British Journal of Applied Science & Technology
3(4): 1201-1214, 2013

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A Study of Sections Interaction Effects on Thermodynamic Efficiencies of a Thermal Power Plant

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Authors' contributions

This work was carried out in collaboration between both authors. Author POA designed the study and the simulation and author ANA was my supervisor for the research. Authors POA and ANA analyzed the data, discussed the results and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

Research Article

Received 8th May 2013
Accepted 27th June 2013
Published 30th July 2013

ABSTRACT

Aim: A study of energy and exergy analyses was carried out on a thermal power plant in order to investigate the interaction effects of coupling sections of the plant and overall system.
Study Design: Simulation, energy and exergy analyses were used.
Place and Duration of study: The plant is located at Egbin in Lagos State of Nigeria and the duration of study was between March and May 2010.
Methodology: The thermal power plant was simulated using Hyprotech System Simulation (HYSYS) software and Excel spreadsheet was used for the energy and exergy analyses. The sections were grouped into four, namely: turbine-generator, condenser, regenerator and furnace-boiler sections. The energetic and exergetic efficiencies and irreversibilities at different throughputs (50, 75, 100 and 110% power outputs) were evaluated for each section and the sections were coupled into subsections one after the other until the whole sections were coupled.
Results: The results showed that the furnace-boiler and the condenser sections have the least exergetic efficiencies of an average of 24.08% and 38.85%, respectively, while the

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energetic efficiencies of the regenerator and furnace-boiler were the least and were 67.04% and 62.74% on the average, respectively. The overall system energetic and exergetic efficiencies were at an average of 20.21% and 11.17%, respectively. Furthermore, the results showed that the closed loop topology of the thermal plant and the high irreversibilities in the furnace-boiler section made the highest contributions in determining the overall process efficiencies. The overall irreversibilities of the plant increased as the throughput increased, but the overall energetic and exergetic efficiencies were not sensitive to changes in plant throughput.

Conclusion: The overall second-law efficiency (exergy efficiency) of the plant was lower than the overall energy efficiency as was expected because of proper accounting of different types of process exergies of material, heat and work in the plant.

Keywords: Thermal power plant; energy; exergy; efficiency; irreversibility; subsection; HYSYS software.

1. INTRODUCTION

Exergy analysis is a thermodynamic analysis technique based on the first and second laws of thermodynamics which provides an alternative and illuminating means of assessing and comparing processes and systems rationally and meaningfully [1]. Exergy represents the part of energy, which can be converted into maximum useful work. It is used to establish criteria for the performance of engineering devices [2]. In particular, exergy analysis yields efficiencies which provide a true measure of how nearly actual performance approaches the ideal, and identifies more clearly than energy analysis the causes and locations of thermodynamic losses. Consequently, exergy analysis can assist in improving and optimizing designs [3,4].

Unlike energy, exergy is not conserved and gets depleted due to irreversibilities in the processes [5]. The greater the extent of irreversibilities, the greater the entropy production, therefore, entropy can be used as a quantitative measure of irreversibilities associated with a process [5,6]. The performance of engineering systems is degraded by the presence of irreversibilities, and the entropy production is a measure of the magnitudes of the irreversibilities present during that process [6].

Several studies had been carried out by researchers [7−10] to evaluate the performance of thermal power plants using exergy analysis. Energy, exergy and exergoeconomic analyses were used on a steam power plant using natural gas [11]. The comparison of coal-fired and nuclear steam power plants using energy and exergy analyses to identify areas with potential for performance improvement has been investigated [12]. Analysis of a Rankine cycle was carried out on reheat steam power plant to study the energy and exergy efficiencies at different operating conditions with varying boiler temperature, boiler pressure, mass fraction ratio and work output from the cycle [13]. Exergy and cost balances had been used to study gas-turbine cogeneration system [14]. The performance of a thermo-economic analysis of a coal fired electricity generating station was achieved [15] and the investigation of the exergetic destructions of a steam generation system [16].

This study undertook exergy analysis of a natural gas based thermal power plant, located at Egbin in Ikorodu Local Government Area of Lagos State of Nigeria. The objectives of this study were to determine the energetic and exergetic efficiencies and irreversibilities of the four sections and the overall system at different throughputs (50, 75, 100 and 110% power outputs) and the effects of coupling sections of the thermal plant on thermodynamic efficiencies.

2. PLANT DESCRIPTION

The thermal power plant burns fossil fuels, which primarily consists of natural gas (NG) and high pour fuel oil (HPFO) as back up, and generates steam which is converted to shaft work in the turbine and to electric power in the generator. The steam generated in the boiler enters the turbine at temperature of about 540ºC and pressure of 12.5MPa to spin the turbine blade at a very high speed of 3000 rev/min. There are six turbines units, each capable of generating 220 MW. The water from the lagoon is used as cooling water. The water is passed through the condenser to enhance the recovery of water from steam. The recovered water in the condenser enters the condensate polishing plant for treatment before being sent back to the boiler for re-use. The cooling water which gains temperature from the condenser exits through a discharge channel into the lagoon. The temperature of the effluent water from the powerhouse is reduced in the supplementary cooling system before finally being discharged back into the lagoon [17]. The process flow diagram of the plant is shown in Fig. 1. The thermal plant has 23 units and these were grouped into 4 sections, namely; turbine-generator, condenser, regenerator and boiler-furnace sections as shown in Fig. 1.

3. METHODOLOGY

3.1 Simulation

Process data were obtained from the plant and HYSYS (2003) process simulator was used to simulate the plant [18]. The Peng-Robinson equation of state was used for the simulation. In this analysis, the following assumptions were made: Natural gas, which was assumed to be mainly methane, was used as fuel in the plant; the compressed air used in the combustor was standard air; unaccounted heat loss from the system due to radiation and convection was neglected; fuel undergoes complete combustion. The HYSYS model of the thermal plant is shown in Fig. 2.

3.2 Energy and Exergy Analyses

The exergy and energy calculations were done using EXCEL spreadsheet after extracting the thermodynamic data from the HYSYS simulations environment. These were calculated using the formulae given in the theory section applied to each section, subsection and overall process of the thermal plant.

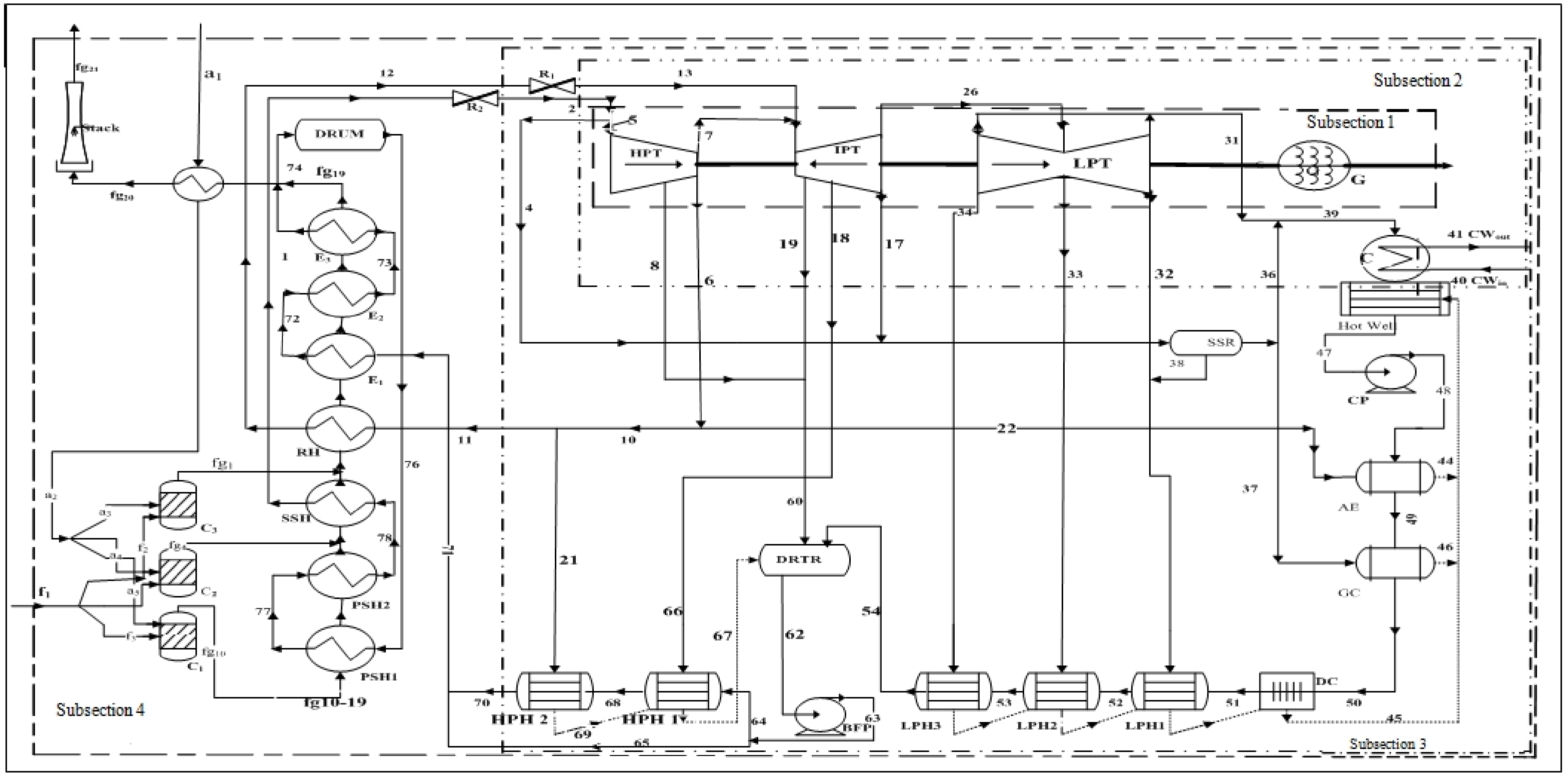

Fig. 1. Process flow diagram of the plant showing the subsections and overall system

Subsection 1: – – – – – ; Subsection 2 — · · — · · · ; Subsection 3 – · – · – · – · ; Subsection 4 /Overall system — — — —

PSH-Primary Superheater, SSH-Secondary Superheater, RH-Reheater, E-Economizer, AP-Air Preheater, HPT-High Pressure Turbine, IPT-Intermediate Pressure Turbine, LPT- Low Pressure Turbine, C-Condenser, CP-Condenser Pump, AE- Aerator Ejector, GC- Grand Condenser, DC-Drain Cooler, LPH-Low Pressure Heater, DRTR-Deaerator, BFP- Boiler Feed Pump, HPH- High Pressure Heater, C_1, C_2,...Combustors, a_1, a_2,... air streams, 1, 2,... Process streams,

f_1, f_2,...Natural Gas, fg1, fg2,....flue gas streams.

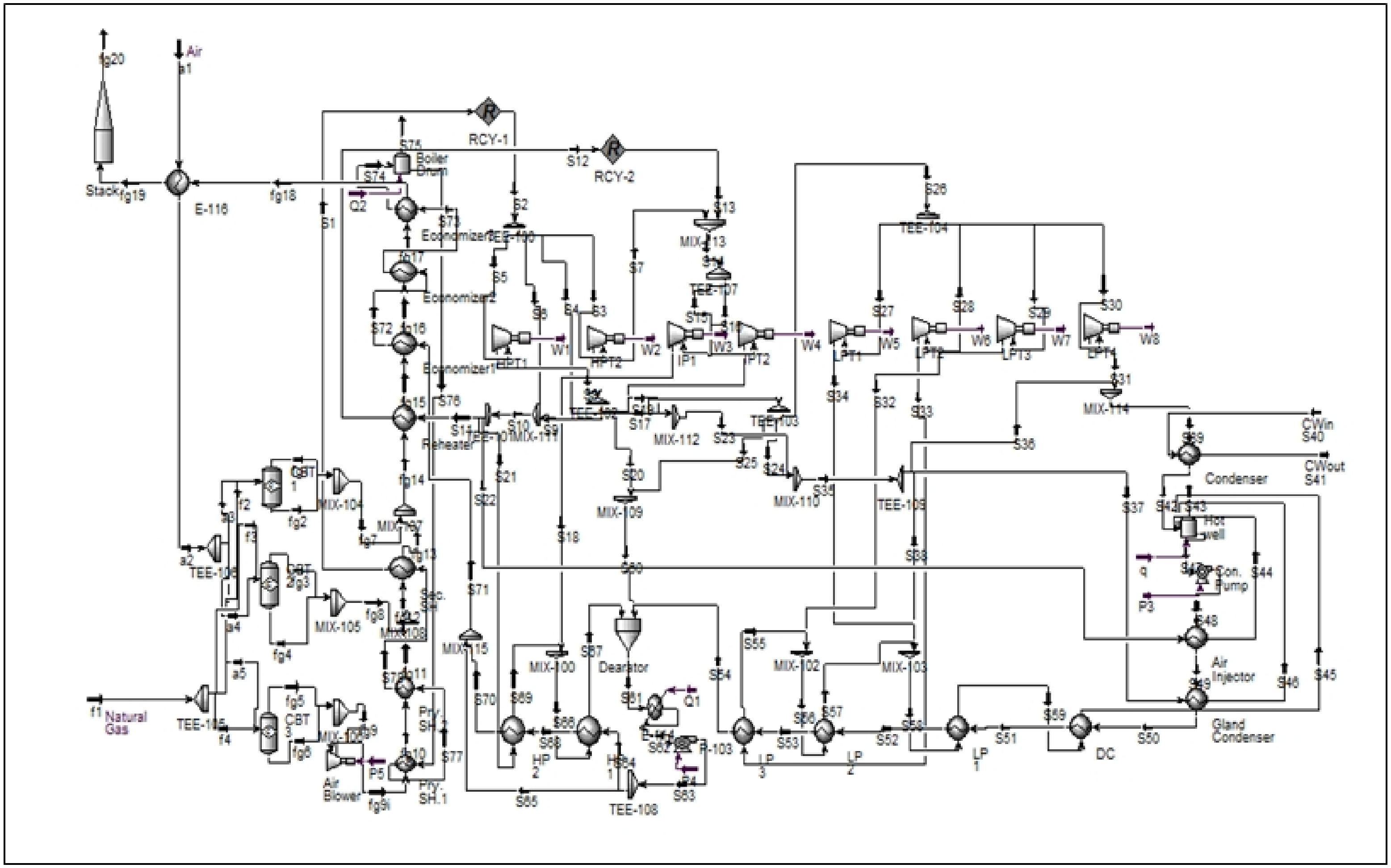

Fig. 2. HYSYS model of the thermal plant

3.2.1 Energy and exergy analyses of sections

3.2.1.1 The turbine-generator section

The energy and exergy of source and sink were calculated by considering all the streams entering and leaving the section.

The following equations were used.

$$\dot{E}_{in} = \dot{E}_{S3} + \dot{E}_{S5} + \dot{E}_{S15} + \dot{E}_{S16} + \dot{E}_{S27} + \dot{E}_{S28} + \dot{E}_{S29} + \dot{E}_{S30} \quad (1)$$

$$\dot{E}_{out} = \dot{E}_{S7} + \dot{E}_{S8} + \dot{E}_{S17} + \dot{E}_{S18} + \dot{E}_{S31} + \dot{E}_{S32} + \dot{E}_{S33} + \dot{E}_{S34} \quad (2)$$

$$\dot{E}_{source} = \dot{E}_{in} - \dot{E}_{out} \quad (3)$$

$$\dot{E}_{\sin k} = P_i \quad (4)$$

$$\dot{E}x_{in} = \dot{E}x_{S3} + \dot{E}x_{S5} + \dot{E}x_{S15} + \dot{E}x_{S16} + \dot{E}x_{S27} + \dot{E}x_{S28} + \dot{E}x_{S29} + \dot{E}x_{S30} \quad (5)$$

$$\dot{E}x_{out} = \dot{E}x_{S7} + \dot{E}x_{S8} + \dot{E}x_{S17} + \dot{E}x_{S18} + \dot{E}x_{S31} + \dot{E}x_{S32} + \dot{E}x_{S33} + \dot{E}x_{S34} \quad (6)$$

$$\dot{E}x_{source} = \dot{E}x_{in} - \dot{E}x_{out} \quad (7)$$

$$\dot{E}x_{\sin k} = P_i \quad (8)$$

Where:
P_i is the power generated.

3.2.1.2 The condenser section

The energy and exergy of source and sink in the condenser section were also calculated by considering all the hot and cold streams entering and leaving the section. The equations are:

$$\dot{E}_{source} = \dot{E}_{S39} - \dot{E}_{S42} \quad (9)$$

$$\dot{E}_{\sin k} = \dot{E}_{S41} - \dot{E}_{S40} \quad (10)$$

$$\dot{E}x_{source} = \dot{E}x_{S39} - \dot{E}x_{S42} \quad (11)$$

$$\dot{E}x_{\sin k} = \dot{E}x_{S41} - \dot{E}x_{S40} \quad (12)$$

3.2.1.3 The regenerators section

The regenerative part of the system is the heat exchangers where the heats are recovered back into the system. The energy and exergy of streams were also calculated by considering all the streams entering and leaving the section. The equations are:

$$\dot{E}_{in} = \dot{E}_{S21} + \dot{E}_{S22} + \dot{E}_{S37} + \dot{E}_{S48} + \dot{E}_{S56} + \dot{E}_{S58} + \dot{E}_{S66} \quad (13)$$

$$\dot{E}_{out} = \dot{E}_{S44} + \dot{E}_{S46} + \dot{E}_{S57} + \dot{E}_{S59} + \dot{E}_{S67} + \dot{E}_{S69} + \dot{E}_{S71} \quad (14)$$

$$\dot{E}_{source} = \Sigma \dot{E}_{in} \tag{15}$$

$$\dot{E}_{\sin k} = \Sigma \dot{E}_{out} \tag{16}$$

$$\dot{E}x_{in} = \dot{E}x_{S21} + \dot{E}x_{S22} + \dot{E}x_{S37} + \dot{E}x_{S48} + \dot{E}x_{S56} + \dot{E}x_{S58} + \dot{E}x_{S66} \tag{17}$$

$$\dot{E}x_{out} = \dot{E}x_{S44} + \dot{E}x_{S46} + \dot{E}x_{S57} + \dot{E}x_{S59} + \dot{E}x_{S67} + \dot{E}x_{S69} + \dot{E}x_{S71} \tag{18}$$

$$\dot{E}x_{source} = \Sigma \dot{E}x_{in} \tag{19}$$

$$\dot{E}x_{\sin k} = \Sigma \dot{E}x_{out} \tag{20}$$

3.2.1.4 The furnace-boiler section

The furnace-boiler section of the thermal plant is the section where energy needed by the plant is generated. The energy and exergy balances are:

$$\dot{E}_{source} = \Sigma \dot{E}_{in} = \dot{E}_{fuel\ in} + \dot{E}_{air\ input} + \dot{E}_{\Delta H_{rxn}} + \dot{E}_{S71} \tag{21}$$

$$\dot{E}_{\sin k} = \Sigma \dot{E}_{out} = \dot{E}_{S1} + \dot{E}_{S12} + \dot{E}_{flue\ gas} \tag{22}$$

$$\dot{E}x_{source} = \Sigma \dot{E}x_{in} = \dot{E}x_{fuel\ in} + \dot{E}x_{air\ input} + \dot{E}x_{rxn}^{Ch} + \dot{E}x_{S71} \tag{23}$$

$$\dot{E}x_{\sin k} = \Sigma \dot{E}x_{out} = \dot{E}x_{S1} + \dot{E}x_{S12} + \dot{E}x_{flue\ gas} \tag{24}$$

Exergy analysis of thermal plants involves chemical reactions of various kinds including reactions of combustion. It is therefore important that the method of analysis used should offer means of dealing, without undue complication, with the chemical aspects of energy conversion [19]. The chemical exergy of the fuel due to combustion was considered along side with the physical exergy. The enthalpy and entropy values used in calculating the heat of reaction and exergy of chemical reaction were taken from literature [19].

The reaction of methane and air is:

$$CH_4 + 2(O_2 + 3.76N_2) \longrightarrow CO_2 + 2H_2O + 7.52N_2 \tag{25}$$

The specific exergy of chemical reaction (kJ/kg) can be written as [19,20]

$$\bar{e}_{in}^{Ch_{rxn}} = \left(\bar{h}CH_4 + 2\bar{h}O_2 - \bar{h}CO_2 - 2\bar{h}H_2O\right) - T_o\left(\bar{s}CH_4 + 2\bar{s}O_2 - \bar{s}CO_2 - 2\bar{s}H_2O\right) \tag{26}$$

This gives the exergy rate of chemical reaction entering the plant as:

$$\dot{E}x_{in}^{Ch} = \dot{m}_{in}^{Ch}\ x\ n_{Ch}\ x\ \bar{e}_{in}^{Ch_{rxn}} \tag{27}$$

Where: $\dot{m}_{in}^{Ch}$ is the mass flow rate of chemical substance at the inlet,

n_{Ch} is the mass fraction of chemical substance.

3.3 Energy and Exergy Balances on the Subsections and Overall System

For the purpose of studying coupling (interaction) effects among sections, the whole thermal plant was grouped into subsections as shown in Fig. 1. For full understanding of these balances the HYSYS model of the plant has to be compared with process flow diagram of the plant.

3.3.1 The turbine-generator as subsection 1 (Base Case)

The turbine-generator section was also chosen as the base case subsection 1. Therefore, the energy and exergy balance equations of plant section 1 given in equations 1 - 8 are applicable here.

3.3.2 Coupling of turbine-generator and the condenser (subsection 2)

The energy and exergy efficiencies were also calculated by considering all the streams entering and leaving the subsections. These are:

$$\dot{E}_{in} = \dot{E}_{S3} + \dot{E}_{S5} + \dot{E}_{S15} + \dot{E}_{S16} + \dot{E}_{S27} + \dot{E}_{S28} + \dot{E}_{S29} + \dot{E}_{S30} + \dot{E}_{S40} \quad (28)$$

$$\dot{E}_{out} = \dot{E}_{S7} + \dot{E}_{S8} + \dot{E}_{S17} + \dot{E}_{S18} + \dot{E}_{S32} + \dot{E}_{S33} + \dot{E}_{S34} + \dot{E}_{S41} + \dot{E}_{S42} \quad (29)$$

$$\dot{E}_{\sin k} = P_i \quad (30)$$

$$\dot{E}_{source} = \Sigma\dot{E}_{in} - \Sigma\dot{E}_{out} \quad (31)$$

$$\dot{E}x_{in} = \dot{E}x_{S3} + \dot{E}x_{S5} + \dot{E}x_{S15} + \dot{E}x_{S16} + \dot{E}x_{S27} + \dot{E}x_{S28} + \dot{E}x_{S29} + \dot{E}x_{S30} + \dot{E}x_{S40} \quad (32)$$

$$\dot{E}x_{out} = \dot{E}x_{S7} + \dot{E}x_{S8} + \dot{E}x_{S17} + \dot{E}x_{S18} + \dot{E}x_{S32} + \dot{E}x_{S33} + \dot{E}x_{S34} + \dot{E}x_{S41} + \dot{E}x_{S42} \quad (33)$$

$$\dot{E}x_{\sin k} = P_i \quad (34)$$

$$\dot{E}x_{source} = \Sigma\dot{E}x_{in} - \Sigma\dot{E}x_{out} \quad (35)$$

3.3.3 Coupling of turbine-generator, condenser and the regenerators (subsection 3)

The regenerative part of the system is the heat exchangers where the heats are recovered back into the system. The efficiencies (energetic and exergetic) were also calculated by considering all the streams entering and leaving the subsections. These are:

$$\dot{E}_{source} = \Sigma\dot{E}_{in} = \dot{E}_{S2} + \dot{E}_{S13} + \dot{E}_{S40} \quad (36)$$

$$\dot{E}_{\sin k} = \dot{E}_{out} = \dot{E}_{S11} + \dot{E}_{S41} + \dot{E}_{S71} \quad (37)$$

$$\dot{E}x_{source} = \dot{E}x_{in} = \dot{E}x_{S2} + \dot{E}x_{S13} + \dot{E}x_{S40} \quad (38)$$

$$\dot{E}x_{\sin k} = \dot{E}x_{out} = \dot{E}x_{S11} + \dot{E}x_{S41} + \dot{E}x_{S42} \tag{39}$$

3.3.4 Coupling of the four sections (the overall system)

In calculating the overall efficiency and overall irreversibility of the thermal plant, the streams of material entering and leaving the entire plant were considered.

The overall energy and exergy balances are:

$$\dot{E}_{source} = \Sigma\dot{E}_{in} = \dot{E}_{fuel\ in} + \dot{E}_{air\ input} + \dot{E}_{\Delta H} + \dot{E}_{cooling\ water\ in} \tag{40}$$

$$\dot{E}_{\sin k} = \Sigma\dot{E}_{out} = \dot{E}_{flue\ gas} + \dot{E}_{cooling\ water\ in} \tag{41}$$

$$\dot{E}x_{source} = \Sigma\dot{E}x_{in} = \dot{E}x_{fuel\,in} + \dot{E}x_{air\,input} + \dot{E}x^{Ch}_{rxn} + \dot{E}x_{cooling\,water\,in} \tag{42}$$

$$\dot{E}x_{\sin k} = \Sigma\dot{E}x_{out} = \dot{E}x_{flue\ gas} + \dot{E}x_{cooling\ water\ in} \tag{43}$$

The total irreversibility of the thermal plant as given by Kotas [3] is:

$$\dot{I} = \Sigma\dot{E}x_{in} - \Sigma\dot{E}x_{out} \tag{44}$$

The net power generated in the plant P_{net} was obtained by subtracting the auxiliary power used by the plant such as power used by the pumps (P^{CEP}, P^{BEP}), compressors and the furnace-boiler from the total power generated. The auxiliary power was assumed to be 5% of the total power generated. The relationship is given by:

$$P_{net} = P_T - P^{Aux} \tag{45}$$

The overall energetic (η) and exergetic (ψ) efficiencies [3, 8]] are given by:

$$\eta = \frac{Net\ power\ generated}{\Sigma\dot{E}_{in} - \Sigma\dot{E}_{out}} \tag{46}$$

$$\eta = \frac{Net\ power\ generated}{Heat\ energy\ generated\ by\ the\ fuel} \tag{47}$$

And

$$\psi = \frac{Net\ power\ generated}{\Sigma\dot{E}x_{in} - \Sigma Ex_{out}} \tag{48}$$

$$\psi = \frac{Net\ power\ generated}{Heat\ exergy\ generated\ by\ the\ fuel} \tag{49}$$

4. RESULTS AND DISCUSSION

4.1 Sections Energetic and Exergetic Efficiencies

The results of sections of the thermal plant on standalone basis are presented in Table 1. It was observed that the sections energetic efficiencies for all the throughputs were approximately an average of 100% for the turbine-generator and the condenser sections, 67% for the regenerators section, and 63% for the furnace-boiler section. The sections exergetic efficiencies for all the throughputs were an average of 81.5% for the turbine-generator section, 24% for the condenser section, 43% for the regenerators section, and 39% for the furnace-boiler section. The results showed that the furnace-boiler and the condenser sections have the least exergetic efficiencies on standalone basis while the energetic efficiencies of the regenerators and furnace-boiler were the least. The low exergetic efficiencies in the furnace-boiler and condenser sections were as a result of the rate of chemical reaction taking place in the furnace-boiler section and the heat lost to cooling water in the condenser section of the thermal plant.

4.2 Coupled Sections (Subsections) and Overall System Energetic and Exergetic Efficiencies

The results of energetic and exergetic efficiencies of coupling the sections are presented in Tables 2 - 4. For the coupling of turbine-generator and condenser as a subsection shown in Table 2, the energetic efficiencies were 100% for all the throughputs but the average exergetic efficiencies were 72.3%. This showed that coupling of turbine-generator and condenser had no effect on the energetic efficiency but had effect on the exergetic efficiency. For the coupling of turbine-generator, condenser and regenerators as a subsection shown in Table 3, the energetic efficiencies dropped to an average value of 78% for all the throughputs and the exergetic efficiency also dropped to an average value of 64.3% for all the throughputs. This showed that coupling of regenerators to turbine-generator and condenser had appreciable effect on both energetic and exergetic efficiencies of the subsection. It was also observed that as the sections were coupled together, the energetic and exergetic efficiencies of the coupled subsections dropped and that throughput did not have much effect on the efficiencies of the coupled subsections.

For the overall system (coupling of turbine-generator, condenser, regenerator and furnace-boiler), shown in Table 4, both energetic and exergetic efficiencies dropped sharply to an average of 20.2% and 11.7% for all the throughputs, respectively. This showed that the closed loop topology of the thermal plant and the high irreversibilities in the furnace-boiler section (Table 5) made the highest contributions in determining the overall process efficiencies. The results further showed that the overall second-law efficiency of the plant was lower than the overall energy efficiency as was expected. The results of a coal-based thermal plant analysis [5] showed that the energy and exergy efficiencies were 32% and 28%, respectively, and are higher in values compared to the results from this study due to the differencies in formulae used in calculating the efficiencies, type and composition of fuel used. The overall energetic and exergetic efficiencies at different throughputs showed further that the thermal plant is not sensitive to changes in plant throughput and suggests that energy and exergy analysis of thermal plants must be complimented with economic analysis to optimize the operation of the plant.

Table 1. The energetic and exergetic efficiencies of the turbine-generator, condenser, regenerators and furnace-boiler sections

Throughputs	Turbine-generator		Condenser		Regenerators		Furnace-boiler	
	Energetic efficiencies (%)	Exergetic efficiencies (%)	Energetic efficiencies (%)	Exergetic efficiencies (%)	Energetic efficiencies (%)	Exergetic efficiencies (%)	Energetic efficiencies (%)	Exergetic efficiencies (%)
50%	99.85	82.01	100	26.61	63.64	38.72	62.08	39.64
75%	99.81	80.01	99.99	24.23	63.81	40.51	62.55	40.24
100%	99.83	82.72	99.98	23.25	63.31	44.01	63.24	37.65
110%	99.98	82.94	99.97	22.23	77.41	46.95	63.17	37.85

Table 2. Energetic and exergetic efficiencies of the turbine-generator and condenser subsection

Throughputs	Energetic Efficiencies (%)	Exergetic Efficiencies (%)
At 50%	100	74.61
At 75%	100	70.01
At 100%	100	72.31
At 110%	100	71.45

Table 3. Energetic and exergetic efficiencies of the turbine-generator, condenser and the regenerators subsection

Throughputs	Energetic Efficiencies (%)	Exergetic Efficiencies (%)
At 50%	79.59	66.22
At 75%	79.46	65.51
At 100%	76.86	63.30
At 110%	75.92	61.97

Table 4. Energetic and exergetic efficiencies of the whole thermal plant

Throughputs	Energetic Efficiencies (%)	Exergetic Efficiencies (%)
At 50%	18.17	10.26
At 75%	19.79	11.22
At 100%	21.42	11.58
At 110%	21.45	11.61

Table 5. The irreversibilities of the sections

Through-put	Turbine-generator (kJ/kmol)	Condenser (kJ/kmol)	Regenerators (kJ/kmol)	Furnace-Boiler (kJ/kmol)
50%	116	127	129	1018
75%	168	188	201	1397
100%	219	250	272	1840
110%	233	270	296	1980

4.3 The Relevance of Irreversibilities on the Thermal Plant

Table 5 shows the irreversibilities at different throughputs in the sections of the thermal plant. The trend showed that the irreversibilities depend on the throughput (fuel input), that is, the higher the fuel input the higher the irreversibilities. The exergy of destruction in the plant which brought about the useful energy in the furnace-boiler was used to heat up the massive tonnes of water to steam of required temperature and pressure and this resulted in high irreversibilities within the plant. It was also observed that about 85.6% of the total irreversibilities occurred at the furnace-boiler section of the thermal plant for all the throughputs and this brought about a great reduction in the energetic and exergetic efficiencies of the overall thermal plant as shown in Table 4. The increase in irreversibilities was caused by heat transfer through a finite temperature difference, chemical reactions, friction, and mixing in the boiler-furnace section of the thermal plant.

Table 6 shows the irreversibilities of the coupled subsections and the overall thermal plant. The overall thermal plant irreversibilities have reduced values as shown in Table 6, because great amount of heat generated at the furnace-boiler was absorbed within the plant.

Table 6. The irreversibilities of the coupled subsections and the overall thermal plant

Through-put	Turbine-generator & Condenser (kJ/kmol)	Turbine-generator, Condenser & Regenerators (kJ/kmol)	Turbine-generator, Condenser, Regenerators & Furnace-boiler (Overall system) (kJ/kmol)
50%	129	157	187
75%	201	233	239
100%	255	322	351
110%	285	352	381

5. CONCLUSIONS

In this work, the energetic and exergetic analyses were performed on a thermal power plant to study sections, subsections and overall system efficiencies and irreversibilities at various throughputs. It was found that the subsections energetic and exergetic efficiencies were sensitive to plant throughputs but the overall thermal plant energetic and exergetic efficiencies were not sensitive to changes in plant throughput. The overall exergetic efficiency was lower than the overall energetic efficiency as was expected because of proper accounting of different types of process exergies of material, heat and work in the plant and the irreversibilties of the thermal plant increased as the throughputs increased.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the assistance received from the Management of Egbin Thermal Power Plant, Ikorodu Local Government Area of Lagos State, Nigeria.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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