Nigerian Journal of Technology (NIJOTECH)
Vol. 33. No. 1, January 2014, pp. **97 – 103**

ISSN: 1115-8443
www.nijotech.com
http://dx.doi.org/10.4314/njt.v33i1.13

LONG TERM ENERGY PERFORMANCE ANALYSIS OF EGBIN THERMAL POWER PLANT, NIGERIA

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Abstract
This study is aimed at providing an energy performance analysis of Egbin thermal power plant. The plant operates on Regenerative Rankine cycle with steam as its working fluid .The model equations were formulated based on some performance parameters used in power plant analysis. The considered criteria were plant efficiency, plant internal consumption ratio, gross station heat rate and net station heat rate. The calculation were based on annual performance data over the 15- year period (1997-2011) The results of the analysis with SCILAB software code indicate the gross station heat rate (GSHR) of (10569.70KJ/kWh to 12191.58KJ/kWh) and net station heat rate (NSHR) of (11141.34KJ/kWh to 12869.76KJ/kWh).The overall efficiency from 29.53 percent to 34.06 percent agrees with the efficiencies of many steam power plants.

Keywords: Energy generation and consumption, efficiency, fuel consumption, steam rate, gross station heat rate, net station heat rate.

Nomenclature
E_{gen} – Energy generated in MWH
$\sum E_{int.cons.}$ – Energy consumed internally in MWH
Vf – Fuel consumed in NCM
Ef – Fuel consumed in MWH
LCV – lower calorific value in Kilojoule per cubic meter
η_{overal} – overall efficiency in %
$\varepsilon_{int.cons}$ – Internal consumption ratio
δ – Gross station rate in KJ/Wh
φ – net station heat rate in KJ/kWh

1. Introduction

The World today faces a critical challenge as all nations strive to satisfy basic human requirements- food, shelter, clothing and work which are so dependent on adequate supplies of energy. Energy supply and consumption consisted predominantly of non-commercial energy, namely fuel wood, charcoal, solar radiation, agricultural waste and residues [1]. The great increase in the use of energy has been met mostly by fossil fuels- primarily-coal, oil and natural gas. Fossil fuels are still by far the most important source of energy, not only for power generation but also in chemical and metallurgical processes, space heating and transportation [2]. Environmental concerns, security of supply, and economic impact all must be balanced as the demand for energy continues to increase. Real economic growth and energy use are still inextricably linked. While the search for ultimate solutions to provide adequate energy supplies continues, interim approaches must be considered for meeting the immediate growth in demand for energy.

Energy plays a vital role in a country's economic development, and it is expected to be more significant in the coming years due to increasing demand [3]. A multiple dimension approach is therefore required, keeping in view the various economic options available through effective demand management. Analysis of power generation systems are of scientific interest and also essential for efficient utilization of resources. The most commonly used method for energy analysis of energy conversion systems is based on the first law of thermodynamics.

The general energy supply and environmental situation requires an improved utilization of energy resources. Therefore, the complexity of power generating units has increased considerably [4]. The need to control atmospheric emissions of green house and other pollutant gases and substances will increasingly affect the efficiency of all energy conversion

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processes and applications especially power generation, transmission, distribution, and final demand. They are also affected by existing consumption patterns and technologies. Electricity consumption per capita is one of the indices of the living standard of people in a given place or country.

On the other hand, some of the known energy sources like fossil fuel (coal, oil, natural gas etc.) have been greatly depleted in recent times. Hence, issues relating to efficient utilization of natural resources including energy, have gained vital importance. For these reasons, deep analysis and evaluation of periodic data for power generation and consumption in the power sector is essential, and are considered as primary conditions to accomplish some of the national goals, which are designed to achieve sustainable development in all sectors of the economy [5]. Electricity production in Nigeria over the last 40 years has varied from gas-fired, oil – fired, hydroelectric power stations to coal-fired stations with hydroelectric power systems and gas-fired systems taking precedence. This is due to the fact that the primary fuel source (coal, oil, water, gas) for these power stations are readily available in the country [6].

Nigeria has abundant reserves of natural gas. In energy terms, the quantity of natural gas used for electricity generation is very significant. The known reserves of natural gas have been estimated at about 187 trillion standard cubic feet or 5.30 x 10^{12} standard cubic meters as of the year 2007 [7].

1.1 Electricity Generation at Egbin Power Station

The supply of electricity is one of the single consumers of primary energy. It accounts for around 40% of primary energy consumption. But because of conversion losses in the generation, transmission, and distribution subsystems, the relative importance of electricity in terms of primary energy and carbon emission is more [5].

The amount of energy consumption is one of the most important indicators showing the development stages of countries and living standard of communities. Population increment, urbanization, industrialization and technological development result directly in increasing energy consumption. As a parallel, this rapid growing trend brings about the crucial environmental problems such as contamination and greenhouse effects [8]. The Egbin Electric power business unit is a steam thermal plant that makes use of steam to drive its turbines in order to generate electricity. The station was established in 1985 and is situated in Egbin village near Ijede town in Ikorodu Local Government Area of Lagos state, Nigeria. At present, the installed capacity of the generating station is 1320MW which comprises of six (6) steam-turbine generators of 220MW maximum plant capacity each. The power station uses natural gas as fuel to fire the boiler. The generated energy is transmitted through the 330kV Ikeja West lines 1 & 2, Aja lines 3 & 4 and Benin lines 7 & 8 and 132kV Ikorodu lines 5 and 6 to the National grid.

The objective of the study is to examine the energy generation history of the steam turbine units at Egbin Power Station with the view to assessing the level of the plant performance parameters, such as plant efficiency, internal consumption ratio and heat rate within the period of the study- that is the 15-year period 1997-2009. These performance parameters were analyzed using Scilab software code. Scilab is a programming language associated with rich collection of numerical algorithms covering many aspects of scientific computing problems. It is a high level language for scientific computing and data visualization built around the idea of an interactive programming environment. The great advantage of an interactive system is that programmes can be tested and debugged quickly allowing the user to concentrate more on the principle behind the programme and less on the programming itself. In this way practical problem can be solved in a shorter time. Scilab is based on high level matix/array language with control flow statements, functions, data structures, input/output, and object oriented programming features. They contain large numbers of functions that utilize proven numerical libraries [9].

3. Materials and Methods

3.1 Source of Data

The data on annual electricity generation, plant internal energy consumption(energy consumed by auxiliaries and energy consumed by personnel in the power station),energy sent out and fuel consumption at Egbin thermal power plant were collected for fifteen years (1997-2011) from the Efficiency Department of the thermal station as shown in Table 1. Again, the defining equations for selected power plant performances were fed into Scilab scientific and engineering software which was used to compute the values of the parameters.

Table 1: Energy Generation, Consumption(MWH) and Fuel Consumption(NCM) from 1997-2009

Year	Energy Generated(MWH)	Energy Consumed(MWH)	Energy Sent Out(MWH)	Fuel Consumption(NCM)
1997	5886102.92	300075.30	5586027.61	1596073176
1998	6507957.44	317884.30	6190073.14	1721080480
1999	5923324.07	302107.00	5621217.07	1602620291
2000	5603228.26	274348.00	5328880.26	1533182568
2001	6941024.98	345,745.40	6595279.58	2044028037
2002	6876965.25	384067.80	6492897.47	1805905547
2003	6890112.69	392732.70	6497379.99	1944897841
2004	7962664.29	419640.40	7543024.89	2154153857
2005	8592097.13	440843.50	8151253.63	2193619658
2006	5004369.08	309790.10	4694578.98	1352955165
2007	3636676.32	233947.40	3694578.98	953214173
2008	4386854.92	263407.30	4123447.62	1283044530
2009	3383990.30	257082.70	3126907.83	959296013.2
2010	5385475.96	290774.20	5385475.96	1576443595
2011	6752677.73	355249.10	6397428.63	1902276755

Source: Efficiency Department

3.2 Performance Parameters

Defining equations were formulated to compute plant performance parameters such as overall plant efficiency, internal consumption ratio, gross and net station heat rate. The overall plant efficiency is the ratio of power available at the generator terminals to the rate of energy released by the combustion of fuel [10]. It is given by

$$\eta_{Overall} = \frac{E_{gen.}}{E_f} \quad (1)$$

The internal consumption ratio is the net power transmitted by the generated to the gross power produced by the plant. The internal consumption ratio is thus

$$\varepsilon_{interna\ consumtion\ ratio} = \frac{E_{gen.} - E_{out}}{E_{gen.}} \quad (2)$$

$$E_f = V_f * LCV \quad (3)$$

The plant Gross Station Heat Rate(GSHR) is the gross electricity produced by power plant per unit fuel energy consumption. This excludes all internal power consumptions. The plant Gross Station Heat Rate (GSHR) is given by

$$GSHR, \gamma = \frac{3600}{E_{gen}} \times Q_{in} \quad (4)$$

$$where, Q_{in} = E_f$$

The Net Heat Rate is net power production at transformer per unit fuel energy consumption by power plant. The plant Net Station Heat Rate (NSHR) is given as

$$NSHR, \gamma = \frac{3600}{E_{gen} - \sum E_{int.cons}} \times Q_{in} \quad (5)$$

3.3 Method of Data Analysis

Analysis of power generation systems are of scientific interest and also essential for the efficient utilization of energy resources [11].

The data collected from the power generating station for the combined steam turbine units for the fifteen years period (1997-2011) were analyzed using Scilab software code [9] with all the input variables fixed in the model equations.

4. Results and Discussions

The energy assessment result of some plant performance parameters of the steam turbine plant at Egbin thermal power station are presented in Table 2. The table shows the values of plant overall efficiency, plant internal consumption, gross station heat rate and net station heat rate of the plant for each year.

The Figures 1 to 4 are plots of the overall plant efficiency, plant internal consumption ratio, gross station heat rate and net station heat rate for the period covered by this study. Figure 1 show the maximum overall plant efficiency of 34.06% in the year 2005 compared to the least overall plant efficiency of 29.53% in 2001. The overall plant efficiency of the steam power plant is suitably measured by the proportion of latent energy in the fuel which is converted into useful mechanical work. Fluctuations in the annual overall efficiency were as a result of one or more of the following factors namely: plant design- age, steam cycle, cooling system, pollution control; plant location-elevation and ambient temperature.

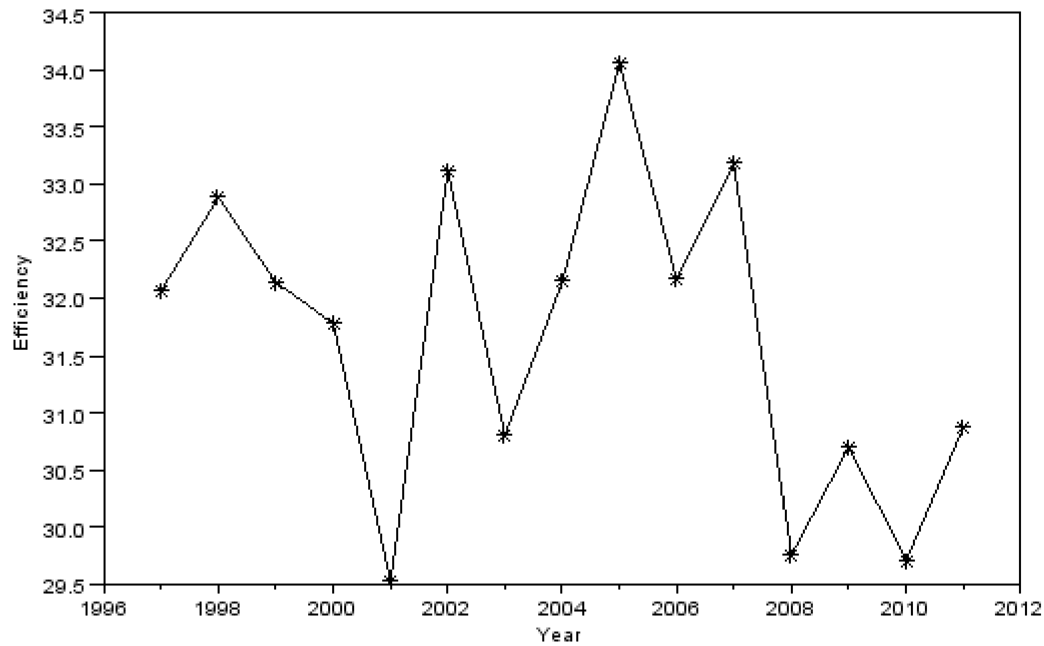

Figure 1: Plot of Plant Efficiency against Year.

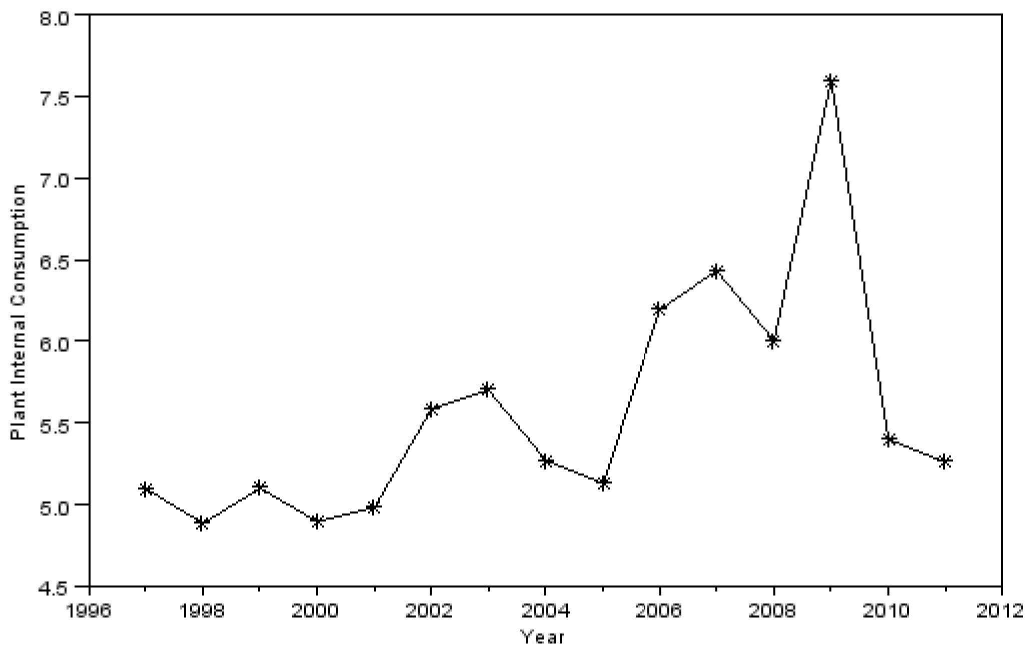

Figure 2: Plot of Plant Internal Consumption Ratio against Year.

Another serious effect could be plant shut down for maintenance owing to system failure. Also, older plants are lagging in efficiency because many of them are operating at 30-50% below their rated capacities. The efficiency of some new design plants may be high, but almost 75 percent of the existing coal-based fleet of plants in the United States is over 35 years old, with an average net plant efficiency of only slightly above 30 percent [12]. The efficiency in 2005 indicates that 34.06% of the energy in fuel is converted to electricity and 65.94% of the energy is lost. The maximum loss in energy is the combined effect of losses from pipes, tubes, valves, boiler, heaters and condenser where heat is rejected to cooling water. This is the loss due to heat/work energy conversion in the cycle or losses due to irreversibilities which stem from the second law of thermodynamics.

Figure 2 is the plant internal consumption ratio. The plant internal consumption ratio includes energy consumed by auxiliaries and personnel in the power station. The auxiliaries are necessary equipments within the plant that consume certain quantities of energy. This includes all motor driven loads, all electrical power conversion and distribution equipment, and all instrument and controls. The motor driven load encompasses power required by circulating water pumps, condensate, fans, boiler feed pumps and so on. The instrumentation encompasses instruments, control and optimization. Others are electrical power systems conversion and distribution equipment which are driven by electricity taken from the energy generated from the power plant. Normally, the values of energy consumed internally are subtracted from the energy generated by the plant. It has the highest maximum value in the year 2009 (7.597%) and the lowest value of 4.885% in 1998. The average internal consumption ratio for the period of the study stood at 5.69%. At rated load on the generator, those auxiliaries require from 4.5 to 6 percent of the generator output for a large modern plant and somewhat more for a small plant. At lower load, the percentage is greater [13]. In India, the percentage auxiliary power consumption of a 250MW capacity plant in 1999-2000 is 8.4%; a 210/200MW plant capacity has 9.16% and a 500MW capacity the same period has the least value of 6.44%.

The parameter which readily reflects the fuel economy is the heat rate, which is inversely proportional to the efficiency and hence, the lower its value the better for the operation of the plant. It indicates broadly the heat added per unit of work produced. Figures 3 and 4 represent the plot of heat rate (gross station heat rate and net station heat rate) of the plant. The fluctuation in the annual heat rates is a function of the level of power output which is dependent on existing thermal combustion/generation technology, type and quality of fuel and certain operating conditions such as temperature and emission control. In reality, heat rates are affected in plant operation because of inadequate maintenance, low quality of fuel, inefficient operation practices, and adverse operating conditions. The input/output relationship for the generating station show a declining amount of thermal energy required as the level of output increases. The figures shows that the maximum value of both gross station heat rate and net station heat rate are 12191.681KJ/KWh and 12830.807KJ/KWh in 2001 respectively. The lowest values of 10569.696KJ/KWh and 11141.336KJ/KWh were recorded in 2005 where the plant has the highest overall efficiency. The average value for both gross station heat rate and net station heat rate for the period are 11391.40 KJ/KWh and 12064.300 KJ/KWh respectively.

Observe that the net station heat rate is always numerically higher than the gross station heat rate because of energy consumed by plant internally such as that consumed by auxiliary equipment and personnel at the power station [13].

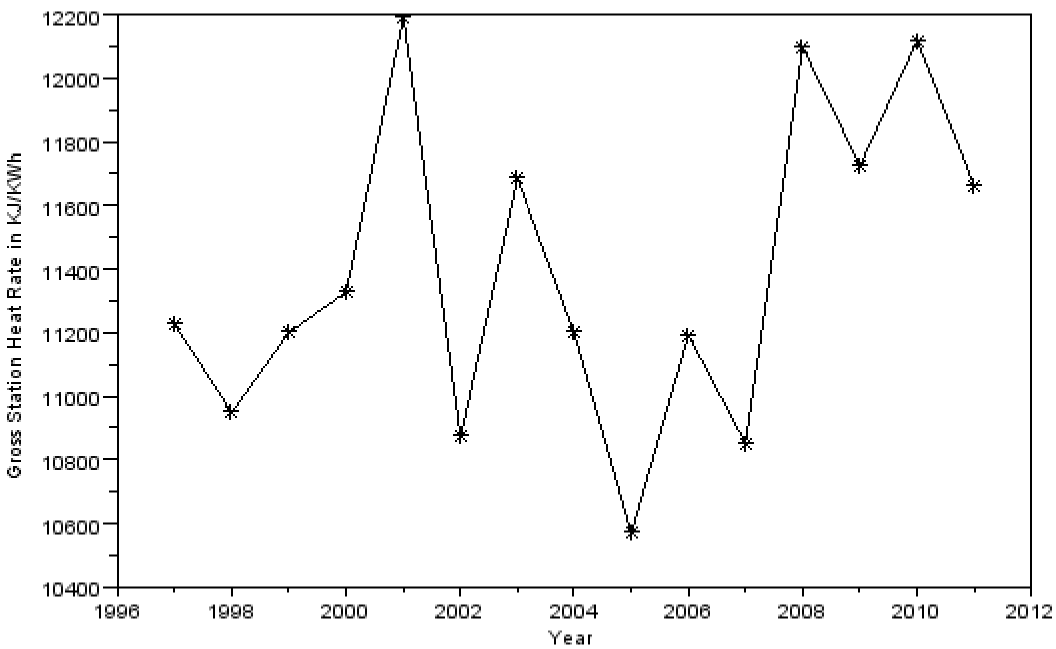

Figure 3: Plot of Gross Station Heat Rate against Year

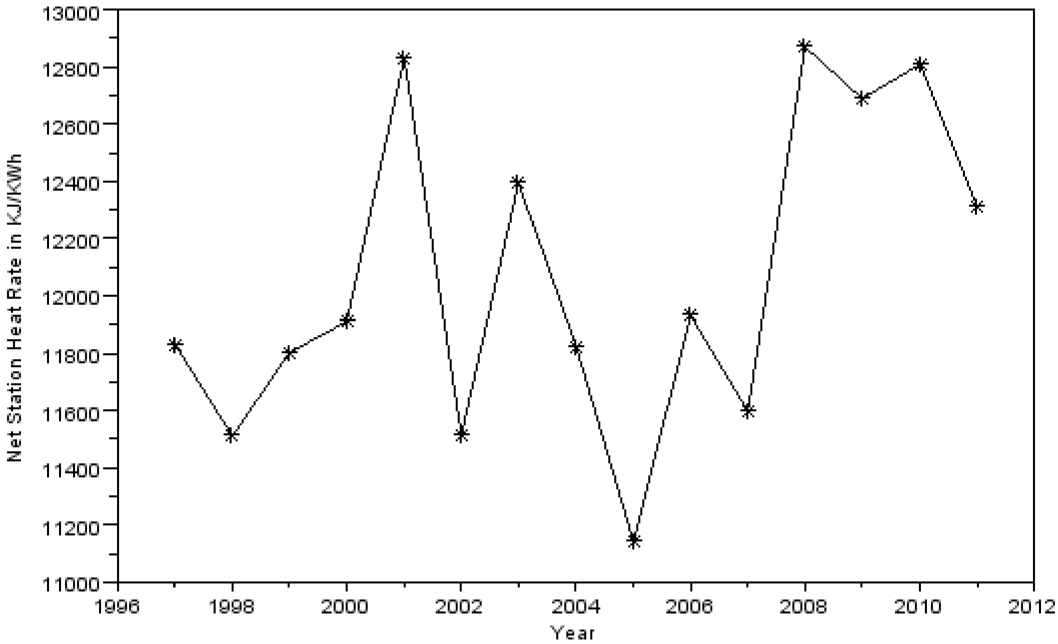

Figure 4: Plot of Net Station Heat Rate against Year.

5. Conclusion

A computational study based on annual performance parameter of Egbin power plant was done. The calculated overall efficiency for the studied period was in the range of 29.53 to 34.06 percent when compared with most steam power plants of its age. The average overall efficiency of the plant over the study period was 31.66%. The efficiency of some new design plants may be high. These calculated efficiencies over these periods can be considered as an important tool for policy makers, energy planners, and operators to get deeper insights into the performance of power sector. Furthermore, such results could provide important guidelines for future research work since large energy losses (65.94 to 70.47 percent) which are seen in this study, should be taken as a challenge to power plant operators. The internal consumption ratio in the plant ranges from 4.89 to 7.59 percent with average of 5.69% which is slightly lower compared to power plant of equivalent capacity in India. The heat rate which is the inverse of efficiency is the amount of fuel energy required to generate a unit of KWh. It can be expressed as either gross or net heat rate depending whether the electricity output is gross or net generation. Therefore the lower the heat rate the higher the efficiency. Plant heat rate or efficiency will degrade over time with use due to wearing of components. Routine maintenance and overhauls are designed to minimize the effect of degradation and maintain heat rate as close to the original design criteria as possible over the life of the plant. Restoring heat rate back to the original design or better, requires significant investment and often involve replacement of the majority of components with technically superior equivalents.

Plant heat rate can be one of the factors influencing plant life, as efficiency ultimately impacts economic viability.

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Appendix

Conversion factors used

1 *Standard cubic foot(scf) ≡ 0.0283 standard cubic meter(scm)*

1 *Normal cubic meter(ncm) ≡ 1.057 standard cubic meter(scm)*

1 *Normal cubic meter(ncm) ≡ 11.5KWh*

1 *KJ ≡* $2.77777778 \times 10^{-7}$ *MWh*

1 *MWh ≡ 3600000kJ*