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Sustainability Analysis of Steam Generation in Nigerian Pharmaceutical Industries

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ABSTRACT:*Sustainability index of steam generation and utilization in Nigerian pharmaceutical industries was assessed in this study at varying operating conditions using exergy analysis approach. Two pharmaceutical plants were considered which include JUHEL and DANA plants located in Awka, Anambra state and Minna, Niger state, respectively. Result revealed that increased ambient temperature and air flow rate resulted in increased environmental effect factor (EEF) and waste exergy ratio (WER) while the overall exergy efficiency (ψ) and sustainability index (SI) decreased for both plants. Contrarily, for boiler inlet pressure increase the OEE and SI increased while the EEF and WER decreased. However, EEF, WER, ψ and SI in JUHEL plant were found at 4.8, 0.84, 17.5% and 0.21 respectively while the same indicators were found at 5.0, 0.87, 16.6% and 0.19 respectively in DANA plant.*

KEYWORDS:*Environmental Effect factor***,** *Sustainability Index, Waste Exergy Ratio, Overall Exergy Efficiency*

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I INTRODUCTION

Steam boiler applications for process heat generation in pharmaceutical and chemical industries cannot be over emphasized, particularly for medicinal herbs processing and drying, sterilizing as well as purifying. The medicine production in a pharmaceutical plant needs to be precise, which means the heat produced must be adequately utilized and system components must be efficient with less heat losses. The low capacity utilization of process heat in most pharmaceutical industries shows there exists large losses between system components. This large gap clearly indicates the level of technical inefficiency in the existing energy conversion systems of the plant. The application therefore, of the exergy concept to ascertain the causes and level of system inefficiencies, low utilization efficiency as well as the environmental sustainability indicators makes this study unique. The subject of sustainability is becoming more important with environmental and cost reduction characteristics. Following the increase in global energy need, the number of thermal generating plants and process heat production increases year to year. The increase in energy source costs and the negative effects of wastes on the environment requires sustainable/renewable energy sources. Sustainability analysis is necessary to overcome present ecological, economic, and developmental problems [1].

Exergy-based sustainability has been applied to thermodynamic system, for example, [2], performed an exergo-sustainability analysis in a turbojet engine. The results show that the exergetic efficiency was calculated at 29.2%, waste exergy ratio 70.8%, exergetic destruction ratio 0.41 and environmental effect factor 2.43, while exergetic sustainability index approaches a maximum value of 0.41. Also [3], performed an exergetic sustainability investigation of a gas turbine power plant. The study indicates that exergetic sustainability index for the gas turbine plants was 0.651 while the steam turbine stood at 0.978. The findings recommend an improvement in the overall efficiency and reviewed exergetic sustainability indicators. In all these application of exergy-based sustainability in thermal plants, non-exist for boiler integrated application like the pharmaceutical plant in consideration. The application of exergetic sustainability analysis in assessing the performance of pharmaceutical plants in Nigeria is not in open literature. However, this study examines the sustainability of steam generation and utilization systems in the Nigerian pharmaceutical industries. 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 and improvement in environmental sustainability. Additionally, as Nigeria is considering and employing the updated national energy plan with more importance on energy efficiency strategies, in both pharmaceutical, chemical, manufacturing, steel and power sectors, this research will offer an insight to the performance of these related plants, and also proffer future efficiency enhancement strategy for process heat generation and utilization in these industries.

II MATERIALS AND METHODS

Exergetic sustainability indicators are exergy based indices which comparatively assesses the performance of energy conversion systems based on exergy efficiency, useful system output, and the environmental impact of such systems which occurs due to large thermodynamic irreversibilities. The exergetic sustainability indicators considered in this study include Overall Exergy Efficiency (ψ), Waste Exergy Ratio and Environmental Effect Factor. The exergy efficiency is obtained from the following relation given by [4] and [5].

$$\psi = \frac{exergyofproduct}{\dot{e}_{FUEL}} = \frac{[h(T_d,P_d)-h(T_0,P_0)]-T_0[s(T_d,P_d)-s(T_0,P_0)]_{Steam}}{\dot{E}_Q=\left[1-\frac{T_0}{T_{Boiler}}\right]*\dot{m}_{FuelOil}*LHV_{FuelOil}} \quad (1)$$

The waste exergy ratio quantifies the degree of cumulative thermodynamic irreversibilities in a plant with respect to the exergy input to the system. For thermal power plants and boilers, the available exergy input is the chemical exergy of the fuel used. The waste exergy ratio(WER) is obtained mathematically as the overall exergy waste (or destruction) for the system on the total exergy input as follows by [6]:

$$\text{WER} = \frac{\dot{D}_{Pre\,heater}+\dot{D}_{Economizer}+\dot{D}_{Boiler}+\dot{D}_{Pump\ 6}}{\left[1-\frac{T_0}{T_{Boiler}}\right]*\dot{m}_{FuelOil}*LHV_{FuelOil}} \quad (2)$$

The environmental effect factor (EEF) quantifies the degree of cumulative thermodynamic irreversibilities in a plant with respect to the plants net exergy efficiency. It also comparatively relates the extent to which a plants useful output is severely affected due to relatively high thermodynamic irreversibilities resulting in environmental degradation. The EEF is expressed by [6], as the ratio of the waste exergy ratio upon the exergy efficiency (Equation 3)

$$EEF = \frac{\text{WER}}{\psi} = \frac{\dot{D}_{Pre\,heater}+\dot{D}_{Economizer}+\dot{D}_{Boiler}+\dot{D}_{Pump\ 6}}{\left[1-\frac{T_0}{T_{Boiler}}\right]*\dot{m}_{FuelOil}*LHV_{FuelOil}*\psi} \quad (3)$$

The exergetic sustainability index (SI) is a non-dimensional term which explains the extent by which an energy conversion system total useful output exceeds the total internal thermodynamic irreversibilities. This term assists in thermodynamically assessing by what fraction a system's useful output overcomes the seemingly inherent net exergetic destruction in the system. Thus, a system with exergy output far larger than the total destruction rate will have sustainability index greater than unity while systems with comparatively large destruction than plant output are not sustainable. The reciprocal of the environmental effect factor is termed the exergetic sustainability indexis expressed mathematically by [6], as follows;

$$SI = \frac{\left[1-\frac{T_0}{T_{Boiler}}\right]*\dot{m}_{FuelOil}*LHV_{FuelOil}*\psi}{\dot{D}_{Pre\,heater}+\dot{D}_{Economizer}+\dot{D}_{Boiler}+\dot{D}_{Pump\ 6}} \quad (4)$$

Substituting for values of exergy efficiency, the SI can be written as:

$$SI = \frac{\dot{E}_d=[h(T_d,P_d)-h(T_0,P_0)]-T_0[s(T_d,P_d)-s(T_0,P_0)]_{Steam}}{\dot{D}_{Pre\,heater}+\dot{D}_{Economizer}+\dot{D}_{Boiler}+\dot{D}_{Pump\ 6}} \quad (5)$$

Thus;

$$SI = \frac{Exergyofproduct}{Grandexergydestruction} \quad (6)$$

III RESULTS AND DISCUSSION

The effect of AT on sustainability indicator for JUHEL plant (Fig. 1) and DANA plant (Fig. 2) at temperature range between 295K and 335K is presented. The sustainabilityindicators include: overall exergy efficiency, environmental effect factor and waste exergy ratio. The ψ decreases from about 17.5 % at 298 K to 12.8 % at 330K for JUHEL plant and decreases from about 16.6% at 298 K to 12.2% at 335 K for DANA plant. At the same temperature range, the exergetic sustainability index decreases from 0.20 to 0.189 for JUHEL plant and 0.19 to 0.18 for DANA plant. The SI dropped approximately by 10 % for both plants respectively. Similarly between the same operating limits the environmental impact was about 12.25 %. For JUHEL plant and 12.08% for DANA plant. Nonetheless, the EEF shows increasing trend for all increasing values of AT.

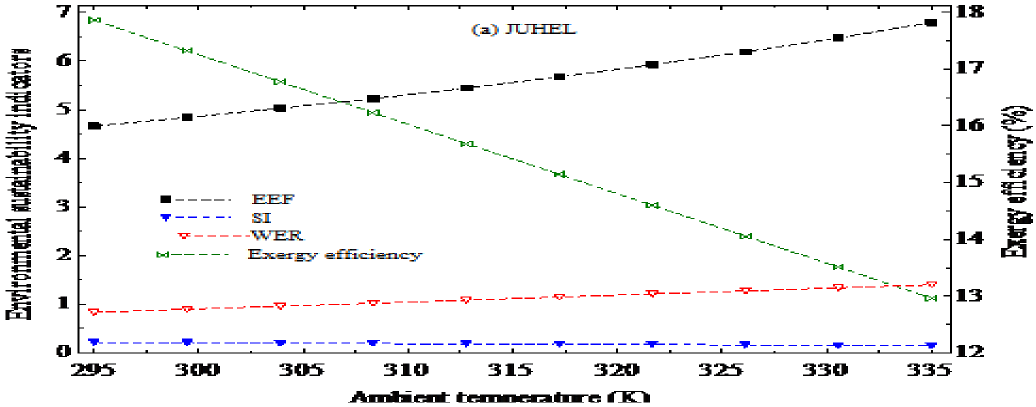

Fig. 1: Effect of Ambient Temperature on Sustainability Indicators of JUHEL Plant

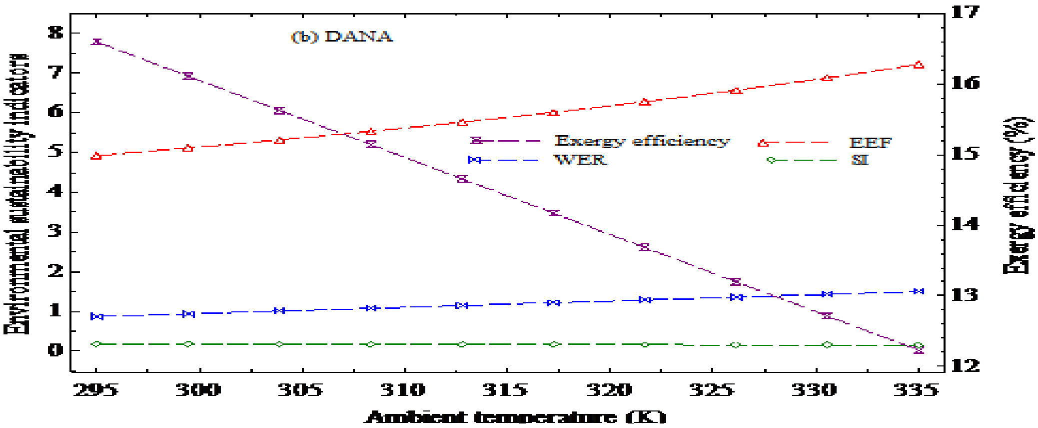

Fig. 2: Effect of Ambient Temperature on Sustainability Indicators of DANA Plant

Analysis of respective boiler inlet pressure of JUHEL and DANA plants presented in Fig. 3 and Fig. 4 showed that for increase in boiler inlet pressure from 10 to 26 bars, sustainability index recorded slight improved values. Thus, the SI also increased from 0.21 to 0.38 in JUHEL and from 0.19 to 0.34 in DANA. However, within the same pressure range, the EEF decreased from 4.7 to 3.6 in JUHEL and 5.0 to 4.3 in DANA plant while the WER

also decreased from 0.84 to 0.62 in JUHEL and 0.87 to 0.64 in DANA plant. The OEE increased from 17.5% to 18.5% in plant and from 16.6% to 17.8% in DANA plant.

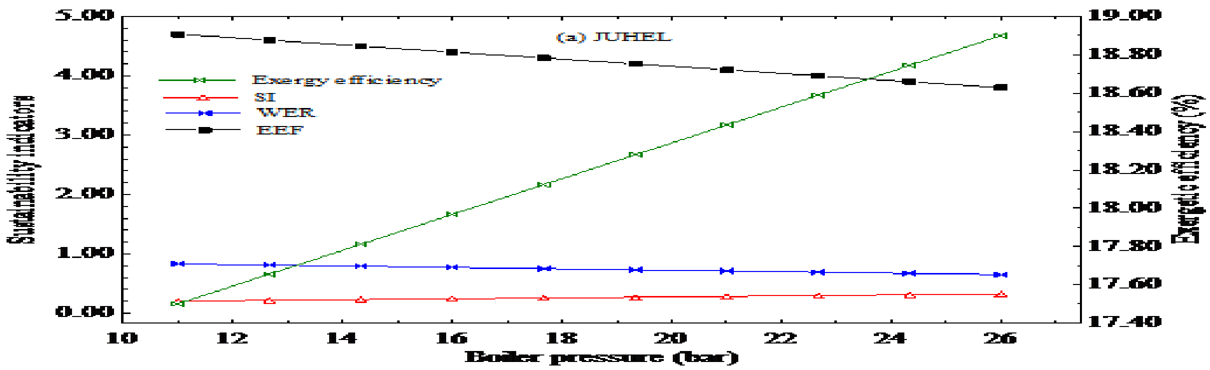

Fig. 3: Effect of Boiler Pressure on Sustainability Indices of JUHEL Plant

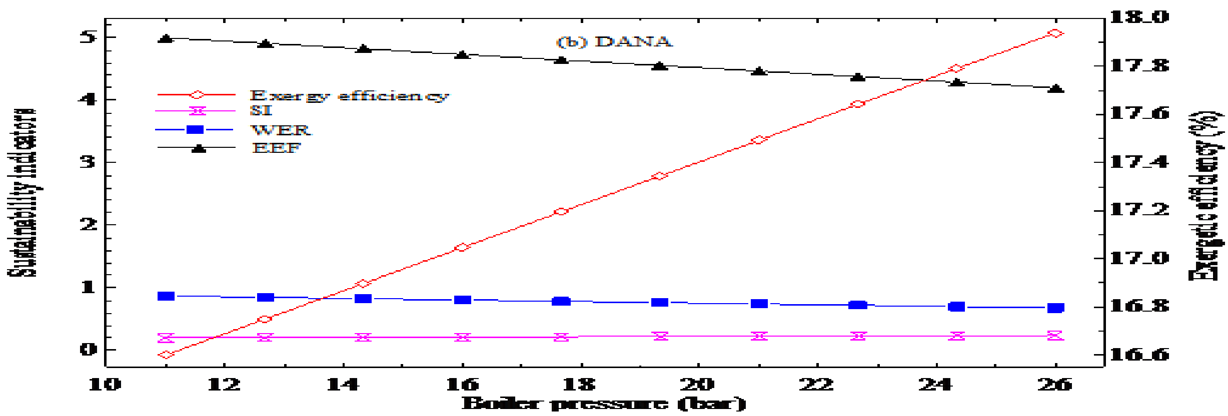

Fig. 4: Effect of Boiler Pressure on Sustainability Indices of DANA Plant

The effect of Air Flow Rate on Environmental Sustainability Indicators of JUHEL (Fig. 5) and DANA (Fig. 6)revealed that the waste exergy ratio increased from 0.84 to 0.98 for JUHEL and 0.87 to 0.91 for DANA plant as air flow increased from 22kg/s to 30kg/s. Environmental Effect Factor also increased slightly from 4.7 to 4.98 for JUHEL and from 5.0 to 5.55 for DANA plant. The Sustainability Index decreased from 0.209 to 0.201 for JUHEL and 0.197 to 0.180 for DANA plant. The overall exergy efficiency decreased from 17.5% to 15% for JUHEL and from 16.6% to 14% in DANA plant.

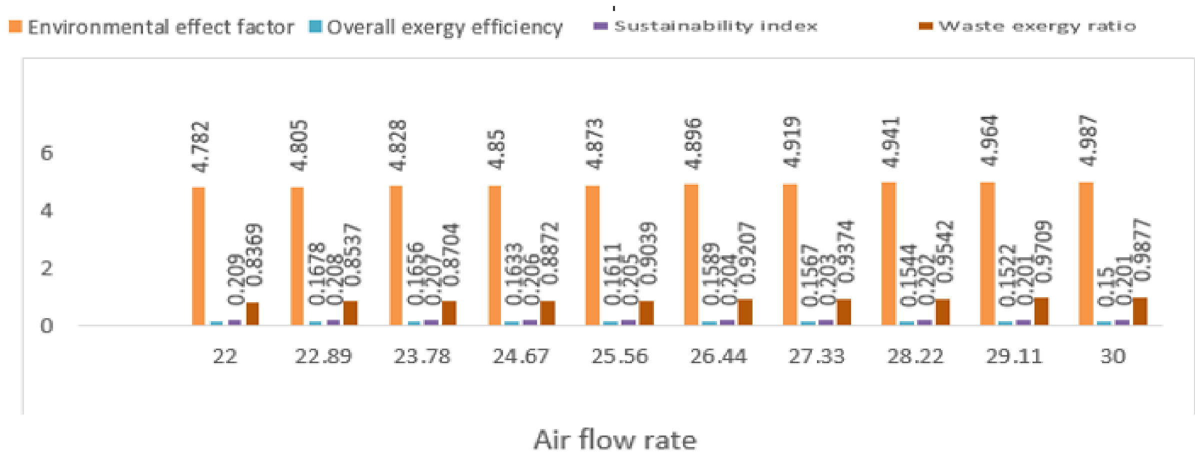

Fig. 5: Effect of Air Flow Rate on Environmental Sustainability Indicators of JUHEL Plant

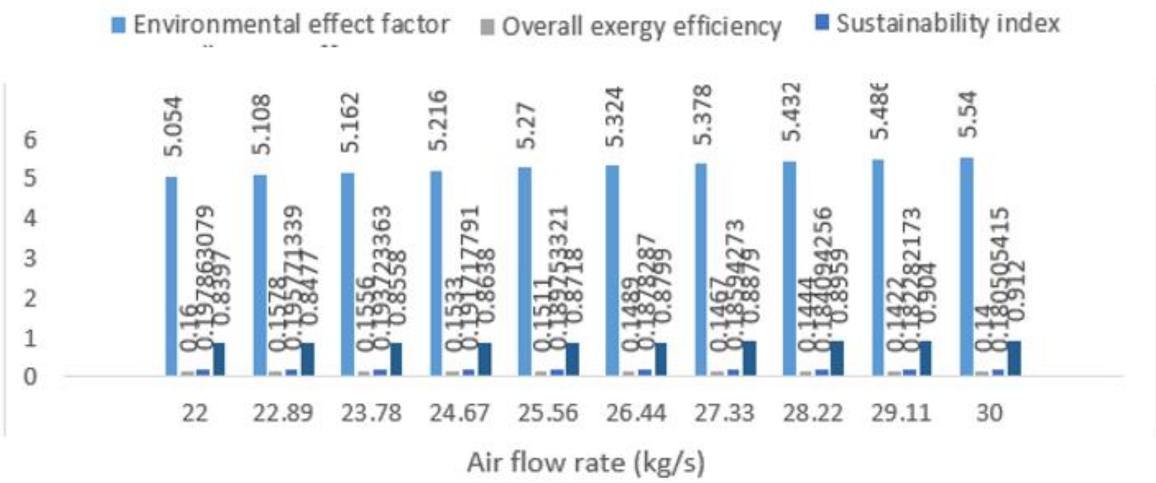

Fig. 6: Effect of Air Flow Rate on Environmental Sustainability Indicators of DANA Plant

IV CONCLUSION

This study showed the exergetic efficiency of JUHEL and DANAboilersas 17.5% and 16.6% respectively. Furthermore, the Environmental Effect Factor (EEF) was found at 4.8 and 5.0 for JUHEL and DANA plants respectively, while the Waste Exergy Ratio (WER) was found at 0.84 for JUHEL and 0.87 DANA plant. The EEF and WER increased with increase in ambient temperature and air flow rate for both plants, but decreased with decrease in boiler inlet pressure. However, both plants recorded slight improved waste exergy ratio of 0.02 % at lower AFR. The sustainability index for both plants was calculated at 0.20 and 0.19 respectively.

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