PERFORMANCE EVALUATION OF EGBIN THERMAL PLANT

By

Adelaja, A. O., Ogunmola, B.Y. and E.O. Williams B.
Department of Mechanical Engineering,
University of Lagos, Akoka, Yaba, Lagos, Nigeria

ABSTRACT

Egbin thermal station is the single largest installed electricity generation plant in Nigeria. It has an installed capacity of 1320 MW and generating capacity of 6.8 TWh. The performance of Egbin thermal plant was evaluated using two methods to determine the overall efficiency. An estimated overall efficiency of 33.46% and a calculated overall efficiency of approximately 22.42% were deduced. The two efficiencies were examined with the aid of the statistical test method and an overall efficiency of 22.42% was verified as the probable measure of the plant's performance. Low plant availability, the unstable grid system and erratic natural gas supply problems were identified, among other reasons as the key factors responsible for the poor performance of the plant.

Keyword: Egbin thermal plant, performance evaluation, efficiencies, energy

1. INTRODUCTION

Egbin thermal plant is located at the suburb of Lagos State, Ijede, area of Ikorodu. The plant was commissioned in 1985 and consists of 6 units of 220 (6X220) MW (Reheat – Regenerative). They are dual fired (gas and heavy oil) system with modern control equipment, single reheat; six stages regenerative feed heating. The plant was constructed under joint Japanese/ French financing on a turnkey contract basis and most of the equipment were Japanese supplied. *The* overall cost of the plant was US $ 1 billion with an expected life of 25 years. The estimate was based on the fact that the plant should run mainly on natural gas which does not give the serious boiler slag and ash problem characteristic of coal fuel (Sule & Anyanwu, 1994). Natural gas is supplied to the plant directly from the Nigerian Gas Company (NGC). Lagos operations department, Egbin gas station, which is annexed to the thermal plant. Since Egbin thermal plant is located on the shores of the lagoon cooling water for the plant's condensers is pumped from the lagoon into the water treatment plant en route to the condensers.

1.1. Major Plant Components

1. Steam Generator is the radiant type, natural circulation with single reheat and duct firing.

2. Steam Turbine is the impulse type, two (2) casings, tandem compound double flow reheat condensing tube. Maximum continuous rating is 200MW, speed 3000rpm. Initial steam pressure = 12500 Kpa, initial steam temperature 538 °C. Exhaust steam pressure 8.5 Kpa, number of stages: High pressure, 8, intermediate pressure, 6, and low pressure 5 * 2 and has 3 low pressure and 2 high pressure heaters with 1 Dearator.

3. Condenser; surface type, cooling water is from lagoon water, No of passes – 2, condensing surface- 10630m^2, No of tubes- 12142.

1.2. Consideration of Performance

The evaluation of the performance of a thermal plant is geared basically towards the determination of the energy efficiency of the plant. A plant's energy efficiency has definite economic significance since the heat input at high temperature represents the energy that must be purchased (oil, natural gas, etc) and the net energy output represents the returns for the purchase according to Look and Sauer,[2].Since 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, consequently, energy conservation and efficient use of energy becomes a major supply option[3].

This paper aims at the determination of the performance of Egbin thermal plant, with the intent of appreciating those conditions favourable or unfavourable for good performance as might be common to all thermal plants of its kind, as well as such conditions that might be unique to Egbin, also, to suggest possible means of ensuring improvements. The performance is assessed based on the plant's overall efficiency, boiler, thermal and turbine efficiencies. An estimated overall efficiency is compared with a calculated overall efficiency. The main values of both efficiencies were found and compared using the method of statistical testing. The performance of the plant is then assessed based on these result.

1.3. An Overview of the Power Sector in Nigeria

With the growth in industrialisation and population, there has been an increasing demand for electrical energy in Nigeria. Power generation in Nigeria is mainly from three hydro-electric power stations, steam and gas thermal stations. Most of these facilities are being managed by the National Electric Power

Authority (NEPA), a government owned utility company that co-ordinates all activities of the power sector be it production, transmission, distribution, or marketing and sales. As outlined by Sule & Anyanwu[1], growth in thermal plants in Nigeria started with the installation of steam thermal plants at Oji river (1956), 4 unit gas thermal plants in Ijora (1966/78), 20 units gas thermal plants in Delta (1966/90), 4 steam thermal plants at Sapele (1978/80), another 18 unit gas thermal plants were installed at Afam (1982) and 6 steam thermal plants at Egbin (1985/87). A total of 6 power stations in all, consist of a total of 55 units capable of producing a total capacity of 5988 MW of electricity. The poor performance of these thermal plants has contributed immensely to incessant power outages and economic loss. Their report revealed that only 15 out of the 55 units were available for power generation as at 1994.

The then Minister of Power and Steel, Chief Agagu[4] put the record at 20 out of 78 units (25.6%) were functional before 1999 and by 2001 the percentage had moved to 43.8% with the additional 2 units added while 17 units were under rehabilitation. For greatest economic benefit, the availability of the most efficient and modern plant must be high. Agbauduta [5] reported that Nigeria's economic losses from unreliable power generation and supply was put at a staggering N66 billion (equivalent to $0.55 billion)*. He identified the lack of qualified maintenance engineers, non-availability of required spare parts and the instability of the national grid among other factors as being responsible for the poor performance of these power stations. Hart [6] reported that the development of power generation and distribution in Nigeria did not initially involve a national grid system and as such, the generating plants were not planned with respect to such a system. The establishment of the grid system was made necessary because a large part of the country did not have generating stations located within them.

2. METHODOLOGY

An energy analysis was carried out on the system as a whole as well as on the major components of the plant namely; the boiler, turbine, and condenser. Several trips were made to the plant during which empirical data were collected from plant records from 1992 to 2002 prepared by the efficiency department of the utility company. Information on the following parameters was used in our analysis.

i. Gross energy generated (MWH)
ii. Energy used in the plant (MWH)
iii. Energy sent out (MWH)
iv. Fuel gas consumed (mmscf)

v. Running hours (hrs)

vi. Equipment availability

vii. Total number of forced and planned outages.

viii. Conditions responsible for forced outages.

Other data acquired from the plant include:

ix. The unit heat rate (KJ/KWH)

x. The unit net heat rate (K/KWH)

xi. Generator efficiency.

xii. Plant energy balance diagram.

2.1. Constraints and Limiting factors

1. Poor record keeping practice.
2. Constant fluctuation and irregularity of plant loading. This is due to the constant fluctuations in the transmission efficiency of the national grid as controlled by the national control centre, Oshogbo.
3. Breakdown of equipment. Only 3 or 4 of the 6 units were in operation throughout the year's review.

2.2. Assumptions

1. Plant ran only on natural gas throughout the year in review.
2. Net heat rate in KJ/KWH was taken to be equal for all the units in operation.
3. The thermodynamic parameters at the various state points are the same in all the units in operation.
4. In calculating the boiler and turbine efficiencies, the enthalpies at the relevant state points were taken to be equal to the initial values based on the commissioning energy balance.
5. Heat rate equals the initial value based on the commissioning energy balance.
6. Plant operated at maximum continuous rating through out the period in review.
7. Generator efficiency is constant at 98%.
8. efficiency is taken to be constant

2.3. Performance Evaluation

Energy analysis of the thermal plant involves the following calculations

i. Estimated overall efficiency.

$$\eta_{oe} = \frac{\text{Energy transfer to fluid}}{\text{Fuel energy Consumed}} \qquad 1$$

ii. Boiler efficiency

$$\beta = \frac{\text{Heat transfer to fluid}}{\text{Fuel Energy Consumed}} \qquad 2$$

Heat transfer to fluid is calculated as net heat rate (KJ/KWh)*Gross energy generated (KWH)

iii. Internal turbine efficiency

$$\tau = \frac{\text{Heat drop in turbine}}{\text{Net energy sent to turbine}} \qquad 3$$

Where,

Heat drop in turbine = [(H_1-H_2) + (H_3H_4)] *Running time (hrs) per unit available 4

H_1=Total heat of Steam at the stop valve (KJ/H)

H_2 = Total heat of Steam to reheat (KJ/H)

H_3 = Total heat of Steam to turbine from reheater (KJ/H)

H_4 = Total heat of Steam at exhaust (KJ/H)

Net heat energy sent to the turbine = net heat rate* gross energy generated per unit available 5

iv. Condenser effectiveness

$$\varepsilon = 1 - Exp(-Ntu) \quad 6$$

Where,

$$Ntu= [T_2-T_1)/ LMTD \quad 7$$

T_1= Inlet temperature of condenser cooling water (°C)

T_2 =Outlet temperature of condenser cooling water (°C)

LMTD = Logarithmic mean temperature difference

v. Thermal efficiency

$$\eta\Box_t = \frac{3412}{\gamma\text{*heat rate}} \quad 8$$

where, γ = generator efficiency heat rate is in Btu/KWH, 1 KWH = 3412 Btu

vi. Calculated overall efficiency

$$\eta_{oc} = \Box_T * \beta * \tau * \gamma \quad 9$$

The estimated overall efficiency, η_{oe}, would be compared with the calculated overall efficiency, η_{oc}, using statistical testing.

$$T = \frac{X - \mu_o}{s/\sqrt{n}} \quad 10$$

where,

$$X = 1/n\Sigma_j=1X_j \quad 11$$

$$S^2 = 1/(n-1)\Sigma_j=1/(X_j-X)^2 \quad 12$$

The mean estimated overall efficiency η_{oe} is taking as our hypothesis (null hypothesis, μ_o). We shall accept the hypothesis if the test suggests that it is true, except for a small error probability, α, called the significance level of the test, otherwise the hypothesis is rejected.

Using the t-distribution with n-1 degrees of freedom (n=number of years under consideration). X and S are the mean and standard deviation respectively of the calculated overall efficiency. Choosing a significance level of 5% (α=5%) from the t-distribution table, we obtained a critical value, c, such that,

$$P(T\leq c) = \alpha = 5\% \text{ or } P(T\leq \hat{c}) = 1- \alpha = 95\% \quad 13$$

So that c=ĉ because of the symmetry of the distribution. If the hypothesis is true, there is a chance of only α (=5%) in which if the value t of T (calculated from our sample) falls between – α and – ĉ it is asserted that the hypothesis (mean estimated overall efficiency) cannot be true thus it is rejected. Then we accept the alternative (mean calculated overall efficiency). If however, t≥ c, the hypothesis is accepted.

3. RESULTS AND DISCUSSION

Due to deficiency in record keeping/filing systems, there were some records that could not be readily available. Though the utility was commissioned in 1985, Tables 1, 2 and 4 show that records of the running hours, gross energy generated, total fuel energy consumed etc could not be found and so were not used for our analysis. The real analysis was made for 1992 to 2002. Table 2 show a similar trend in the gross energy generated and total fuel energy consumed. This shows that they are directly proportional.

Table1: No of units in operation, total running hours and non functional units

Year	No of units Available	Running hours	No of units outs of functionality
85	3		$_4$, ST_5, ST_6
86	6		
87	6		
88	6		
89	6		
90	6		
91	4		$_5$, ST_6
92	4	,797.33	$_5$, ST_6
93	3	,251.16	$_4$ ST_5, ST_6
94	3		$_4$ ST_5, ST_6
95	4	,014.92	$_4$, ST_6
96	4	,788.99	$_4$, ST_6
97	4	,340.04	$_4$, ST_6
98	4	,998.67	$_4$, ST_6
99	4	,904.51	$_4$, ST_6
00	4	709.21	$_4$, ST_6
01	4	,426.08	$_4$, ST_6
02	4		$_3$, ST_4

Sources: Egbin Thermal Station, Lagos, Nigeria

Na = not available

ST_5 was off grid on 19/2/90 due to turbine bearing defect and was synchronised on 3/2/95 after unit was overhauled.

ST_6 was off grid on 4/10/90 due to boiler explosion till 1998 ST_4 was off grid on 23/11/92 due to boiler explosion till 1998

Figure 1 reveals the power output from each of the six units and the total output from the plant. It can be seen that there was a steady increase in the total power output until 1991, 1992 when unit 5 and 6 were off grid. By 1993/94, unit 4 was off grid and the situation remains unabated. The overhaul of unit 5 and injection into the grid brought and improvement in the total output until 1999 when there was a reduction in the output from unit 3 and by 2001 only unit 4 and 6 were out of functionality though they were receiving attention.

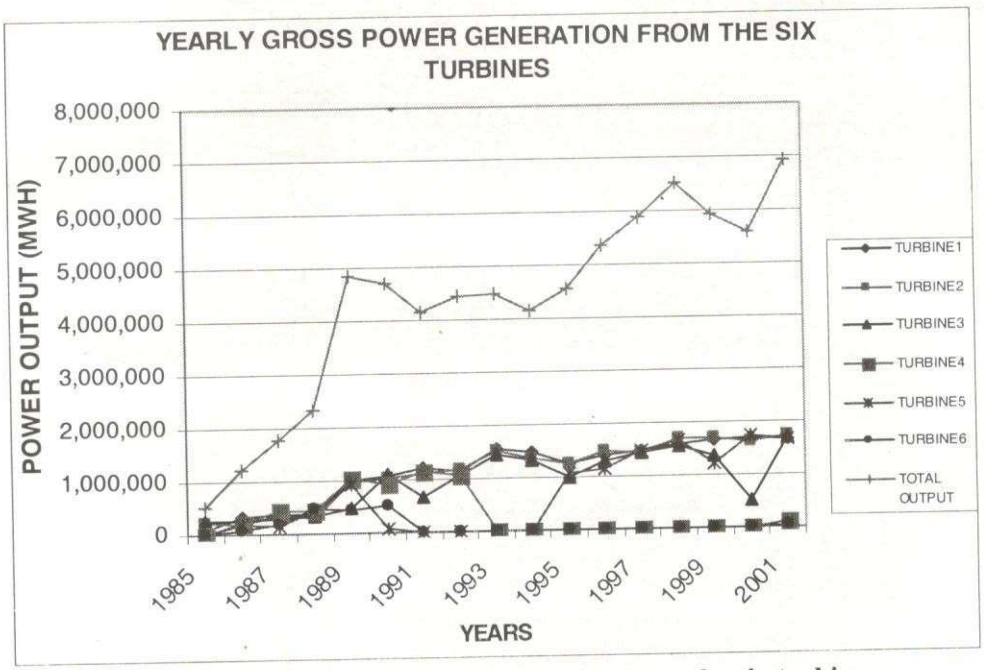

Figure 1. Yearly gross power generation from the six turbines

There is a consistence growth until 1999 after which there was a decline until 2001. According to Table 1 since the plant was commissioned, all the six (6) units only worked between 1986 and 1990. Except for 1993 and 1994 when the plant run on three (3) units, four of six units have always run. Unit ST_4 and ST_6 were off grid in 1992 and 1990 respectively due to boiler explosion. Unit ST_6 was off grid due to turbine bearing no. 5 defect and was synchronised in 1995 after unit was overhauled.

Table 2: Yearly gross energy generated and corresponding fuel energy consumed

Year	Gross Energy Generated (TWH)	Total Energy Sent Out (TWH)	Total Fuel Energy Consumed (TWH)
1992	4.462558000	4.195470000	13.233618870
1994	4.160964000	3.936169000	12.327941098
1996	5.358349680	5.071845000	15.418254508
1998	6.502957440	6.185073000	19.054686781
2000	5.603227760	5.328880000	16.974402962
2002	6.870965250	6.492897000	19.993814897

Source: NEPA, Lagos thermal station, Egbin

The Table 2, above shows the general trend of increasing energy demand in the country as a whole with each progressing year, which results in increasing fuel energy consumption. Though this data is specifically for Egbin thermal plant, it is a good indication of how increasing demand for energy (electrical energy) places more strain on the energy resources of the country. Comparing the amount of energy generated and energy sent out, it would be seen that far greater amount of fossil energy resources is been used up to produce much less output. As a consequence of this it seems that the country is depleting its limited energy resources at a far quicker rate for much less returns, thus, the need to pay great attention to the performance of such facilities like the Egbin thermal plant.

The estimated efficiency, η_{oe}, got for the period is 33.46% .

The mean condenser effectiveness, $\varepsilon = 0.671$

Table 3: calculated efficiencies of plant's components

Year	B (%)	τ (%)	γ (%)	η_t (%)	η_{oc} (%)
1992	91.55	85.6	98.0	37.60	29.00
1994	91.64	50.65	98.0	37.60	17.10
1996	94.34	73.80	98.0	37.60	25.69
1998	92.66	61.08	98.0	37.60	20.85
2000	89.62	68.55	98.0	37.60	22.64
2002	93.38	n/a	98.0	37.60	-

The Table 3 above shows the efficiencies of the components of the plant which was used to calculate the overall efficiency of each year and the mean overall efficiency for the ten (10) year period, 1992-2001 was 22.42%.

Applying the statistical test method, equations 10-13 were used:

From equation 11, X =22.42%

From equation 12, S = 0.034067

From equation 10, μ_o= 33.46%

T = 8.642

For P (T≤ c) = α = 5%, and n = 10,

the critical value, c, is -1.83, that is T<c.

Consequently the hypothesis is rejected, that is, the estimated overall efficiency, 33.46% and the performance of the plant was based on the calculated mean overall efficiency which is 22.42%.

The estimated overall efficiency calculated for the plant for the year 1992 to 2001 shows a maximum value of 34.75% estimated for 1996 and the least value approximating 30.7% estimated for 2001. The overall efficiency is a function of the plant cycle efficiency or thermal efficiency. The overall efficiency for the plant was approximately 37.6%.

3.1. The Efficiencies

i. The boiler efficiencies (β)

This has a similar trend with the overall efficiency. It climaxed in 1996 with a value of 94.3% and has a minimum of 83.3% in 2001.

ii. Turbine efficiency (τ)

The internal turbine efficiency is 50.6% at its lowest in 1994 while maximum approximates 86% for 1992. Gaffert [7] gave values of turbine efficiency capacity up to 75MW and increasing with speeds up to 3600 rpm with maximum efficiency of 82%, this compares with 86% with speeds up to 3600 rpm with maximum efficiency of 82%, this compares with 86% calculated for a capacity of 220MW and speed of 3000rpm.

iii. Generator efficiency (γ)

For a hydrogen cooled generator, the efficiency is taken to be 98% [7-9].

iv. Condenser effectiveness (ε)

This gives the effectiveness of the condensate. The condenser effectiveness was calculated for the year 2001. The maximum value was obtained in June 2001 (80.9%) while the mean effectiveness is 67.1%.

3.2. Factors Responsible for Drop in Performance

3.2.1. Boiler Losses

Table 4: Fuel energy consumed in boiler and energy in steam

Years	Fuel energy consumed (TWH)	Energy in steam (TWH)
1992	13.2336	4.5642
1994	12.3279	4.2557
1996	15.4183	5.4804
1998	19.0547	6.6510
2000	16.9744	5.7308
2002	19.9938	7.0336

The boiler efficiency is a function of the quantity of heat transferred to steam and the amount of energy consumed. As shown in table 4 & fig.2, in 2001, an extra 2.63 TWH of fuel energy was used to produce 0.0655 TWH heat of steam more than that produced in 2002. The gross electrical energy generated being only 0.0641 TWH more than that of 2002.

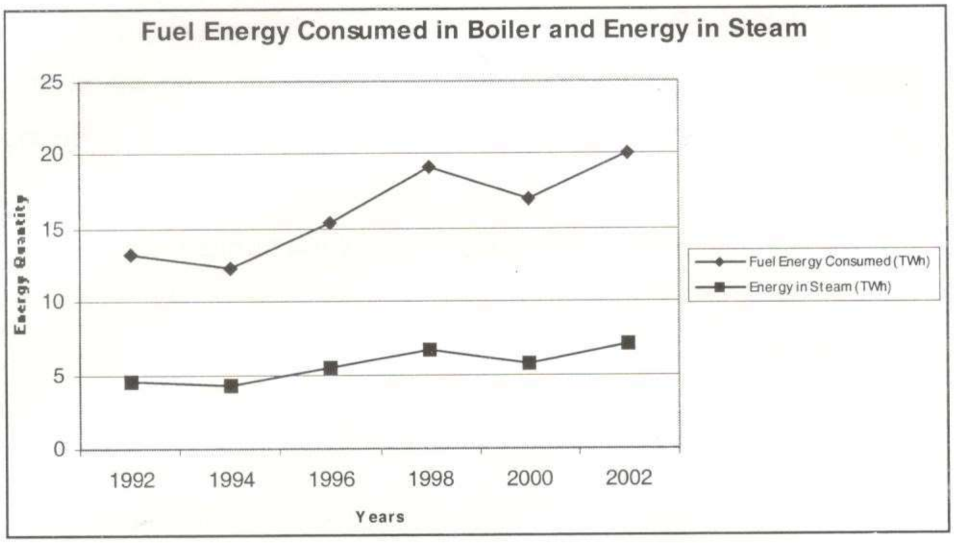

Fig. 2. Fuel energy consumed in boiler and energy in steam

Drop in performance as a result of the boiler losses can be traced to two key factors:

i. heat losses in flue gas and radiation losses

ii. Losses due to forced outages

i). Heat loss in flue gases and radiation losses: This occurs when the burners are producing more heat than that required for a specific load and also when heat transfer surfaces within the boiler are not functioning properly and this leads to heat transfer surfaces contamination and require cleaning.

Radiation losses are caused when some heat is transferred to the surrounding from the boiler due to radiation. Damaged or poorly installed insulation greatly increase the potential of heat losses.

ii). Losses due to forced outages

Forced outages are as a result of various faults at the station. These faults could be attributed to the following:

a. Plant faults

b. Gas supply problems

c. Operational faults

d. System faults

Table 5: Gas supply problems and resultant output loss

Year	Gas Supply Problems	Loss in Output (MWH)
1996	5	4917.0
1997	6	8423.8
1998	2	7333.3
1999	4	4188.8
2000	10	8624.7
Total	**27**	**33487.5**

Between 1996 and 2000, there were a total of 27 gas supply faults (for 4 running units), leading to a total energy loss equal to 33,487.6MWH.

Table 5 shows the number of gas supply problems and the corresponding resultant loss in output. Factors responsible for gas supply problems are as follows:

a. External low gas supply pressure problem

b. Pigging operation

c. Labour –related problems of the workers of the Nigerian Gas Company- Strike actions.

* Problems during pigging operation in1992, lead to in rush of gas condensate from the NGC metering station which resulted in furnace explosion of unit 4 of the plant and a total station outage for on gas for 14 days. A similar occurrence was reported in 1997 although proper handling prevented the occurrence of any ugly incidence [10].

Drop in Turbine Efficiency

The result presented actually paints a good picture of the state of the plant with respect to equipment condition and plant operations. As of 1994, when the plant recorded the lowest turbine internal efficiency of 48.8%, the plant's annual report showed that all the major equipment were long over due for overhauling and that "the plant was been run to destruction". A period of 3 years between overhauling has been specified. Although allowance is given for economic reasons, for running the plant at the deteriorating efficiency until the cost of outage for overhauling is outweighed by the cost of continued running of the plant at low efficiency. Consideration which affected the efficiency of the steam turbines fall, roughly into two categories, namely, those connected with day to day operation and those that are associated with the internal conditions of the machine, such as:

i. Deposit

Deposits on the turbine blades causes partial chocking of the area available for steam flow. This will result in an increased pressure difference across the gaps of the stages affected.

ii. Erosion

The two main factors producing blade erosion are the wetness of steam and the velocity of impact of the water droplets on the blade. Solid matter carried over from the boiler can also cause erosion of turbine blade, although, this happens only rarely.

iii. Clearance

The efficiency operation of a turbine depends to a large extent on the maintenance of the correct clearance between fixed and moving element.

4. CONCLUSION

An energy analysis of the Egbin thermal station has been carried out using two methods of thermodynamic analysis. One, considering the ratio of energy generated per annum to the amount of the fuel consumed and the other involves products of the plants thermal efficiency and the efficiencies of the boiler, turbines and generator. The first technique gave an estimated mean efficiency, η_{oc} of 33.46% and the second a calculated mean efficiency, η_{oc} of 22.42%. Using statistical test method, η_{oc} was deduced as the acceptable measure of the plants performance from 1992 to 2001 which places the performance of the plant at very much below optimum.

A number of reasons were adduced to be responsible for this poor performance. These includes low availability due to breakdown spanning almost ten years, the instability of the national grid system and disruption in gas supply from the Nigerian Gas Company (NGC) as well as accidental in-rush of gas condensate into the plant which led to an explosion in boiler furnace and consequently plant outages.

REFERENCES

1. **Agbauduta, G** (1998): Performance Evaluation of Delta Power Station Turbines, Unpublished, B.Sc. Project, Mechanical Engineering, University of Lagos.

2. **Gaffert, G. A.** (1953): Steam Power Station; 4th Edition, Longman.

3. **Hart, I. I.** (1992): Gas Turbine Operation Experience in the Niger Delta Area of Nigeria, official Journal of the Nigeria Engineer, vol. 27, no 3, pp 198-199.

4. **Iwanaga, K, Ishki, Y, Mimuro and Ohji, A.** (1990): General Planning and Construction of the 700MW Unit with Advanced Steam

Condition, Steam Plants for the 1990s, Proceedings of the ImechE, C386/001, pp 25-30.

5. **Look, D. C and Sauer, H. J.** (1986): Engineering Thermodynamics, pp 257-319.

6. **Martinez-Frais, J, Aceves, S. M., Smith, J. R. and Brandt, H.** (2004): Thermodynamics and Cost Analysis of a Zero-Atmosphere Emissions, Coal Power Plant, Lawrence National Laboratory and Clean Energy Systems, Inc.

7. **Sule, E. I. K and Anyanwu, C. M.** (1994): An Appraisal of Electricity Supply in Nigeria and the Privatisation Option, Research Department Occasional Paper No. 9.

8. **Utgikar, P. S, Dubey, S. P and Rao, P. J. P** (1995): Thermoeconomic Analysis of Gas Turbine Cogeneration Plant, A Case Study. Proceedings of Institute of Mechanical Engineering, vol. 209, pp 45-54.

9. **The Punch, Nigeria**, August 12-19, 2002.

10. **Annual Report**, Egbin Thermal Station, 1992 and 1997.