess air values of above 14 %, there is a sharp increase in gas temperatures due to unburnt oxygen which carries heat away through the flue gas.

Similarly, results of gas temperature effect on combustion efficiency is shown in Fig. 4b. Higher gas temperatures which resulted from addition of excess air beyond 14% affected the combustion efficiency. For JUHEL and DANA plants, gas temperatures varied between 150 to 194 ^{o}C, and 152 to 209 ^{o}C, respectively. Combustion efficiencies increased marginally from 30.4 to 74.7 % corresponding to temperature increase from

150 to 154 °C after which the combustion efficiency dropped to 53.7 % at flue gas temperature of 194 °C for JUHEL. Similarly, Combustion efficiencies increased marginally from 22.4 to 77.8 % corresponding to temperature increase from 152 to 159 °C after which the combustion efficiency dropped to 59.17 % at flue gas temperature of 208.87 °C for DANA.

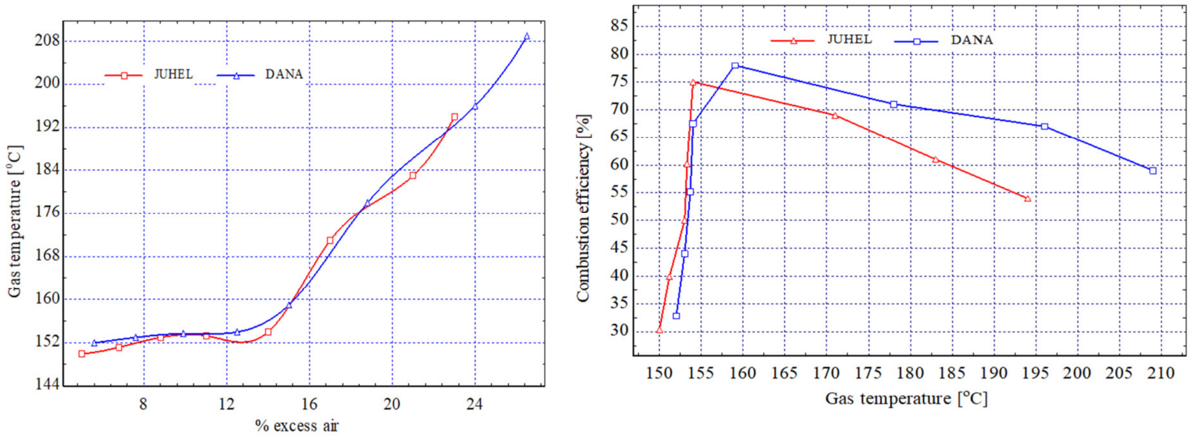

Fig. 6 (a) and (b): Effect of excess air on flue gas temperature (a) and effect of gas temperature on combustion efficiency (b)

4.1 CONCLUSION

The energy-exergy based performance analysis of pharmaceutical plants in Nigeria was studied. Detailed exergy analysis at the state points was studied with the operating data for the two plants. Some of the operating data considered include ambient temperature, boiler inlet pressure and air flow rate. The variations of this parameters were studied based on their corresponding effect on exergy destruction and exergy utilization efficiency. However, high exergy losses were recorded in the boiler, autoclave and the distillers for the two plants. The boiler chamber was found to have the highest level of exergy destruction, this is so because of inherent contributions of losses from more than one source.

Furthermore, the research has shown that variations in ambient temperature and other operating factors like boiler inlet pressure and air flow rate influences the performance of the plants. The results showed that for a 1°C increase in ambient temperature, the exergy destruction increases by about 0.9 % in the components and about 0.11% for the overall ED. Furthermore, the rate of exergy destruction in the boiler is about 4 times the rate of exergy destruction in the distillers and about 2 times the rate of exergy destruction in the autoclave.

The following findings were made after conclusion of the research:

The fuel utilization efficiency varies from 30.4 to 67.2 % for energy efficiency and 17.5 to 55.6 % for exergy efficiency for JUHEL plant. Similarly, the FUE for DANA plant vary from 22.4 to 68.9 % for energy efficiency and 16.6 to 54.9 % for exergy efficiency.

The total exergy destruction for JUHEL and DANA plants was found at 13532kJ/hr for JUHEL and 14086KJ for DANA. The findings also show that for a 1°C increase in AT, the exergy destruction increases by about 0.9 % in the components and about 0.11% for the overall ED. However, the boiler, preheater and the autoclave recorded the highest exergy destruction.

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