Ijeas Ideal Journal of Engineering and Applied Sciences 2(5) 173-177 Ijeas

© Ideal True Scholar (2016) (ISSN: 2067-7720)
http://ijeas.truescholar.org

EXERGY AND ENERGY ANALYSIS OF NIGER DELTA UNIVERSITY POWER PLANTS

Adigio, E. M. and Ohwofadjeke, P. O.
Department of Mechanical Engineering,
Faculty of Engineering,
Niger Delta University, Nigeria
Corresponding Author: Adigio, E.

ABSTRACT
Power generation and distribution in Nigeria is not regular and most industries and institutions are apparently sustained by electricity generated from diesel driven generators, leading to high cost of products and services, including the contribution to undesirable emissions. This is not helping the increase in the rate of exploitation of energy resources resulting in the continuous depletion of energy reserve. The key object is to adopt energy management in every field of human endeavor to reduce wastages of energy sources and enhance cost effectiveness without affecting productivity and quality. This research work was designed to study and audit energy consumption in Niger Delta University, Wilberforce Island, Bayelsa state Nigeria by creating a balance between energy consumption and supply, with a view to minimizing wastages and reduces cost on energy. The audit was carried out using a three phases, ten steps energy audit model. Results show that using generators cost average of 25 to 30 Naira (Nigerian currency) kWh of electricity, while supplies from Power Holding Company of Nigeria (PHCN) cost an average of 4 Naira per kWh of electricity. Thermal and exergetic efficiencies obtained from the analysis are in ranges of 13.59% to 15.96% and 0.636% to 2.686% respectively. The study will give the Niger Delta University a guide to maximize the energy production and consumption in the institution.

KEYWORDS: Retrofitting; Energy; Exergetic Efficiency; Recommendations; Conservation; Exergy; Payback; Energy Audit; Productivity; Depletion; Exploitation

INTRODUCTION
Energy is a critical enabler and an indispensable commodity which is required for the economic growth and development of any nation. It is an asset and resources for mankind without which human survival will be impossible. The industrial growth of any country is determined by the availability and utilization of energy, that is, increase in energy consumption is an indication of economic growth (Odularu and Okonkwo, 2009, Ahmad *et al*, 2012, Mustapha and Fagge, 2015).

Exergy analyses provide useful information, which can directly impact process designs and improvements, where this methods help in understanding and improving efficiency, environmental and economic performance as well as sustainability, providing better insights into beneficial research in terms of potential for significant efficiency, environmental and economic gains, (Rosen, 2008). Exergy analysis have a significant role in assessing and improving the efficiencies of electrical power technologies and systems, and provides a useful tool for engineers and scientists as well as decision and policy makers, (Rosen and Bulucea, 2009). Investigation has shown that exergy can play a significant role in achieving more efficient, environmentally benign, sustainable and economic energy use, (Dincer, 2011, Boroumand Jazia *et al*, 2012).

Exergy is a measure of the departure of the state of a system from that of the environment, and is therefore an attribute of the system and environment together. Once the environment is specified, however, a value can be assigned to exergy in terms of property values for the system only, so exergy can be regarded as an extensive property of the system. Exergy can be destroyed and, like entropy, generally is not conserved (Ebotion, 1996).

Current global energy consumption is estimated at 4.1×10^{20} J annually, which is equivalent to an instantaneous yearly-averaged consumption rate of 13×10^{12} W (13 trillion watts, or 13 terawatts ,TW). Projected population and economic growth will be more than twice this global energy consumption rate by the mid-21st century and more than triple the rate by 2100, even with aggressive conservation efforts. Hence, to contribute significantly to global primary energy supply, a prospective energy resource has to be capable of providing at least 1-10 TW of power for an extended period of time (Golup, 2005).

In Nigeria for example; in spite of recent reforms, the challenges ahead are tremendous. A growing economy like ours requires massive energy to power it. Recent estimates have shown that; to achieve the Vision 2020 goal of making Nigeria one of the twenty largest economies in the world, electricity generation will have to increase from the present level of 3,650 MW to about 45,000 MW [(Adenikinju, 2008).

The industrial sector in Nigeria is a major energy consumer accounting for a larger percentage of the commercial energy consumption in the country when compared to country like India with about 30% of the commercial energy consumption in that country. Efficient energy utilization is a major determinant of the profitability of a productive system (Adenikinju, 2008).

This research is the study and audit of energy consumption in Niger Delta University, Wilberforce Island, Bayelsa state Nigeria by creating a balance between energy consumption and supply, with a view to minimizing wastages and reduces cost on energy. The study include analyzing fuel consumptions of generator (Table 1) used in all the campuses of the University

Table 1: Available Generators In Niger Delta University For The Study

S/N	Generator	Mode of usage	Capacity (kVA)	Fuel Type
1	A (Caterpillar)	Prime power	1000	Diesel
2	B (Perkins, stand-by)	Stand-by power	1000	Diesel
3	C (Perkins)	Prime power	500	Diesel
4	D (Perkins)	Prime power	250	Diesel
5	E (Perkins)	Prime power	500	Diesel

MATERIALS AND METHOD

The energy audit of Niger Delta University was carried out using a three phase, ten steps audit process model by some researchers (Capehart, 2003). Phase 1 is the pre audit phase, phase 2 is the audit phase and phase 3 is the post audit phase respectively

Data Collection

The data for this study were obtained through various means; the primary source of data is through direct measurements of energy related parameters within the University and Oral/personal interview of Top Energy Managers in the Works Department was conducted.

Method of Data Analysis

The data were analyzed using Calculations involving:

- ✓ Total fuel consumption per year
- ✓ Annual cost of fuel
- ✓ Rate of fuel consumption in litres per hour
- ✓ Thermal Efficiency
- ✓ Exergic efficiency
- ✓ Cost rate of losses due to exergy
- ✓ Fuel specific exergy of Generators
- ✓ Heat Rates
- ✓ Total energy demand
- ✓ Annual Generated Energy
- ✓ Cost of self-generated Energy using Generators
- ✓ Determination of cost benefit analysis or Economic viability of major energy projects using Pay back method on major energy projects or energy retrofitting initiatives in Niger-Delta University.

Governing Equations

The Formulae and equations used for analysis of data of this research are;

- **Volume of Cylindrical Fuel Tank**

  Volume of a cylindrical fuel Tank = $\pi r^2 h$

$$\text{Vol} = \pi\left(\frac{Cir}{2\pi}\right)^2 h \equiv \frac{Cir^2}{4\pi} h \qquad 1$$

where; Vol is the volume in m^3 or litre, (1000 m^3 ≡ 1 litres), r is the radius in m, Cir is the circumference in m h is the height or depth of cylindrical fuel tank in m

- **Fuel consumption**

  Rate of fuel consumption =

$$\frac{\text{vol of fuel consumed in litres}}{\text{time taken in hours}} \qquad 2$$

where; Rate of fuel consumption is in litre/hr, Volume of fuel consumed in litre, Time taken in hours

- **Annual fuel consumption**

  Annual fuel consumption = *Rate* of fuel consumption x number of hours in each day x number of days in a year 3

Where; Annual fuel consumption in litre/yr, fuel consumption is measured in litre/hr and number of days in the year, measured in days.

- **Annual Generated Energy**

  Annual Generated Energy = Generated Energy in kW x number of hours in each day x number of days in a year 4

Where; Annual Generated Energy in kWh, Number of hours in each day in hours and Number of days in a year is measured in days

- **Thermal Efficiency** (ŋ)

  The thermal Efficiency of generators' was calculated using the formula;

$$\eta_{\text{Thermal of Generator A}} = \frac{\text{Energy produced}}{\text{Total energy input}} = \frac{W_e}{M_f \ x\, \gamma_f \ x\, C_v} \times 100\% \qquad 5$$

Where; We is the power Generated or produced in kW, C_v is the Calorific value of Diesel = 42640 kJ/kg ≡ 36240 kJ/l, M_f is the mass of Fuel (diesel) Consumed in kg/hour and γ_f is the exergy grade function = 0.994

- **Heat Rate of generator**

  The Heat Rate of generator was calculated using the formula;

$$\text{Heat Rate produced by Generator} = \frac{M_f \; x \; C_v}{\text{power generated in kW}} \qquad 6$$

Where; We is the power Generated or produced in kW, C_v is the Calorific value of Diesel = 42640 kJ/kg ≡ 36240 kJ/l and M_f is the mass of Fuel (diesel) Consumed in kg per hour.

- **Exergy of fuel (diesel)**

  The Exergy of fuel (diesel) was calculated using the formula;

$$\varepsilon f = \Upsilon_f \; x \; C_v \qquad 7$$

Where; εf is the exergy of fuel (diesel) in kJ/kg, C_v is the Calorific value of Diesel = 42640 kJ/kg ≡ 36,240 kJ/l and Υ_f → exergy grade function of diesel = 0.994

- **Exergic Efficiency (Ψe)**

$$\Psi e \text{ of Generator "A"} = \frac{\text{Exergy in products}}{\text{Total exergy input}} \; x \; 100 \equiv \frac{We}{M_f \; x \; C_v} \qquad 8$$

Where; We is the exergy input into generator in kJ/Kg, C_v is the calorific value 42640 kJ/kg ≡ 36,240 kJ/l and M_f is the mass of Fuel (diesel) Consumed in kg per hour

- **Cost Rate of exergy loss**

  The Cost Rate of exergy loss was calculated using the formula;

$$\text{Cost rate of exergy loss} = C_F\left(1 - \frac{T_o}{T_1}\right) Q_1 \qquad 9$$

Where: C_f is the unit cost of fuel in Naira/kWh $= \dfrac{\text{Annual fuel cost}}{\text{Annual generated energy}}$

Where 300 Naira is equivalent to 1 dollar, Q_1 is the Energy lost to the surroundings by heat transfer in kWh = F_f x C_v, F_f is the volume of Fuel (diesel) Consumed in m^3/hr, C_v is the calorific value 42640 kJ/kg ≡ 36,240 kJ/l, T_o is the Ambient temperature in Kelvin, 25℃ = 298 k and T_1 is the Temperature of the exhaust gases in Kelvin K

- **Cost benefit analysis**

  The Cost benefit analysis using simple payback period was calculated using the formula;

$$\text{Payback period} = \frac{\text{Cost of project}}{\text{Annual benefit}} \qquad 10$$

LIMITATION OF STUDY

The study was limited to the Niger Delta University and all data was collected from the five campuses of the University. Although, this study was supported by the University Authority, oftentimes, the operators at the power stations were not forthcoming with useful information. Certain measuring equipment, like flow meters could not be obtained, thus, the need for the direct measurement of fuel tanks for volumetric fluid flow analysis reported.

The study was also limited to one year, thus, the investigation did not emphasize on other sources of energy, for example, wind, solar and tidal energy.

RESULTS

Tables 2 to 4 show the results of the analysis, using the necessary relationships.

Table 2: Summary of Energy Generated Using Generators and Annual Fuel Consumption

Gen	Fuel Consumption in (l)	Hourly fueling Cost (l/h)	Annual fuel consumption in (l)	Annual cost of fuel in (Naira)	Energy Generated (kWh)	Annual Generated (kWh)
A	92	16,560	805,920	145,065,600	800	7,008,000
B	109	19,620	954,840	171,871,200	800	7,008,000
C	52	9,360	455,520	81,993,600	400	3,504,000
D	23	4,140	201,480	36,266,400	200	1,752,000
E	59	10,620	516,840	36,266,400	400	3,504,000
Total	**335**	**60,300**	**2,934,600**	**528,228,000**	**2,600**	**22,776,000**

Effective total fueling cost = total – fueling cost stand-by plant Annual cost of fuel = 356,356,800 Naira

Similarly Effective total Annual Generated Energy = 15,768,000 kWh

Table 3: Summary of Exergic and Thermal Efficiency

Generator	Thermal Efficiency %	Heat Rates kJ/kWh	Fuel specific exergy kJ/kg	Exergic Efficiency %	Average Cooling Water Temperature ^{0}C
A	23.99	4168.06	42384.2	1.28	83
B	20.25	4938.25	42384.2	1.08	80
C	21.22	4711.72	42384.2	2.27	78
D	23.99	4168.06	42384.2	5.14	83
E	18.7	5345.99	42384.2	2.01	73

Table 4: Summary of Quantities of Self-Generated Electrical Energy Using Generators

Generator	Average cost of generated energy (Naira/kWh)	Average Exhaust Gas Temperature (K)	Cost rate of Exergy loss in Million Naira
A	20.7	783	42,753,756
B	24.52	739	57,818,362
C	23.4	735	26,098,540
D	20.7	780	10,163,053
E	26.55	730	33,911,204

DISCUSSION OF RESULTS

A total of five generators were evaluated during the study, results show the following hourly diesel consumption; generator "A" consumes 92 litres/hr, generator "B" which serves as a back-up power for the University main Campus; takes about 109 l/hr, generator "C" consumes about 52 litres/hr and generator "D" consumes about 23 l/hr . While generator "E" takes average of 59 l/hr.

Similarly, results show the following annually diesel consumption; generator "A" consumes 805,920 l/yr, generator "B" which serves as a back-up power for the University main Campus; takes about 954840 litres/year, generator "C" consumes about 455,520 l/yr and generator "D" consumes about 201,480 l/yr. While generator "E" takes average of 516,840 litres per annum. This can be seen in Table 2

An exergic efficiency analysis show that Generators "A" had 1.28 % exergic efficiency, generators "B" had 1.08%, generators "C" had 2.27 %, generator "D" had 5.14 %, and generator "E" had 2.01 % respectively as shown in table 3, which is suggesting the existence of a negative relationship between; fuel consumption, generator capacity and exergic efficiency of the generators evaluated.

Table 4 shows the Cost rate of exergy loss in individual generators as follows; 42,753,756.00 Naira per annum for generator "A". 57,818,362.00 Naira per annum for generator "B", 26,098,540.00 Naira per annum for generator "C", 10,163,053.00 Naira per annum for generator, "D", 33,911,204.00 Naira per annum for generator "E", This Finding shows some level of relationship between generator capacity, fuel consumption and Cost rate of exergy loss. The significance of this is that larger capacity generators will consume more fuel (diesel) which in turn results to higher Cost rate of exergy losses.

A further analysis of the Cost of self-generated Electrical Energy using generators in Naira/kWh, gave the following averages; generator "A" & "D" each will require 20.7 Naira to per kWh of electricity, generators "B" requires 24.5 Naira per kWh of electricity, generator "C" supplied electricity at 23.4 Naira per kWh, while generator "E" requires 27 Naira to generate 1 kWh of electricity, as can be seen in Table 4. It implies that it is cheaper and more cost effective to use generators "A" and "D" than generators.

Table 3 shows that generator "A" had thermal efficiency f 23.99 %, generator "B" had 20.25 %, generator "C" had 21.22 %, generator "D" had 23.99 %, and generator "E" had 18.7 %. Analysis shows that no definite relationship exists between thermal efficiency and exergic efficiency for the five generators evaluated.

Generators "A" had 416806 kJ/kWh Heat Rate, generator "B", had 4938.245 kJ/kWh, generator "C" had 4711.72 kJ/kWh Heat Rate, generator "D" had 4168.06 kJ/kWh Heat Rate, generator "E" had 5345.99 kJ/kWh Heat Rate, as can be seen in Table 3. There is only a very slight variation in Heat Rates of these generators. However, generators "A" and "D" both have equal thermal and exergic efficiency.

Similarly, Table 2 shows the generators' hourly fueling cost as follows; ₦16,560/hr for generator "A", ₦ 19,620/hr for generator "B", 9,360 Naira/hr for generator "C", 4,140 Naira/hr for generator "D", and 10,620 Naira/hr for generator "E" culminating into 40,680 Naira/hr excluding the hourly fueling cost of generator "B" which serves the main campus as a back-up power source.

A further analysis of the Cost of self-generated Electrical Energy using generators in Naira/KWh, gave the following averages; generator "A" & "D" each will require 20.7 Naira per kWh of electricity, generators "B" requires 24.5 Naira per KWh of electricity, generator "C" supplied electricity at 23.4 Naira per kWh, while generator "E" requires 27 Naira to generate 1 KWh of electricity, as can be seen in Table 4. It implies that it is cheaper and more cost effective to use generators "A" and "D" than generators.

AKNOWLEDGEMENT
The authors appreciate the support of the management of Niger Delta University, particularly, the Vice Chancellor of the University Professor Humphrey A. Ogoni for his permission to access information.

CONCLUSION
Generators "A" and "D" delivered cheaper Electrical Energy with an average of 25.2 Naira per kWh than other Generators studied which had an average of 28.50 Naira per kWh of electricity delivered. The implication is that it is more economical to use generators "A" and "D". From investigation it is far cheaper to use the electricity supply from Power Holding Company of Nigeria (PHCN) which cost an average of 4.22 Naira per KWh of electricity

Findings show some level of relationship between generator capacity, fuel consumption and Cost rate of exergy loss. The significance of this is that larger capacity generators will consume more fuel (diesel) which in turn results to higher cost rate of exergy loss. And there is only a very slight variation in Heat rates of these generators studied.

The use of diesel generators also have negative effect on our environment; as carbon mono oxide and other green house gases which are product of combustion of diesel are released in to the surroundings resulting in air, water and soil which may result in environmental pollution.

The significance of this study is that the cost of generation of electricity by the institution is 600% more than the provision from the National grid. The institution must therefore, make concerted effort to sustain the electricity from the National grid. The study also showed that fuel consumption rate varies from one generator to the other. The study gave a blue print to the institution for the annual budgeting in the area of power generation.

REFERENCES
Adenikinju, A. (2016) Efficiency of the Energy Sector and its Impact on the Competitiveness of the Nigerian Economy, International Association for Energy Economics, pp 27 -31, 2008, (last visited 30th October https://www.iaee.org/documents/newsletterarticles/408adeola.pdf

Ahmad, N. Hayat, M. F. Hamad, N. and luqman, M. (2012) Energy Consumption And Economic Growth: Evidence from Pakistan, Australian Journal of Business and Management Research, Vol.2 No.06 pp 9-14, ISSN: 1839 – 0846

BoroumandJazia, G. Saidura, R. Rismanchia, B. and Mekhile, S. (2012) A review on the relation between the energy and exergy efficiency analysis and the technical characteristic of the renewable energy systems, Renewable and Sustainable Energy Reviews, Vol 16, pp 3131– 3135, Doi:10.1016/j.rser.2012.02.057

Capehart, B. L. Turner, W. C. and Kennedy, W. J. (2003) Guide to Energy Management, by The Fairmont Press, Inc , 700 Indian Trail Lilburn, GA 30047 ISBN 0-88173-425-X

Dincer, I. (2011) Exergy as a potential tool for sustainable drying systems, Sustainable Cities and Society pp 91– 96, www.elsevier.com/locate/scs

Ebotion, O, (1996), Energy, Economic Growth and Quality in Developing Countries, Energy Policy, Vol 24, pp 447- 453.

Golup, J. (2005) "Global Competition and EU Environmental Policy", Routledge Taylor and Francis Group, ISBN 0-415-15698-X

Mustapha, A. M. and Fagge, A. M. (2015) Energy Consumption and Economic Growth in Nigeria: A Causality Analysis, Journal of Economics and Sustainable Development Vol.6, No.13, ISSN 2222-1700

Odularu, G. O. and Okonkwo, C. (2009) Does Energy Consumption Contribute to Economic Performance? Empirical Evidence from Nigeria, Journal of Economics and International Finance Vol. 1(2), pp. 44-58,

Rosen, M. A. (2008) Exergy as a Tool for Sustainability, 3rd IASME/WSEAS Int. Conf. on Energy & Environment, University of Cambridge, UK, pp 90 – 99, ISSN: 1790-5095

Rosen, M. A. and Bulucea, C. A. (2009) Using Exergy to Understand and Improve the Efficiency of Electrical Power Technologies, Entropy, Vol 11, pp 820-835, doi:10.3390/e11040820