EVALUATION OF ENERGY CONVERSIONS IN ELECTRICITY GENERATING SYSTEMS

(A CASE STUDY OF SUNSEED NIGERIA PLC, ZARIA)

By

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DECLARATION

I declare that the work in this Thesis entitled 'Evaluation of Energy Conversions in Electrical Energy Generating Systems (case study of Sunseed Nigeria PLC, Zaria)', was done by me in the Department of Chemical Engineering under the supervision of Professor Adefila S.S.

The information derived from the literature has been duly acknowledged in the text and a list of reference provided.

No part of this Thesis was previously presented for another degree or diploma at any university.

ABDULKADIR, Ibrahim Ahmad	___________________	September 2006
Name of student	Signature	Date

CERTIFICATION

This Thesis entitled 'Evaluation of Energy Conversions in Electrical Energy Generating Systems (case study of Sunseed Nigeria PLC, Zaria)' by ABDULKADIR, Ibrahim Ahmad meets the regulations governing the award of Master of Science in Chemical Engineering of Ahmadu Bello University and is approved for its contribution to Knowledge and literary presentation.

Professor S. S. Adefila Date:

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Professor A. U. Umoh

Dean Post Graduate School Date

DEDICATION

This work is dedicated to the memory of my **late father** and to my **mother** in appreciation of all they have done to see to my education.

ACKNOWLEGDEMENT

I would like to acknowledge the support I got from my supervisor, Professor S.S. Adefila, from whose sea of knowledge I have benefited immensely.

I am also grateful to Mr. Olawale for his attention despite very tight schedules, I am grateful for his immense contribution and assistance in making this work possible.

My profound gratitude also goes to my departmental post graduate coordinator DR Mohammad I. A. for his guidance and assistance to see that this work comes to completion.

I would like to express my thanks to the management of Sunseed Nigeria PLC, for giving me unlimited access to the factory for taking technical data and rendering me support by allowing me use of some of it's facilities for the purpose accessing the internet and for producing part of this write-up

I would like to thank both Halimas: my Wife and my Mother each for her love and understanding.

ABSTRACT

Virtually all activities of man is centered around conversion of energy from one form or type to another. From the basic functioning of human body mechanism to all practical activities of man starting from burning of wood to generate heat during stone age to latest satellite communication all involve energy transformation.

The inter-convertibility of all forms of energy and their guiding laws have been established by basic thermodynamics, mechanics, electrostatics and electrodynamics theories. However, the theories are either not explicit enough to be subject-able to verification, where available they are dispersed in various literature.

Owing to the importance of energy conversions it has been considered as worthwhile to collate the energy conversion data expressions and present them in a manner that lends itself to easy application. Test the equations so made available by applying to practical situation in a running processing outfit, a case study of SUNSEED Nigeria PLC.

A very wide variety of literature sources were consulted ranging through virtually all areas of science.

First, preview of historical developments and milestone discoveries of energy conversion systems by scientists from seventeenth to the twentieth centaury was carried out. The laws developed were presented in form of mathematical expressions.

Energy forms and types were classed and presented as mathematical expressions in terms of measurable parameters.

Case study of energy conversion from chemical, mechanical and thermal energy as input to Electrical energy. Diesel powered, 1500kVA generators at Sunseed Nigeria PLC(edible oil division) Zaria, was analyzed using some of the expressions generated.

First law analysis of the conversion efficiency was carried out with a view to identifying areas of energy waste due to inefficiency of conversion, first law efficiency of conversion was found to be 70.03 **%**

Cost comparison of a unit of electricity ₦40.62/kWh when generated using the diesel powered generator appear grossly uneconomical when compared to ₦ 8.50/kWh, price sold by Power Holding Company of Nigeria (PHCN)

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SYMBOL	DESCRIPTION	UNIT
A	Amplitude of waves in first medium	m
B	Amplitude of waves in second medium	m
B	Magnetic flux	Wb
C	Carbon atom	dimensionless
C	Capacitance	F
C_v.	Specific heat capacity at constant volume	J/kg K
C_p	Specific heat capacity at constant pressure	J/kg K
c	Velocity of light	m/s
D	Magnetic flux density	Tesla
D	distance	m
eV	Electron volt.	V
e	Natural log base	dimensionless
E	Energy	J
F	Force	N
F	Faraday constant	dimensionless
g	Local acceleration due to gravity	m/s
$\mathbf{g_c}$	Dimensional constant	dimensionless
H_2	Hydrogen molecule	dimensionless
H	Enthalpy	J
I	Current, luminous intensity, Moment of Inertia,	A, cd, Nm
J	Electron drift velocity or mechanical equivalent of heat	m/s
k	Boltzman constant, Ratio of specific heat capacity (C_p/C_v)	dimensionless
l	Displacement of the particle of a medium	m
M	multiplying factor,	dimensionless
m	Mass	kg
$\mathbf{m_e}$	Electron mass	kg

N	Number of moles of electrons	dimensionless
N_o	Avogadro's number	dimensionless
$\mathbf{N_2}$	Nitrogen molecule	dimensionless
n	Number of moles	dimensionless
$\mathbf{n_e}$	Number of electrons	dimensionless
$\mathbf{n_e}$	Electron number density	m^{-1}
p	Absolute static pressure	Nm^{-2}
P	Pressure	Nm^{-2}
Q	Heat	J
q	Electrical charge	C
R	Universal gas constant	J/mol.K
r	Radius	m
S	Sulphur atom, Seebeck coefficient	dimensionless
T	Temperature	K
U	Internal Energy	J
U	specific internal energy	J/kg
V	Volume	m^3
V	Voltage	V
V_m	Maximum Voltage (amplitude Voltage)	V
v	Velocity	m/s
W	Work, mass flow rate	J, kg/s
W_n	Net work done	J
$\mathbf{W_e}$	External work done on or by the system	J
x	Distance	m
Z	Height above any arbitrary datum plane	m

GREEK SYMBOLS

Π	Peltier coefficient	dimensionless
α	Transmission coefficient	dimensionless
β	Angle of deflection	Rad
χ		
δ	Sound energy intensity (decibels)	db
ε	Dielectric constant	
η	Efficiency, Illuminace	dimensionless, lm/m^2
λ	Wavelength	m
μ	Electron mobility	
ν	Stoichiometric number, cell open voltage	dimensionless,V
π	Ratio of circumference to diameter of circle	dimensionless
θ	Angle	Rad
ρ	Density	kgm^{-3}
σ	Electron conductivity	
τ	Mean time between molecular collusions	s
υ	Photon Energy, frequency	J, s^{-1}
ϖ	Time average energy density in space	Jm^{-3}
ω	Angular Velocity	s^{-1}
ω_c	Frequency of electron collision	s^{-1}
ψ	Electric potential	V
Δ	Change in quantity	dimensionless
Φ	Electric field strength	Vm^{-2}
Ω	Resistance	ohm
$\cos \varphi$	Power factor	dimensionless

SUBSCRIPTS

t	Transmitted
t	Incident
th	thermal
v	volume
p	pressure
m	maximum
e	electron

LIST OF ABBREVIATIONS

MHD	Magneto hydrodynamics
ATP	Adenosine tri phosphate [$C_{10}H_8N_4O_2NH_2(OH)_2(PO_3H)_3H$]
NADPH	Nicotinamide adenine dinucleotide
NADP	Nicotinamide adenine dinucleotide
ADP	Adenosine diphosphate
FADH	Flavin adenine dinucleotide
PHCN	Power Holding Company of Nigeria

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CHAPTER 1

INTRODUCTION

Man has always known two types of things around him in the world; **matter and energy.** Man's continuous effort to master the handling and inter-conversion of matter and energy can be considered to be the basic historical development of man from stone age till date. In the mean time during the early part of the twentieth century, Einstein showed that a relationship exists between matter and energy, as given in Equation 1.1

$$E= mc^2 \qquad [J] \qquad (1.1)$$

Since our civilization depends on the mastery of inter-convertibility of **energy to energy**, **matter to matter** and **matter to energy,** efficiency and effectiveness of conversion becomes important, in the process. The need for pre and post analyses of the systems under investigation makes the qualitative and quantitative grasp of the processes of energy inter-conversion imperative. Accordingly, the aim of this work is to look closely at the concepts, theory and the quantitative expression of the process converting from one form or one type of a form to another.

Right from the stone age until the twentieth century man has always been more concerned with the inter-conversion of energy from heat to work and vice versa. A close study of man even well into the first half of the twentieth century reveals that although forms of energy as they are known today were employed by scientists and engineers in practical problem solving, the various types of the forms being put to effective use were limited in scope.

Other types of energy like electro-magnetic and nuclear, - to name a few, were not put into extensive application, for real life problem solving by engineers. This is attributable to the limited understanding of them and fact that other types, easier to use were available.

For decades the response to the ever-growing need for energy in a more readily usable form, as typified by the case of electrical energy, was to build more generation capacity in form of more or larger steam power plants.

1.1 Problem Statement

The necessary expressions needed by all engineers and scientists working in the field of energy conversion are usually formulated through thermodynamics, mechanics, electrostatics and electrodynamics theories, which are scattered in wide literature sometimes in rudimentary forms. However, the energy conversion guiding laws are either not explicit enough to be subject-able to verification, where available they are dispersed in various literature.

1.2 Justification

- Since energy conversion guiding laws are generally not explicit enough to be subject-able to verification, therefore a work to provide a reference material for Engineers and scientists working in the field of energy conversion would be a tremendous help
- There is the need to bring to light in economic terms, the wastages in practical energy utilization, being essentially a conversion process.
- The need to simplify conversion processes like metabolism, photosynthesis, etc to single mathematical expressions that will serve as link between Science of Biochemistry and Engineering for purpose of human development

1.3 Objectives

The objectives of this work are

- To look closely at the concepts, theory and the quantitative expression of the process of converting from one form or one type of a form of energy to another.

- To present energy forms and types as mathematical expressions in terms of measurable parameters
- To present some examples of conversion of each form of energy into other forms in quantifiable mathematical expressions.
- To apply some of the expressions to a practical energy conversion situation, a case study of electrical energy generation and consumption at: Sunseed Nigeria PLC, (edible oil division) Zaria, with a view to identifying areas of wastage or inefficient use. This will facilitate cost comparison with cost of Power from Power Holding Company of Nigeria

1.4 Scope and Limitations

- A limited number of theories and mathematical models has been studied and presented owing, mainly time factor
- The case study analysis of energy conversion is limited to first law of thermodynamics
- The evaluation of energy conversion in electrical energy generating system was carried out, generator room was defined as system boundary

CHAPTER 2

SURVEY OF LITERATURE

2.1 Introduction

The inter-convertibility of all forms of energy and their guiding laws have been established by basic thermodynamics. However, the guiding laws are either not explicit enough to be subject-able to verification, where available they are dispersed in various literature. The aim of this chapter is to find and collate such laws sometimes from rudimentary forms and ultimately in mathematical and verifiable forms. A list of some types of energy with their quantitative expressions is presented. Subsequently the conversions of one form to the other three forms along with examples of a conversion system in practical use, where applicable, are presented.

Finally, this chapter reviews energy propagation in terms of particle motion or wave motion, this is imperative to facilitate derivation of energy transformation equations.

2.2 History of Energy Conversions

Table 2.1 shows that throughout the history of human technological development from stone- age till late 20th century, with the exception of first electric current generator in 1831 and first hydroelectric power at Niagara Falls in 1895, all significant discoveries in the history of energy conversion is about conversion of thermal form of energy to mechanical form. It reveals the need for engineers to explore and put to practical application other energy conversion devices that will enable exploitation of other forms of energy, though known but not adequately harnessed.

TABLE 2-1: SOME SIGNIFICANT EVENTS IN THE HISTORY OF ENERGY CONVERSION

Name of Scientist		Discovery/Invention	Conversion	Year
1	Giovanni Branca	Impulse steam turbine proposal	Thermal to Mechanical	1629
2	Thomas Newcomen	Atmospheric engine using steam (first widely used heat engine)	Thermal to Mechanical	1700
3	James Watt	Separate steam condenser idea;		1765
4	James Watt	First Boulton and Watt condensing steam engine	Thermal to Mechanical	1775
5	John Barber	Gas turbine ideas and patent	Thermal to Mechanical	1791
6	Benjamin Thompson (Count Rumford)	Observed conversion of mechanical energy to heat while boring cannon	Mechanical to Thermal	1798
7	Robert Fulton	First commercial steamboat	Thermal to Mechanical	1807
8	Robert Stirling	Stirling engine	Thermal to Mechanical	1816
9	N. L. Sadi Carnot	Principles for an ideal heat engine	Thermal to Mechanical	1824
10	Michael Faraday	First electric current generator	Mechanical to Electrical	1831
11	Robert Mayer	Equivalence of heat and work	Thermal to Mechanical	1842
12	James Joule	Basic ideas of the first law of thermodynamics		1847
13	James Joule	Measurement of mechanical equivalent of heat	Thermal to Mechanical	1849
14	Rudolph Clausius	Second law of thermodynamics		1850
15	William Thompson (Lord Kelvin)	Alternate form of the second law of thermodynamics		1851
16	Etienne Lenoir	Internal combustion engine without mechanical compression		1860
17	A. Beau de Rochas	Four-stroke cycle internal combustion engine concept	Chemical to Thermal to Mechanical	1862

18	James C. Maxwell	Mathematical principles of electromagnetism		1865
19	Niklaus Otto	Four-stroke cycle internal combustion engine	Chemical to Thermal to Mechanical	1876
20	Charles Parsons	Multistage, axial-flow reaction steam turbine	Thermal to Mechanical	1884
21	Thomas Edison	Pearl Street steam-engine-driven electrical power plant	Thermal to Mechanical to Electrical	1884
22	C.G.P. de Laval	Impulse steam turbine with convergent-divergent nozzle	Thermal to Mechanical	1889
23	Rudolph Diesel	Compression ignition engine	Chemical to Thermal to Mechanical	1892
24	Rudolph Diesel	First hydroelectric power at Niagara Falls	Mechanical to Electrical	1895
25	Albert Einstein	Mass-energy equivalence		1905
26	Ernst Schrödinger	Quantum wave mechanics		1926
27	Frank Whittle	Turbojet engine patent application;	Thermal to Mechanical	1930
28	Frank Whittle	First jet engine static test	Thermal to Mechanical	1937
29	Otto Hahn	Discovery of nuclear fission	Chemical to Thermal	1938
30	Hans von Ohain	First turbojet engine flight	Chemical to Thermal to Mechanical	1939
31	J. Ackeret, C. Keller	Closed-cycle gas turbine electric power generation	Chemical to Thermal to Electrical	1939
32	Enrico Fermi	Nuclear fission demonstration at the University of Chicago	Chemical to Thermal	1942
33	Felix Wankel	Rotary internal combustion engine	Chemical to Thermal to Mechanical	1954
34	Felix Wankel	Production of electricity via nuclear fission by a utility at Shipping port, Pennsylvania	Chemical to Thermal to Mechanical	1957
35	NASA , USA	Rocket-powered landing of man on the moon	Chemical to Thermal to Mechanical	1969
36	Electricité de France	Superphénix 1200-MW fast breeder reactor. (first grid power)	Chemical to Thermal to Mechanical	1986

Source: Weston K.C, `kenneth-weston@utulsa.edu`*, December 2000*

2.3 Classification of Energy Forms

In line with the overall objective of reducing all forms of energy to mathematical equations in terms of directly measurable parameters of systems, a need arises to highlight forms of energy and their inter-convertibility. The main forms and types of energy are:

2.3.1 Electrical energy

3. Electrostatic
4. Electricity
5. Electromagnetic

2.3.2 Mechanical energy

1. Pressure
   - Energy stored in compressed gas:
   - Sound Energy
2. Potential
   - Hydro
   - Magnetic
3. Kinetic
   - Tidal
   - Wind

2.3.3 Chemical energy

1. Fossil Fuel
   - Coal

- Petroleum

2. Biochemical

- Solid waste
- Food

3. Nuclear

- Fission
- Fusion

2.3.4 Thermal energy

1. Solar
2. Ocean thermal energy
3. Geothermal energy
4. Released in the process of combustion

2.4 Inter-conversion of Energy Forms

Figure 2.1 depicts the inter-relationship of the forms of energy. The direction of convertibility is indicated by the arrows, the thicker solid lines show the well developed paths in terms of application in day to day practical use, while the thin lines show conversion paths that have not received wide patronage due to a variety of reasons including the relative ease with which the others can be exploited.

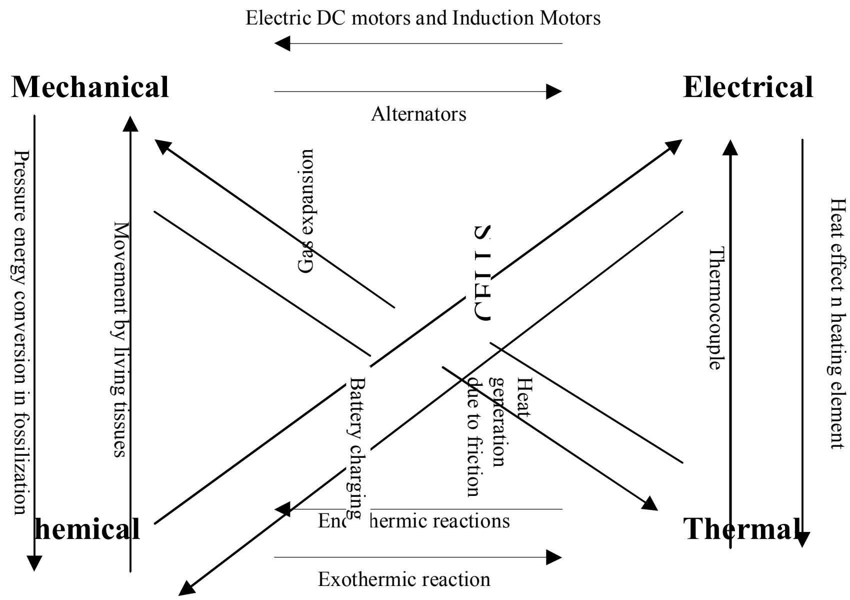


FIGURE 2.1: FORMS OF ENERGY AND THEIR INTER-CONVERTIBILITY

2.4.1 Electrical energy types

Electrical energy is stored in the form of potential known generally as electromotive force; this is forced by the separation of opposite charges of electricity. This separation may be caused by physical motion, or it may be initiated or completed by chemical, thermal or magnetic causes or by radiation. The classifications of the various phenomena based on these causes were studied and presented by Foeke (1961), as described below in sections 2.4.1.1 to 2.4.1.6

2.4.1.1 Electromagnetic induction

Electromagnetic induction is the production of an electrical potential difference across a conductor situated in a changing magnetic flux. Michael Faraday in 1831, discovered that electromotive force produced along a closed path is proportional to the rate of change of the magnetic flux through any surface bounded by that path.

2.4.1.2 Contact of dissimilar substances

The electrical potential energy between two charges q_1 and q_2 is:

$$\mathbf{E = q_1q_2/(4\pi\varepsilon r)} \qquad [J] \qquad (2.1)$$

The electric *potential* generated by charges q_1 (denoted V_1) and q_2 (denoted V_2) is:

$$\mathbf{V_1 = q_1/(4\pi\varepsilon r)} \qquad (2.2)$$

$$\mathbf{V_2 = q_2/(4\pi\varepsilon r)} \qquad (2.3)$$

$\boldsymbol{\varepsilon}$ is the di-electric constant

$\mathbf{r}$ is the distance between the two charges q_1 and q_2

Michael and Philip (1995)

2.4.1.3 Thermoelectric action

Seebeck, in 1821 discovered that a voltage was developed in a loop containing two dissimilar metals provided the two junctions were maintained at different temperatures. Peltier, in 1834 found that electrons moving through a solid can carry heat from one side of the material to the other side. The true nature of Peltier effect was explained later by Lenz who stated that upon flow of current, heat is absorbed or generated between two conductors and demonstrated this effect by freezing a drop of water at a bismuth-antimony junction and melting the ice by reversing the current The ratio of heat flow to current for a particular material is known as Peltier coefficient, **P**. Its value is closely related to another intrinsic property, the Seebeck coefficient. Thomson (Lord Kelvin) (1854), established a relationship between the Seebeck and Peltier coefficients and predicted the third thermoelectric effect, the Thomson effect. This effect relates to the heating or cooling in a single homogenous conductor when a current passes along it in the presence of a temperature gradient. These three effects are connected to each other by a simple relationship

$$\mathbf{S} = \mathbf{\Pi} / \mathbf{T} \tag{2.4}$$

S is seebeck coefficient,

Π is Peltier coefficient,

T is thermal gradient

When a thermal gradient, T, is applied to a solid, it will be accompanied by an electric field, V, in the opposite direction; this is known as Seebeck effect. The ratio V/T is defined as the Seebeck coefficient (**S**), expressed in volts per degree, or more often microvolts per degree, (μV/K). Kenneth (2000)

2.4.1.4 Chemical action

Alessandro Volta in 1800, gave the first description of the concept of generating electrical energy from chemical action, hence electrochemical cell. The exchange of electrons in redox reactions in electrolytes result in flow of the electrically charged particles, flow is facilitated by the potential difference between the anode and cathode, hence the flow of electrical current

2.4.1.5 Friction between dissimilar substances

The electrical energy resulting from this type of action is primarily in form of static charge

2.4.1.6 Photoelectric effect.

Flow of electrical current results when light energy is incident on specially prepared semi conductor materials. The force F, acting on a charge due to the electric field q, is explicitly represented by the vector equation given as.

$$\mathbf{F = qE} \qquad [N] \qquad (2.5)$$

Jackson (1962)

The flow of positive charges q, through an electric field is measured in C/s or Amperes, this is given as:

$$\mathbf{I = dq/dt} \qquad [A] \qquad (2.6)$$

As discovered by Sir William Thomson (Lord Kelvin) in 1854, rate of energy flow as result of the current flow in a direction of decreasing potential in an electric field is the rate at which work is done in moving the positive charges.

$$\mathbf{Energy/time = Power} \qquad [W] \qquad (2.7)$$

$$\mathbf{= dw/dt}$$

$$\mathbf{= Vdq/dt} \qquad [W]$$

$$\mathbf{= VI} \qquad [W] \qquad (2.8)$$

Kenneth (2000)

2.4.1 Conversion of electrical energy to others forms

The conversion of electrical energy into other forms of energy has been considered details of concept with example of specific device in practical application.

2.4.1.1 Conversion of electrical energy to thermal energy

Discovery of Lord Kelvin (1854) shows that electrical energy conversion to thermal energy is generally achieved by passing electric current (I) through conducting medium with resistance R. When presented per unit time Joules law gives:

$$\textbf{Power = Energy/time}$$

$$\mathbf{P = I^2R} \qquad [W] \qquad (2.9)$$

Kenneth (2000)

Since it is logical to assume that there is no practically existing electric conductor that has no resistance, it can be put forward that electric energy transportation is always accompanied by conversion to thermal energy.

Jean Peltier in1834 discovered that when current is passed across the junction between two different metals, an evolution or absorption of heat takes place and this effect is different from the heat loss due resistance of electrical conductors, referred to as the Joule-Thompson effect owing to the resistance of the junction. The Peltier effect is reversible, heat being evolved when the current passes in one direction and absorbed when passed in the other direction

In a somewhat conversed way, Thomas Johann Seebeck in1821 discovered that in a closed electrical circuit consisting of two different metals, if the junctions are maintained at different temperatures, within certain temperature ranges electric current flows.

2.4.1.2 Conversion of electrical energy to light energy:

When electrons pass through the element of a light bulb, they collide with the nucleus of the lattice causing them to vibrate with larger amplitude. Eventually the energy is radiated away as electromagnetic waves called photons. The spectrum consists of the infrared, the visible and the ultraviolet. This is the energy that escapes from the light bulb.

James Prescott Joule studied the conversion of electrical energy into heat and light in 1889, using the experimental setup in shown Figure 2.3. He carried out two experiments, in the first experiment, infrared is absorbed by the water, causing the water temperature to increase while visible light passes through the water.

The amount of electrical energy, E consumed by the light bulb was calculated from Equation 2.8 when the light bulb is surrounded by material that will absorb almost all of the photons and whose specific heat is known, the total heat was found by using Equation 2.10

$$\mathbf{Q = [\Sigma\{(mC_p)_{water} + (mC_p)_{mercury}\}]\ \Delta T} \qquad [J] \qquad (2.10)$$

Anthony (1996)

However in a second experiment the material absorbed all the radiation except the visible part of the spectrum, the efficiency of the lamp in producing light can be calculated from the following,

In the first experiment, the water absorbed all energy produced by the light bulb. By monitoring the temperature of the water, the heat produced by the lamp can also be calculated. The ratio between the electrical energy that flows into the lamp and the heat energy produced by the lamp determines the electrical equivalent of heat.

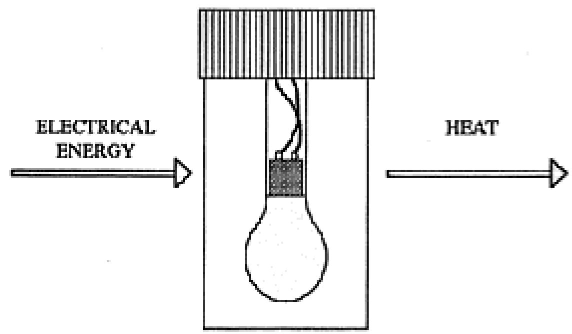


FIGURE 2.2: SCHEMATIC OF EXPERIMENT ON ELECTRICAL ENERGY CONVERSION TO HEAT AND LIGHT IN A BULB.

In a second experiment, the efficiency of the incandescent lamp was measured. The details were similar to the first experiment, but no ink was added to the water. Without the ink, some of the energy from the lamp is absorbed into the water, while some visible light energy escapes. To determine the amount of energy that was released as light, the heat transferred into the water was subtracted from the total electrical energy that flowed into the lamp. The ratio between the light energy and the electrical energy gives the efficiency of the bulb.

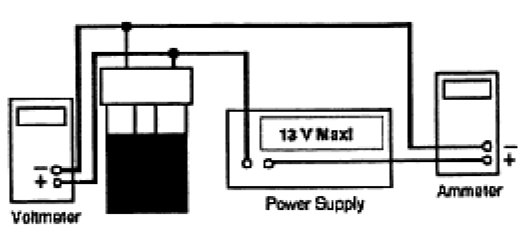


FIGURE 2.3: ELECTRICAL ENERGY TO HEAT EXPERIMENTAL SETUP

In order to calculate the electrical equivalent of heat (J_e), there is need to determine the total electrical energy, E that flowed into the lamp and the total heat Q absorbed by the water and the experimental assembly.

$$\mathbf{Q = \{(mC)_{water} + (mC)_{EEH\ jar} + (mC)_{thermometer}\}\Delta T} \qquad [J] \quad (2.11)$$

where m is mass in kg,

C is specific heat capacity,

$\Delta T = T_2 - T_1$, is temperature change

Therefore,

$$J_e = E/Q \qquad [\text{Dimensionless}]$$

(2.12)

$$\mathbf{E_{light} = E_{electrical\ energy\ input} - E_{thermal\ for\ EEH\ jar}} \qquad [J] \quad (2.13)$$

The efficiency of an incandescent light bulb was thus calculated. Anthony (1996)

An alternative method of computing lighting efficiency makes use of the inverse-square law, which states that the illuminance at a point on a surface perpendicular to the light ray is equal to the luminous intensity of the source at that point divided by the square of the distance between the source and the point of calculation.

$$\mathbf{\eta = I/d^2} \qquad [\text{dimensionless}] \qquad (2.14)$$

Where:

η Is the illuminance, **I** is the luminous intensity and **d** is the distance between the source and the point of calculation. Fink (1978).

Conversion of electrical energy into light energy is achieved indirectly through any one of the following ways:

2.4.1.2.1 Incandescent lamps: when an electric current flows through a wire, there is a temperature rise which is greatest for small wires with high resistance, the heating increases the resistance further and as the voltage is increased the wire glows and becomes light source. Thomas Edison put this principle into use in the design of incandescent lamp. Brill (1980)

2.4.1.2.2 Sodium and mercury lamps*:* They are sometimes called discharge lamps. In these light sources, the volatile metal mercury or sodium is excited by electrons, which have been accelerated between two electrodes as a result of applied voltage. Collision between excited gaseous metal atoms produces luminescence, which yields a great deal of visible light. Brill (1980)

2.4.1.2.3 The fluorescent lamp: First experiments with fluorescent lamps were conducted by Henry Bacquerel in 1867. Fluorescence is an effect whereby a substance can absorb radiation at one wavelength and re-radiate it at different, usually longer wavelength. If ultraviolet in addition to visible radiation falls on such substance some of the ultraviolet radiation is re-emitted as visible light, if emission occurs immediately it is known as fluorescence but if the emission is delayed and the energy is emitted over a period of time it is known as phosphorescence. Brill (1980).

2.4.1.2.4 The flash bulb: Flash bulb light sources operate on the principle of'wool' of reactive metal (magnesium, aluminum, zirconium, etc.) to produce bright flash upon a discharge of electricity in the bulb, the bulb contains oxygen to enhance the combustion rate and temperature. Brill (1980)

2.4.1.3 Conversion of electrical energy to mechanical energy:

This is achieved by conversion of electrical energy to magnetic force through the principle of electromagnetic force exerted between two current carrying conductors hence a mechanical potential.

Guide to calculation of electromagnetic forces exerted on current carrying conductors during short-circuit condition is stated in; ANSI Standard (C37.32-1972). The force is a function of current, its decrement rate, the shape and arrangement of conductors and the natural frequencies of the complete assembly. Because of the large number of variables involved including the wide range of constants for support structures, the force calculated by the following expression is that produced by the peak maximum current.

$$\mathbf{F = 5.4X10^{-7}\,.M.\,I^2/x} \qquad (2.15)$$

where;

F is the force in Newton

M is the multiplying factor dimensionless

$\mathbf{I_{sc}}$ is the short-circuit current in Amperes

x is the distance between the two current carrying conductors. Perry et al (1977)

In most cases the calculated force is higher than that which actually occurs, due to inertia and flexibility of the systems and this fact tends to compensate for resonant forces, the equation therefore is sufficiently accurate for usual practical conditions.

The mechanical energy stored in form of magnetic potential can be considered to be the mechanical work to be done by the magnetic force in bringing the two conductors together.

For a general case of circuit with two coils wound on top of one another, suppose that each coil is connected to an independent electrical energy source with potential difference $V_1$and V_2 respectively, the circuit equations, as presented by Richard (2002) are

$$\mathbf{V_1 = R_1I_1 + L.dI_1/dt + M.dI_2/dt} \quad (2.16)$$

$$\mathbf{V_2 = R_2I_2 + L.dI_2/dt + M.dI_1/dt} \quad (2.17)$$

Clearly, the total magnetic energy stored in the two coils is

$$\mathbf{W_B = ½\, L_1I_1^2 + ½\, L_2I_2^2 + MI_1I_2} \quad (2.18)$$

$$\mathbf{L = \mu_o N^2.\pi.r^2} \boldsymbol{l}$$

where **L** is the self inductance, **N** number of turns per unit length of the solenoid, **r** the radius and ***l*** is the length. The field inside the solenoid is uniform with magnitude

$$\mathbf{B = \mu_o N.I} \quad (2.19)$$

Note the mutual inductance term increases the stored magnetic energy (**I_1**and **I_2** are of the same sign), that is, the currents in the two coils flow in the same direction, so that they generate magnetic fields, which reinforce one another. Conversely, the mutual inductance term decreases the stored magnetic energy if **I_1** and **I_2** are of the opposite sign.

2.4.1.4 Conversion of electrical energy to chemical energy:

When chemical reaction proceeds spontaneously via an ionic mechanism, it is possible in principle to convert part of the energy change on reaction directly into electric energy. Conversely some chemical reactions can be made to occur via ionic mechanism by addition of electric energy to a suitably contrived reactor system. Electrochemical cells are the devices used to achieve either of the aforementioned. The analysis of electrochemical cells is presented in detail in Section 2.4.1.3. The reverse of the chemical reactions presented in Section 2.4.1.3 achieves conversion of electrical energy into chemical energy

2.4.3 Mechanical energy

The principle of conservation of energy requires that the mechanical energy of a system remains unchanged if it is subjected only to forces, which depend on position or configuration.

2.4.3.1 Pressure energy

Pressure Energy is defined, as the energy required to introduce a fluid into a confined space.

- ***Energy stored in adiabatically compressed gas:***

Energy stored is equal to the work done in adiabatic compression

$$\mathbf{E = \gamma/(\gamma\text{-}1)(mRT_1/9806)[(P_2/P_1)^{(\gamma-1)/\gamma} - 1]} \qquad (2.20)$$

where m is the mass flow (mol/s), R molar gas constant, γ ratio of specific heat capacity at constant pressure to that at constant volume, T_1 and T_2 are temperatures at the initial and final stages respectively. Perry et al (1997)

- ***Energy stored in isothermally compressed gas:***

$$\mathbf{E = RT.ln(p_1/p_2)} \qquad (2.21)$$

Perry et al (1997)

- ***Energy stored in polytropically-compressed gas:***

$$\mathbf{E = C_V\, \Delta T + P\Delta V} \qquad (2.22)$$

Perry et al (1997)

<u>2.4.3.2 Sound energy</u>

Sound is a form of wave motion and is formed by vibrating matter; an example is the string of a guitar. The sound waves will last as long as the vibrations last. Since a sound wave is a disturbance, which is transported through a medium via the mechanism of particle interaction, a sound wave is characterized as a mechanical wave. Sound waves are distinguished from electromagnetic waves by the fact that:

- An oscillating object produces sound waves while electromagnetic waves are not.
- Sound waves are not capable of traveling through a vacuum while electromagnetic wave can.
- Sound waves are not capable of diffracting while electromagnetic wave is.
- Sound waves are capable of existing with a variety of frequencies while some electromagnetic waves, light for instance, have a single frequency.

Sound waves move out spherically from a point source of sound, and as they do, they become less intense. Sound pressure is inversely proportional to distance from the source as long as the sound does not encounter obstacles,

Sound pressure levels may be stated in terms of peak values of pressure variations. They are usually quoted in decibels above the average threshold of hearing level.

Energy per unit time transmitted by sound is proportional to the square of the pressure.

$$\boldsymbol{\delta = 20\log_e(p'/p_o)} \tag{2.23}$$

$$\boldsymbol{P' = (e^{\delta/20})\, P_o} \tag{2.24}$$

Morse (1948)

Where δ is in decibels and standard excess pressure $P_o = 2x10^{-10}$ bar, V is the volume of space for which average value of δ is taken.

$$\textbf{Energy} = \boldsymbol{P'.\ V} \tag{2.25}$$

$$\boldsymbol{= 2x10^{-10}\,(e^{\delta/20})} \tag{2.26}$$

Morse (1948)

2.4.3.2 Kinetic energy

The kinetic energy of a particle in linear motion was proposed by Isaac Newton in1720 and is given by:

$$\mathbf{E = \frac{1}{2}\rho v^2} \tag{2.27}$$

In 1950, Albert Einstein proposed his relativistic mechanics, in which he proposed the kinetic energy of a body in motion especially at near light velocities as given by:

$$\mathbf{E_k = mc^2(\gamma\text{-}1) = \gamma mc^2 - mc^2} \tag{2.28}$$

$$\mathbf{E_k = \gamma mc^2 - mc^2 = \{1/(\sqrt{(1-v^2/c^2)})\}mc^2} \tag{2.29}$$

Where $\gamma = 1/(\sqrt{(1-v^2/c^2)})E_k$ is the kinetic energy of the body, v is the velocity of the body, *m* is its rest mass, *c* is the velocity of light in a vacuum. γmc^2 is the energy of the body and mc^2 is the rest mass energy . Richard et al (1965).

Where gravity is weak, and objects move at much slower velocities than light, Newton's formula is an excellent approximation of kinetic energy of a body in linear motion.

The exact Taylor series is

$$\mathbf{E_k = \frac{1}{2} mv^2 + {}^{3}/_{8}\, m(v^4/c^2) + {}^{5}/_{16}\, m(v^6/c^4) + \ldots}$$

The kinetic energy of a rigid body rotating about a fixed axis is

$$\mathbf{E = \frac{1}{2} I_o\omega^2}$$

$$\mathbf{= \frac{1}{2}(\rho R)\omega^2} \tag{2.30}$$

where $\mathbf{I}_o$ is the mass moment of inertia about the axis of rotation. $\boldsymbol{\omega}$ is the angular velocity in radian/second about the center of rotation, **R** is the radius of rotational motion and $\boldsymbol{\rho}$ is the mass per unit volume. Richard et al (1965)

Total kinetic energy is the algebraic sum of the translation kinetic energy of the center of gravity and the rotational kinetic energy about the center of gravity.

$$\mathbf{E = ½\rho v^2 + ½(\rho R)\omega^2} \tag{2.31}$$

R is the radius of the of rotational motion of the center of mass, **v** the velocity, is the velocity at the center of gravity and the moment of inertia I is the centroidal moment of inertia. Richard et al (1965).

2.4.3.3 Potential energy

2.4.3.3.1 Potential due to mutual attraction

The 'law of mutual attraction' clearly points out that, two particles attract each other with a force **F** proportional to their mass $\mathbf{m_1}$ and $\mathbf{m_2}$ and inversely proportional to the square of the distance between them, the total potential energy in a body by virtue of its position from another

$$\begin{aligned} \mathbf{E} &= \textbf{force x distance apart} \qquad (2.32) \\ &= \mathbf{G.m_1.m_2/\,l^2 \times l} \\ &= \mathbf{G.\ m_1.m_2/\,l} \end{aligned}$$

where G is the gravitational constant with a value of $\mathbf{G=6.673x10^{-11}}$

This implies therefore that when a body is at rest the forces acting externally to it must form an equilibrium system; potential energy is therefore the energy possessed by virtue of location with reference to certain fixed datum. Michael and Philip (1995).

2.4.3.3.2: Potential energy due to gravitational pull with reference to a point.

The basic equation of static is obtained by consideration of particle at rest with respect to other particles at rest subject to only gravitational force.

Energy stored in the particle per unit volume is given by:

$$E = \rho g h \qquad (2.33)$$

where h is the height from a reference point in the gravitational field, $g = 9.98 m/s^2$ is the acceleration due to earth's gravity. Michael and Philip (1997)

2.4.3.3.2: Tensile energy stored in a stretched elastic material due to applied force.

This is also essentially a potential energy. If elastic limit is not exceeded, extension is proportional to applied load so force in the wire has increased from **0** to **F**.

Energy stored in the wire is equal to the work done in stretching the wire.

$$\mathbf{E = \tfrac{1}{2} F.\Delta l} \qquad (2.34)$$

Where Δl is the elongation of the wire. Perry et al (1997).

2.4.3.3.3: Energy stored in a deflected magnet

Applying similar analogy as in tensile energy in a stretched wire to energy stored in a deflected magnet by virtue of the change in position and its tendency to return to original location may also be considered as potential energy

Energy stored in a magnet deflected from a position of balance may be equated to the work done in deflecting the magnet. When the deflection is for the angle $\boldsymbol{\beta}$ the pole **N** has moved along distance AB along a direction of the field and work done on the pole N is measured by the product of the force and the distance. Perry et al (1997)

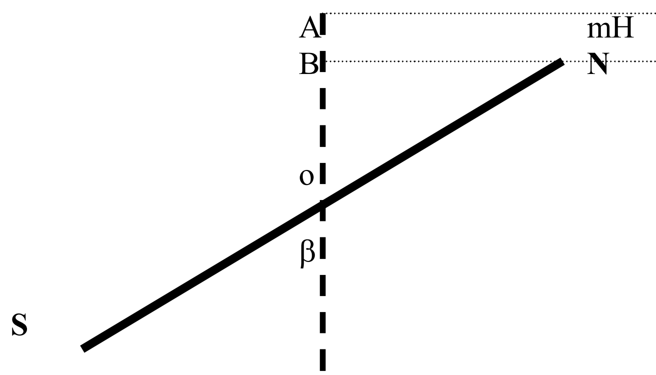


FIGURE 2.4: ENERGY IN DEFLECTED MAGNET

Work = mH x AB

The work done on the pole **S** is equal to this, hence if 2xL be the length of the magnet:

Total work = 2mH x AB = 2mH (AO-BO)

= 2mH(L – L Cos β)

= 2mLH(1 – Cos β)

$$\mathbf{E = mH(1- Cos\ \beta)} \qquad (2.35)$$

Perry et al (1997)

2.4.3.3.4: Energy in a uniform magnetic field:

Total energy E, in a uniform magnetic field **B** of volume **V**

$$E= \tfrac{1}{2}\, kB^2V$$

(2.36)

where k is constant.

Perry et al (1997).

2.4.4 Conversion of mechanical energy to other forms of energy

Conversion of mechanical energy to other forms of energy has found wide application in day-to-day science and technology due to the relative ease.

2.4.4.1 Mechanical energy conversion to electrical energy:

The effect whereby the relative motion of a magnet and an electric coil produced a current, known as electromagnetic induction, was simultaneously discovered in 1831 by Michael Faraday (1791-1867) in England and Joseph Henry (1799-1878) America. Faraday used his discovery to prepare the first dynamo in which the continuous rotation of a conducting copper plate between the poles of a magnet produced a continuous current. In a dynamo mechanical energy is converted into electrical energy via a magnetic field. (Fifty years later, Faraday's discovery was applied to the commercial generation of electricity.

The induced electromagnetic force across a conductor is proportional to the rate at which the conductor cuts magnetic flux. We can equate the emf, ε to the rate at which the flux is cut.

The work done by the force exerted on a wire by a field is Force x Distance.

Force, $\mathbf{F = BI}\boldsymbol{l}$**,** [N] (2.37)

Energy supplied $\mathbf{E = BI}\boldsymbol{l}\mathbf{x}$**.** [J] (2.38)

The definition of the electromotive force ε as the energy E changed from other forms of energy to electrical energy per unit charge q gives

$$E = q\,\varepsilon. \qquad (2.39)$$

Charge q is the product of current and time so

$$E = \varepsilon\, I\, t. \qquad (2.40)$$

Combining these equations 2.39 and 2.40

$$\mathbf{\varepsilon . It = BI\mathit{l}x,}$$

$$\mathbf{E = (B\mathit{l}x)/(tI)} \qquad [J] \qquad (2.41)$$

According to Lenz's Law ‘The direction of any induced current is such as to oppose the flux change that causes it, Fink and Beaty (1978).

This means that the emf produced must be negative, as the voltage causing it is taken to be positive, as is the field that it produces, which in turn causes the emf, ε

Magnetic flux $$\mathbf{\Phi = B\mathit{l}x} \qquad (2.42)$$

.
$$\mathbf{\varepsilon = -\Phi/t} \qquad (2.43)$$

Or according to the original statement, the emf is proportional to the rate of change of flux. Fink and Beaty (1978).

widely used method of electric power generation owing to the ease and less cost compared to other methods practicable.

2.4.4.2 Mechanical energy conversion to chemical energy:

Applying mechanical energy as pressure to a gas under isothermal condition results in volume decrease, at critical point the gas condenses to liquid, thereby converting the mechanical energy applied into chemical energy,

Change in chemical energy = Latent heat of vaporization

$$E = L \qquad [J] \qquad (2.44)$$

where L is latent heat of vaporization.

2.4.4.3 Mechanical energy conversion to thermal energy:

James Prescott Joule in 1886, through experiment of converting mechanical energy into heat, observed the heat by measuring the increase in temperature of matter of known masses and of known specific heat capacity.

The common experience with friction is a direct evidence for a relation between mechanical and thermal energy. When two reasonably rough objects are rubbed together they tend to warm up. Joule noticed this fact and proposed that the mechanical work W done in rubbing is directly proportional to the quantity of heat Q produced,

$$\mathbf{Work = J.\,Q} \qquad [J] \qquad (2.45)$$

where J is Joule's constant of proportionality. Joule devised elegant experiments that confirmed this relationship . He also showed that W could be any form of energy, not just work against friction, provided it is all converted to heat.

$$\mathbf{Q = mC\,\Delta T = mC(T_2 - T_1)} \qquad [J] \qquad (2.46)$$

where m is the mass and T_1 and T_2 are the initial and final temperatures, respectively. The constant of proportionality C, called the specific heat relates the temperature change of a given body to the quantity of heat that produces it. Perry et al (1997).

It is a characteristic of the material of which the body is composed. This relationship is an approximation that is good over temperature range not more the 100 ^{o}C apart. The specific heat capacity C changes significantly if temperature change is wider.

This experiment consists of a moving part, which rotates against a stationary brass mass containing a thermometer. These two parts exert frictional forces on each other, which generate heat. The stationary mass is constrained from rotating only by a measured force *F* applied at a radius *r* from its center.

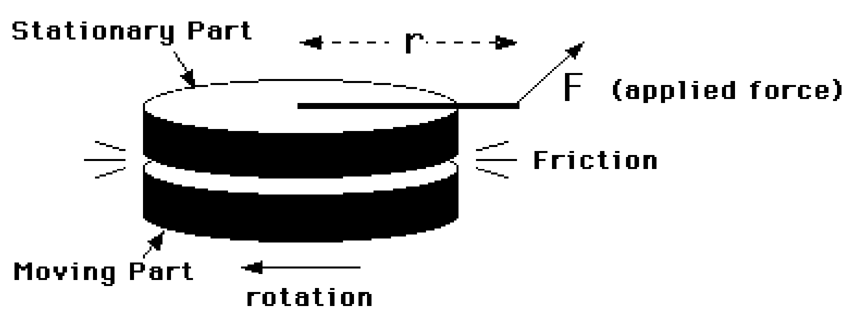


FIGURE 2.5 SCHEMATIC DIAGRAM OF JOULES EXPERIMENTAL SETUP

The moving part is rotated at a rate so that the frictional force transmitted to the stationary part just balances a constant torque applied to it and keeps it from moving. Under these conditions, all the work done to keep the moving part rotating is converted to heat by friction.

In N revolutions the force effectively acts over a distance $s = 2\pi N$, so that the work done, which is the rate at which mechanical energy is converted into heat in both situations is,

$$\mathbf{W = F.2\pi N} \qquad [J] \qquad (2.47)$$

Perry et al (1997).

By measuring the resulting change in temperature ΔT with the thermometer, the heat absorbed by each of the parts is

$$\mathbf{Q = mC\Delta T} \qquad [J] \qquad (2.48)$$

Perry et al (1997)

Then, from these results, Joule's constant,

$$J = W / Q$$

$$\mathbf{J = F.2\pi N/ (mC\Delta T)} \qquad [\text{Dimensionless}] \qquad (2.49)$$

was calculated to give the relationship between mechanical energy and heat.

Perry et al (1997).

2.4.5 Chemical energy

Chemical energy refers to that form of energy stored in natural or synthetic materials, the energy is liberated primarily by breaking chemical bonds between atoms or molecules comprising the initial molecules and recombining to form different set of molecules or to smaller atoms as in the case of nuclear fission reaction.

Chemical fuels for the purpose of energy production to satisfy practical needs of today are found in nature in the form of fossil fuels and radioactive materials.

2.4.6 Conversion of chemical energy to other forms

2.4.6.1 Chemical energy conversion to thermal energy

The most notable examples in this category are combustion and nuclear reactions.

The chemical reaction equations merely indicate the initial and final chemical compositions of species inferred in a reaction. In most cases the reactions involve a sequence of steps, leading from the reactants to the products, the nature of which depends on the temperature, pressure, and other conditions of combustion. Fuel molecules, for instance, may undergo thermal cracking, producing more numerous and smaller fuel molecules and perhaps breaking the molecules down completely into carbon and hydrogen atoms before oxidation is completed.

In the case of solid fuels, combustion may be governed by the rate at which oxidizer diffuses from the surrounding gases to the surface and by the release of combustible gases near the surface.

The heat of combustion, of a fuel is defined as the energy transferred during a steady-flow process in which the fuel is completely burned and where the products are returned to the temperature and pressure of the reactants. The heat of combustion evaluated at the standard state may be determined from the heats of formation.

The negative of the heat of combustion of a fuel burned in air is usually referred to as the heating value of the fuel.

$$\mathbf{CH_4 + 2O_2 \rightarrow 2H_2O} \qquad \mathbf{\Delta H} = -\,0.8975 \text{ kJ/kg} \qquad (2.50)$$

Nuclear energy is described by using the terminology **electron volt**, defined, as the amount of energy required in moving an electronic charge through a distance corresponding to voltage change from 0 to 1 volt. The energy that binds valence electron to an atom is of the order of few electron volts where as the energy that binds nucleons (protons and neutrons) together to form an atomic nucleus is in the tune of ten million of electron volt per nucleon. Consequently the energy released per atom in burning fossil fuel is of the order of few electron volts, where as the energy released in a nuclear interaction is measured in millions of electron volts.

Chemical Reaction:

$$\mathbf{2H_2 + O_2 \rightarrow 2H2O + 5.92\ eV} \qquad (2.51)$$

Fission Reaction:

$$\mathbf{U^{235} + n \rightarrow \text{stable nuclei} + 1.65x10^8\ eV\ (\text{average value})} \qquad (2.52)$$

Fusion Reactions:

$$\mathbf{H_2 + H_2 \rightarrow He_3 + n + 3.2\ x10^6\ eV} \qquad (2.53)$$

The average energy per deuteron is **4.84×10^6 eV.**

In contrast the kinetic energy of a gas molecule at room temperature is about **1/40 eV.**

The unit eV is equivalent to $1.602 x 10^{-19}$ J. Controlled thermonuclear fusion is still not in practical application as a means of energy source. Kenneth (2000)

Whereas nuclear fusion annihilates mass by forming larger atoms from smaller atoms, fission is a process of breaking massive atoms into two, more-or-less equal-sized atoms, with an accompanying mass loss and energy release eventually in form of heat.

2.4.6.2 Chemical energy conversion to mechanical energy

The most common example of this conversion system is the metabolic activity in living tissues resulting in motion of body parts.

Adenosine triphosphate (ATP) is the primary energy source found in all living things. ATP fuels most cell activities, including muscle movement, protein synthesis, cell division, and nerve signal transmission. In the computer graphic representation of an ATP molecule, given in Figure 2.6, the three phosphate groups are shown in right half. ATP's chemical energy is stored in its phosphate bonds.

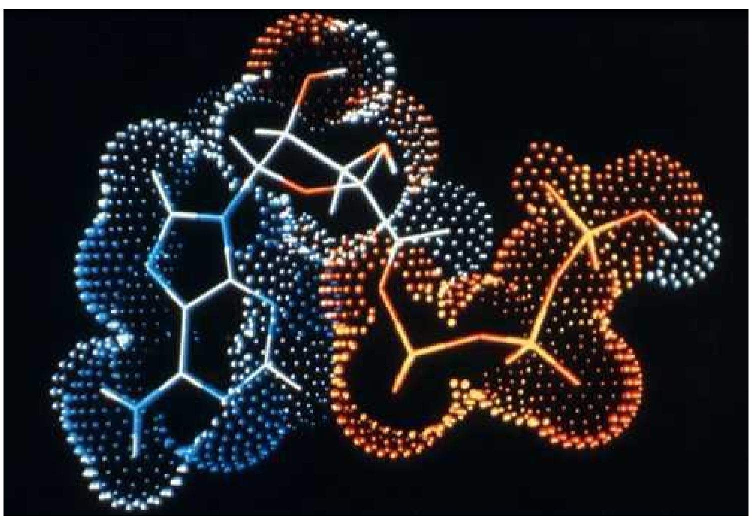


FIGURE 2.6 COMPUTER GRAPHIC REPRESENTATION OF AN ATP MOLECULE

The metabolism of one mole of glucose will be considered in detail to arrive at an expression that could be used to estimate the amount of energy expected from any energy giving food.

In metabolism of glucose, two different pathways are involved; anaerobic and aerobic pathways.

The anaerobic process occurs in the cytoplasm and is only moderately efficient. The aerobic cycle takes place in the mitochondria and results in the greatest release of energy. As the name implies, though, it requires oxygen. Each NADH (Nicotinamide adenine dinucleotide) will be oxidized to NAD (Nicotinamide adenine dinucleotide) molecule, generating three ATP (Adedosine tri phosphate $C_{10}H_8N_4O_2NH_2(OH)_2(PO_3H)_3H$)molecule, although it "costs" one ATP to transfer the NADH (Nicotinamide adenine dinucleotide) generated during anaerobic metabolism into the mitochondria for reduction. For each molecule of glucose we can calculate the useable energy produced:

Anaerobic process Consumed: 2 ATP Produced: 8 ATP Net: 6 ATP

Aerobic process Consumed: 0 ATP Produced: 2x 15 ATP Net: 30 ATP

Thus, for glucose molecule that enters the muscle, up to 36 ATPs can be generated.

The overall equation for ATP hydrolysis is usually written:

$$ATP + H_2O \leftrightarrow ADP + Phosphate$$

$$C_{10}H_8N_4O_2NH_2(OH)_2(PO_3H)_3H + H_2O \leftrightarrow C_{10}H_{15}N_5O_{10}P_2 + \text{inorganic phosphate (Pi)}$$

$$\Delta G^{o\prime} = -30.66 \text{ kJ/ mol} \tag{2.54}$$

For ATP synthesis, the reaction is written in the reverse direction, and the sign of the free energy change is reversed, so that:

$$ADP + \text{inorganic phosphate (Pi)} \leftrightarrow ATP + H2O \qquad (2.55)$$

$$\Delta G^{o\prime} = +30.66 \text{ kJ/mol}$$

Finally it can be inferred that energy generated by glucose in a metabolic process per unit time is therefore given by:

$$\mathbf{Energy = 36N_m^{glucose}x(- 30.66)}$$

$$\mathbf{E = 1103.76N_m^{glucose}} \qquad [kJ] \qquad (2.56)$$

2.4.6.1 Chemical energy conversion to electrical energy

When a chemical reaction can proceed spontaneously via an ionic mechanism it is possible to convert part of the energy on reaction directly into electrical energy; conversely some chemical reactions can be made to occur via ionic mechanism by addition of electric energy to a suitably contrived reactor system, called **electrochemical cells**. Devices that produce electric energy via chemical reaction are called **'Galvanic cells'** while those devices in which chemical reactions occur by the addition of electrical energy are called electrolytic cells. Electroplating process is an example of such reactions.

In a typical cell; at the anode, the lead releases two electrons to the external load as it is converted to lead sulphate

$$\mathbf{Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e.} \qquad (2.57)$$

At the cathode, lead dioxide is converted to lead sulphate in the reduction reaction involving hydrogen and sulphate ions from the electrolyte and electrons from the external circuit:

$$\mathbf{PbO_2\ (s) + 4H^+ (aq) + SO_4^{\ 2-} (aq) + 2e^- \leftrightarrow PbSO_4 + 2H_2O\ (l)} \qquad (2.58)$$

The overall cell reaction is the sum of ionic reaction occurring in the cell.

$$\mathbf{Pb(s) + PbO_2\ (s) + 2H_2SO_4\ (aq) \leftrightarrow 2PbSO_4\ (s) + 2H_2O\ (l)}$$

The overall reaction for a Hydrogen-Oxygen fuel cell

$$\mathbf{H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O} \qquad (2.59)$$

The charge of an electrochemical cell can be regarded as an auxiliary thermodynamic function, which provides a measure of the availability of the species participating in the chemical reaction. It is related to the reaction co-ordinate $\boldsymbol{\varepsilon}$

Manfred (1969)

.

$$\mathbf{dq = -nFd\varepsilon} \qquad (2.60)$$

where n is the number of moles of electrons produced at the anode per ν_i of component i, F is the Faraday constant, $\boldsymbol{\varepsilon}$ is the extent of reaction or reaction coordinate evaluated as:

$$\mathbf{F = j\ x\ (electrons\ per\ mole)\ x\ (charge\ per\ electron)}$$

$$\mathbf{= j\ x\ 6.023x10^{23} x\ 1.602x10^{-19}} \qquad [C] \qquad (2.61)$$

$$\mathbf{d\varepsilon = dn_1/\nu_1 = dn_2/\nu_2 = dn_3/\nu_3 = dn_4/\nu_4} \qquad (2.56)$$

j is the number of moles of electrons released per mole of reactants for lead – acid batter j=2.

The electric current in a cell may be related to the rate of reaction in the cell as:

$I = jn_cF$ [A] (2.62)

$\mathbf{n_c}$ is the number of moles of the electrode reactant.

The instantaneous power delivered by the cell:

$$\textbf{Power} = \mathbf{jn_cFV} \qquad [W] \qquad (2.63)$$

The cell electrode and electrolyte materials and the cell design determine the maximum cell voltage. Michael et al (1997)

Fuel cell thermodynamic analysis shows that theoretical maximum work of an isothermal fuel cell is the difference in Gibbs free energy of the reactants(r) and the products (p).

The work leaving the control volume is:

$$W = H_r - H_p - Q \qquad [J/gmol] \qquad (2.64)$$

For reversible isothermal process $Q = T(S_p - S_r)$ and the maximum work output of which a fuel cell is capable

$$W = H_r - H_p - T(S_p - S_r) = G_r - G_p \qquad [J/g\ mol] \qquad (2.65)$$

The maximum energy available from the cell in an adiabatic steady flow process is the difference in inlet and exit enthalpies. The cell thermal efficiency is given as:

$$\boldsymbol{\eta_{th} = (G_r - G_p)/(H_r - H_p)}$$

$$\boldsymbol{= 1 - T(S_r - S_p)/(H_r - H_p)}$$

Kenneth (2000)

2.4.6.4 Chemical energy conversion to light energy

An example of direct conversion of Chemical energy into light energy is Bioluminescence, which refers to production of light by biological reaction in light emitting species among bacteria, dinoflagellates, fungi, insects, polychaetes, jellyfish, shrimp, squid, fish etc.

Details of light emission differ with groups of animals

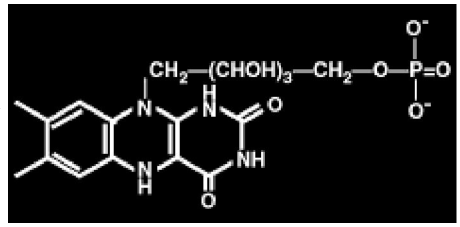
In all cases, it involves a substrate (luciferin) and an enzyme (luciferase). Oxygen is always required.

$$FMNH2 \quad + \quad RCHO \quad + O2 \rightarrow FMN + H2O + RCOOH + light$$

Long chain aldehyde (2.66)

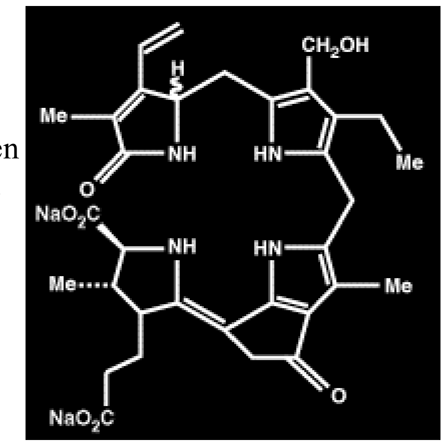
Reduced flavin mononucleotide

Bacterial luciferin is a reduced riboflavin phosphate ($FMNH_2$, pictured here) which is oxidized in association with a long-chain aldehyde, oxygen, and a luciferase.



Dinoflagellate luciferin is derived from chlorophyll, and has a very similar structure. In the genus *Gonyaulax*, at pH 8 the molecule is "protected" from the luciferase by a "luciferin-binding protein", but when the pH lowers to around 6, the free luciferin reacts and light is produced.

A modified form of this luciferin is also found in herbivorous euphausiid shrimp, perhaps indicating a dietary link for the acquisition of luciferin.



The quantity of light energy, E produced in the reaction can be evaluated using the 1st law of thermodynamics, by considering the change in total heat of formation of all reactants compared to total heat of formation of all products species.

$$\mathbf{E}_{\textbf{light emmitted}} = (\Sigma\, \mathbf{E}_{\textbf{formation}})_{\textbf{reactants}} - (\Sigma\, \mathbf{E}_{\textbf{formation}})_{\textbf{products}} \quad [J] \qquad (2.67)$$

The Equation 2.67 is valid when the reaction is assumed to occur in isothermal condition, if not, the thermal energy change will be algebraically deducted from the right hand side of the Equation

2.4.7 Thermal energy

Thermal Energy refers to heat energy from whatever source, usually the transformation of energy from one form to another happens with heat being an intermediate form, an example is the transformation of chemical energy to mechanical energy in internal combustion engine. It has the lowest potential compared to the other three. The sources of thermal energy are diverse, it can be considered as present in almost all chemical transformation and mechanical activities necessary for day-to-day life. It can be considered to be of basically one type. Mode of transmission is by radiation, convection and conduction.

The blackbody radiation law gives the rate of energy emission per unit area of surface as

$$\mathbf{E = \sigma T^4} \qquad [\mathrm{W/m^2}] \qquad (2.68)$$

where σ is the Stefan-Boltzmann constant,

$\sigma = 5.66961\times10\ -8\ \mathrm{W/m^2\ K^4}$,

Stanley (1987).

Max Planck in 1900, studied light and radiated thermal energy, pictured as form of wave motion where sources emit energy in the form of electromagnetic waves that spread out in all directions. The energy of radiation is proportional to its frequency,

$$\mathbf{E = h\nu} \qquad (2.69)$$

Energy of a photon is directly proportional to its wave frequency **ν,** another form of Equation 2.69 as given in Equation 2.70. Duffie (1980)

$$\mathbf{E = hc/\lambda} \qquad (2.70)$$

The intensity of light is proportional to the square of amplitude of electric vector. This is given as

$$\mathbf{I=ka^2} \tag{2.71}$$

The change in thermal energy of body per unit time, expressed as a function of its temperature is given by

$$E = mC_p.\Delta T \qquad [W] \tag{2.72}$$

Perry et al (1997)

2.4.8 Thermal energy conversion to other forms of energy

2.4.8.1 Conversion of thermal energy to chemical energy

Through a series of energy transducing reactions, the photosynthesis process transforms light energy into chemical energy. Most of our current energy needs are met by photosynthesis.

The overall equation for photosynthesis is deceptively simple. A complex set of physical and chemical reactions must occur in a coordinated manner for the synthesis of carbohydrates. To produce a sugar molecule such as sucrose, plants require nearly 30 distinct proteins that work within a complicated membrane structure. Crofts (1996)

The net equation of photosynthesis is frequently written as:

$$6CO_2 + 12H_2O + \text{Light Energy} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

The standard free energy for the synthesis of glucose is +2,870 kJ/mol.

Through synthesis of ATP by the ATP Synthase Enzyme, a single protein complex known as ATP synthase accomplishes the conversion of proton electrochemical energy into chemical free energy. This enzyme catalyses a phosphorylation reaction, which is the formation of ATP by the addition of inorganic phosphate (Pi) to ADP. Crofts(1996)

$$ADP^{-3} + Pi^{-2} + H^{+} \rightarrow ATP^{-4} + H_2O. \qquad (2.73)$$

The reaction is energetically uphill (ΔG = +32 kJ/mol) and is driven by proton transfer through the ATP synthase protein. Myers (1974)

2.4.8.2 Thermal energy conversion to electrical energy

Solar Photovoltaic

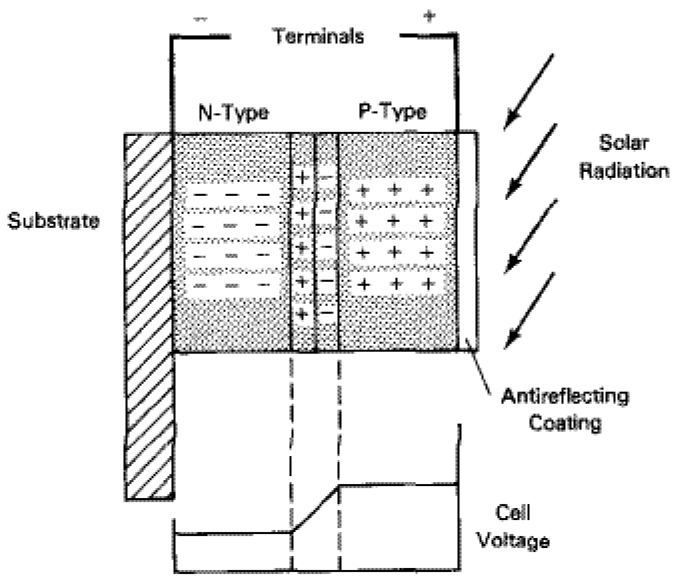


FIGURE 2.7 CRYSTALLINE SILICON P-N JUNCTION SOLAR CELL

Source: Weston K.C, `kenneth-weston@utulsa.edu`, *December 2000*

Photovoltaic rely on specially prepared **semiconductors**, which produce useful current flows when illuminated with solar or artificial radiation.

$$\textbf{Photon energy} = \mathbf{h}\upsilon \qquad [J] \qquad (2.74)$$

where **h** is Planck's constant

υ is the frequency of the radiation.

When the point of contact of p-type and n-type doped semiconductor usually referred to as a p-n junction is irradiated by an energetic photon, energy of the photon may be absorbed, raising an electron into the conduction band and leaving a hole behind. Thus a single photon creates an electron-hole pair. Ioffe (1956), Kenneth (2000).

The band gap, or energy separation, between conduction and valence bands is 1.1 eV for silicon p-n junctions. This is the energy necessary to move an electron into the conduction band of the semiconductor.

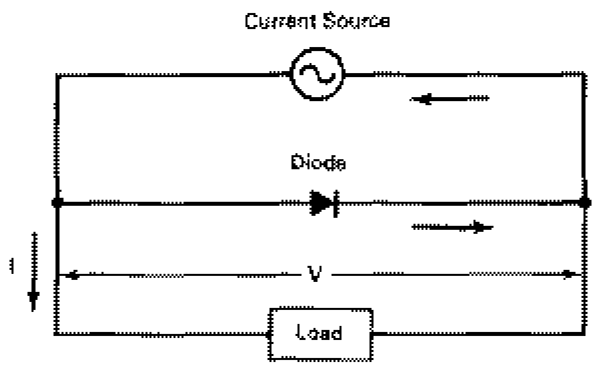


FIGURE 2.8 SOLAR CELL MODEL EQUIVALENT CIRCUIT.

The p-n junction acts like a combination of a current source and a diode in parallel as shown in Figure 2.7. For a given level of cell irradiation, a cell electrical characteristic may be represented by

$$\mathbf{I = I_{sc} - I_o(e^{qV/kT} - 1)} \qquad [A] \qquad (2.75)$$

where **k** is the Boltzmann constant, **q** is the electronic charge, and $\mathbf{I_o}$ and $\mathbf{I_{sc}}$ are called the dark current and short-circuit current, (corresponding to a cell potential difference =0) is proportional to the rate of incident irradiance.

The cell power output is the product of the current and cell potential difference:

$$\mathbf{P = IV = [I_{sc} - I_o (e^{qV/kT} - 1)]V} \qquad [W] \qquad (2.76)$$

Ditchburn (1991).

2.4.8.3 Thermal energy conversion to mechanical energy

Examples of this conversion are found in expansion of solids, liquids and gases when heated under constant volume conditions. It is mainly due the transformation of thermal energy into mechanical energy in metals that expansion gaps in railway lines and members in construction beams become necessary to avoid damage to structures.

Generally for any system, the first law of thermodynamics is

$$Q = \Delta U + W \qquad [J] \qquad (2.77)$$

$$\mathbf{Q = \Delta H + W} \qquad [J] \qquad (2.78)$$

Where Q is heat transferred into the system from the surroundings, W is work done by the system, and ΔU is the change in internal energy of the system. Pressure-volume work in the case of a gas on a piston is defined to be W= PΔV, work done by the system can be considered as mechanical energy in transit.
Van-Wylen (1986)

2.4.9 Energy in waves:

It is the energy that exists and is being transmitted in waves that makes the existence of any wave possible in the first place, a wave can not exist without energy content hence energy propagation is an important factor in wave motion.

It is reasonable to consider a wave as a deformation of elastic medium and further suppose it to be characterized by relative motion of parts of the medium in single direction, hence a one dimensional dilatational wave. The power P, per unit area represented by the propagation of wave is given by:

$$\mathbf{P = Y\, \underline{l}\, (\delta l / \delta x)} \qquad (2.79)$$

$$\mathbf{P = -(YA^2\omega^2/v)\, \sin^2(\omega t - kx)} \qquad (2.80)$$

where ω is the angular velocity of the wave,

Y is modulus of elasticity,

v is the linear velocity of the wave,

k=ω/v.

Robert (1960)

When the medium is squeezed energy is flowing into it from another part of the medium that is expanding. Taking an average over time at any particular place, we find the average flow of power per unit area of wave front at that place.

$$\mathbf{P' = \tfrac{1}{2}\, YA^2\omega^2/v} \qquad (2.81)$$

Since the time average of $\mathbf{sin^2(\omega t\text{-}kx)}$ is about ½ as the interval over which the average is taken increases indefinitely. This time average can be considered as the intensity of the wave.

$$\mathbf{I = P'} \qquad [w/m^2 s] \qquad (2.82)$$

In terms of the maximum stress $\mathbf{X_{max}}$

$$\mathbf{X^2_{max} = YA\omega/v} \qquad (2.83)$$

$$\mathbf{I = \tfrac{1}{2}\, vX^2_{max}/Y} \qquad (2.84)$$

The intensity of a dilatational wave of the kind under discussion is proportional to the square of the excess stress; if the medium is solid, X is the tensile stress, if it is fluid X is to be pressure.

Since the tensile stress expresses the average power transmission per unit area of wave front in the wave, it is possible to present it as the product of wave velocity and the total energy per unit volume in the portion of the medium being traversed by the wave. The energy per unit volume is referred to as the energy density and its time average is denoted by ϖ

$$\mathbf{P' = I = \varpi v} \tag{2.85}$$

The energy density decreases as the wave progresses, this will be a measure of energy loss through damping or absorption. Robert (1960)

$$\boldsymbol{\varpi = \varpi_o e^{-2\alpha x}} \tag{2.86}$$

Where α is the spatial absorption coefficient

$\boldsymbol{\varpi_o}$ is the average energy density at some chosen reference point.

For dilatational stationary waves however the intuitive notion of energy flow will not apply, but the total energy density can be calculated as a sum of kinetic and potential energy density can be calculated as follows:

$$\boldsymbol{\varpi = \varpi_{k,n} + \varpi_{p,n}} \tag{2.87}$$

For n^{th} vibration mode, forming space-time average gives:

$$\boldsymbol{\varpi = (n^2\pi^2 Y C_n^2)/4l^2 = (\rho\omega_n^2\, C_n^2)/4} \tag{2.88}$$

Robert (1960)

This gives the average total energy density for n^{th} mode. it is worth noting that in a stationary wave the potential energy density reaches its maximum amplitude, while the kinetic energy density reaches its maximum amplitude at a loop.

Considering all modes are present the total average energy density over a sufficiently long time is obtained thus:

$$\boldsymbol{\varpi = \tfrac{1}{4}\, \rho \Sigma \omega_n^2 C_n^2} \tag{2.89}$$

Equation 2.41 demands an averaging time T having the property $\mathbf{T >> 2l/V(r\text{-}s)}$

Robert (1960)

2.4.9.1 Wave propagation across boundaries

When energy in a wave is incident on a boundary of two different mediums, wave propagation and reflection are possible. Assuming a plane harmonic wave of angular frequency ω, and ignoring possible motion of the source or receiver, the reflected and transmitted amplitudes of the disturbances can be estimated thus:

$$\mathbf{A_r = ((1\text{-}\rho_2 v_2/\rho_1 v_1) /(1+\rho_2 v_2/\rho_1 v_1))A_i} \tag{2.90}$$

$$\mathbf{A_t = (2/(1+\rho_2 v_2/\rho_1 v_1))A_i} \tag{2.91}$$

Robert (1960)

For the limiting case in which $\rho_2 v_2=\rho_1 v_1$ the reflected component is absent. While if $\rho_2 v_2>>\rho_1 v_1$, yield $A_r= -A_i$ the entire disturbance is reflected but with a change in phase. The incident average power per unit area:

$$\mathbf{P'_i = \tfrac{1}{2}\, \rho_1 v_1 \omega^2 A_i^2} \tag{2.92}$$

And the transmitted average power:

$$\mathbf{P'_t = \tfrac{1}{2}\, \rho_2 v_2 \omega^2 A_t^2} \tag{2.93}$$

Consequently:

$$\mathbf{P'_t = ((4\rho_2 v_2/\rho_1 v_1)/(1+\rho_2 v_2/\rho_1 v_1)^2)\ P'_i} \tag{2.94}$$

Robert (1960)

The coefficient of $\mathbf{P'_i}$ in equation 2.46 is called ‘Transmission Coefficient’ α.

The product $\rho\mathbf{v}$ controls the transmission of energy from one medium to the other, if the media are well matched the values are close together and considerable energy transmission takes place. In the case of sound waves the product is given the special name acoustic resistance for a plane wave.

Selective Wave Transmission

An important feature of wave transmission across boundary is its independence of frequency; there are however, some circumstances in which the transmission is selective with respect to frequency, this is typically so when wave passes through a finite layer of a second medium and emerges into a third medium which may be same as the first.

Considering a case of linear non dissipative media and assuming harmonic waves:

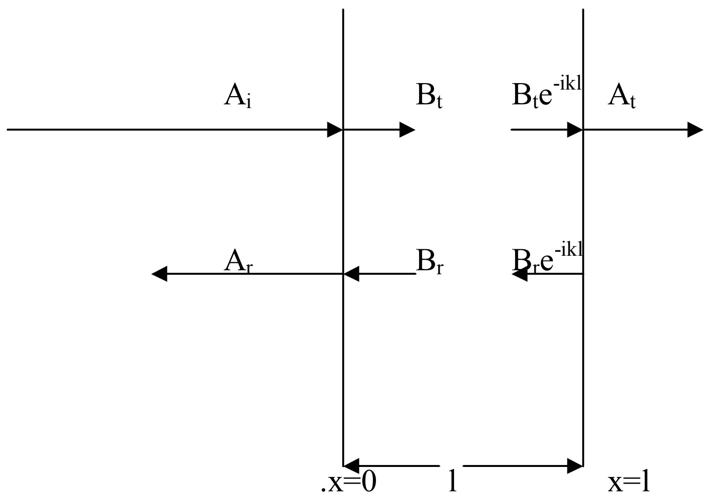


FIGURE 2.9: WAVE TRANSMISSION THROUGH A FINITE LAYER OF A MEDIUM

B_t is the amplitude of the wave at x=0, the corresponding wave at x=l has amplitude $B_t e^{-ikl}$ since it has changed its phase only by a multiplication factor e^{-ikl}.

Given the four boundary conditions:

$$A_i + A_r = B_t + B_r \quad (2.95)$$

$$\rho_1 v_1 (A_i - A_r) = \rho_2 v_2 (B_t - B_r) \quad (2.96)$$

$$B_t e^{-ikl} + B_r e^{ikl} = A_t \quad (2.97)$$

$$\rho_2 v_2 (B_t e^{-ikl} - B_r e^{ikl}) = \rho_1 v_1 A_t \quad (2.98)$$

Equations 2.60 and 2.61 hold at the left hand interface while 2.62 and 2.63 apply at the right hand interface. Morse (1948), Robert (1960)

The transmitted average power per unit area in terms of the incident power is expressed thus:

$$\mathbf{P' = (|A_t|^2/|A_i|^2)\ P'_i}$$

$$\mathbf{= [1/(\cos^2 k_1 l + ((r+1/r)^2/4)\ \sin^2 k_1 l)]\ P'_i} \quad (2.99)$$

Morse (1948) and Robert (1960)

The reciprocal of the coefficient of **<u>P</u>** $\underline{\mathbf{P_i}}$ on the right is the transmission coefficient T, $r=R_2/R_1$, k is the Boltzmann's constant per molecule

2.4.9.2 Radiation from a radially vibrating sphere:

For a vibration produced by a finite vibrator with known conditions at the surface of the sphere, the average rate of energy dissipation is given by:

$$\mathbf{P' = \{R + (4\pi a^4 \omega \rho_o k)/(1 + k^2 a^2)\}\ f'^2_a} \quad (2.100)$$

Morse (1948)

Where $\boldsymbol{\rho_o}$ is the density of the surrounding medium, $\boldsymbol{\omega}$ is the frequency of the driving force, $\boldsymbol{\omega_{res}}$ the angular resonance frequency

$$\mathbf{\omega = \sqrt{(1/Cm)}} \quad (2.101)$$

$$\mathbf{\omega_{res} = \sqrt{((1/C)/(m+4\pi a^3 \rho_o/1+k^2 a^2))}} \quad (2.102)$$

m is the effective mass, **1/C** is the effective stiffness, **C** is referred to as the compliance, $\mathbf{k=\omega/v}$ and **a** is the radius of the sphere. Morse (1948) and Robert (1960)

2.4.9.3 Energy in a Vibrating String

The frequency of uniform, perfectly flexible string of length l, fastened rigidly at the two ends stretched with tension T_o is:

$$\mathbf{\nu_n = nV/2l = n/2l\ (T_o/\rho_l)} \quad (2.103)$$

The time average total energy in the string while it is vibrating in this mode is given by

$$\mathbf{E_n = \pi V^2 n^2 \rho_l A^2)/4l} \qquad (2.104)$$

Where $\mathbf{A = (8h/\pi^2 n^2)\sin(n\pi/2)}$

Robert (1960)

The kinetic and potential energies balance each other in such a way that the total energy remains constant in time.

For the special case of plucked string:

$$\mathbf{E_n = 16h^2V^2\rho_l/\pi^{2n2} l \sin^2(n\pi/2)} \qquad \text{when } \mathbf{n} \text{ is odd} \qquad (2.105)$$

$$\mathbf{E_n = 16h^2V^2\rho_l/\pi^2 n^2 l} \qquad \mathbf{n} \text{ is even} \qquad (2.106)$$

$$\mathbf{E_{tot} = 2h^2V^2\rho_l/l} \qquad \mathbf{n} \text{ takes all integral values} \qquad (2.107)$$

Value of $\mathbf{E_{tot}}$ is equal to the original potential energy given to the string when it was plucked aside just before it was let go. Robert (1960)

2.4.9.5 Waves in Membranes

Following are assumed to apply: Two-dimensional, perfectly flexible continuum possessing a uniform surface density or mass per unit area, σ and stretched with uniform surface tension, **T**.

It is assumed that the equilibrium position of the membrane is an xy plain and the disturbance at any point in the plain, ξ in the z-direction. The displacement is considered small everywhere compared with the dimensions of the plain and is assumed insufficient to produce a noticeable change in the surface tension and surface density.

$$\text{Wave velocity, } \mathbf{v = \sqrt{(T/\sigma)}} \qquad (2.108)$$

The equation of motion is in the form:

$$\xi = \mathbf{(T/\sigma)\nabla^2\xi} \tag{2.109}$$

Evaluation of the two dimensional Laplacian depends on the shape of the membrane in the plain, assumption of **circular membrane** (reference 54) evaluation of the fundamental frequency in a complicated vibrating system in which the exact displacement cannot readily be determined, yields:

$$\boldsymbol{\omega = (2.406/a)\ \sqrt{(T/\sigma)}} \tag{2.110}$$

From which,

$$\boldsymbol{\upsilon = (1.205/\pi a)\ \sqrt{(T/\sigma)}} \tag{2.111}$$

Where **a;** is the diameter of the circular membrane. Robert (1960)

2.4.9.6 Wave propagation in crystal lattices

The continuum theory provides satisfactory approximations if we deal with relatively large disturbances, those in which relatively large aggregates of atoms act as a whole. As the wavelength of disturbances decreases we expect to encounter effects due to atomic particles individually. In solids, the frequency on which this occurs is higher than can be produced by macroscopic elastic disturbances of the conventional sort. The situation is different in gases at very low pressure.

Whenever any one particle is disturbed from its equilibrium position, the disturbance is communicated to neighboring particles, which also move from their equilibrium position. For linear aggregate of equally spaced particles all of the same mass m each, **l** is half the equilibrium separation between to adjacent particles, T_o is mean tension and **f** is the equivalent stiffness defined as the restoring force proportional to the change in its distances from the two neighboring particles.

The total average energy density is:

$$\boldsymbol{\varpi = (fA^2/l)\sin^2 kl} \tag{2.112}$$

The average Power transmitted:

$$\mathbf{P' = 2A^2(\sqrt{f/m})\,Sin^2kl\;Cos\;kl} \tag{2.113}$$

The ratio $\mathbf{P'/\varpi}$ may be taken to represent physically the average velocity with which energy flows along the lattice due to wave propagation.

$$\mathbf{P'/\varpi = 2l(\sqrt{f/m})Cos\;kl} \tag{2.114}$$

Where the wave parameter $k=\omega/v$ and v is the wave front velocity. Robert (1960)

CHAPTER 3

MODELS OF ENERGY IN SYSTEMS

3.1 Introduction

This chapter presents the mathematical models of energy in systems and energy conversion processes, these models comprise of models obtained from Chapter 2. The mathematical models are presented with their limitations and conditions of application. Models of energy in systems are first presented for each form as types followed by energy transformation models as it converts from one form to the other three forms.

3.2 Electrical Energy

3.2.1 Energy of charge in an electric field

When a charge in an electric field of intensity E is moved a distance l at and angle **θ,** with respect to the direction of the field the amount of work done and hence the energy in transit when expressed per unit time is given as;

$$\text{Energy/time} = QE.l(\cos\theta)/t \qquad [W] \qquad (3.01)$$

$$E = QE.l(\cos\theta) \qquad [J] \qquad (3.02)$$

Jackson (1962)

3.2.2 Energy of a charged capacitor

The total energy of an electric field in a capacitor whose capacitance is C, when charged to potential difference V is

$$\mathbf{E = VQ} \qquad [J] \qquad (3.03)$$

If the capacitor plates were at same potential V=0, the average energy needed to charge the capacitor to voltage V can be considered as the energy stored in the capacitor

$$E_{\mathbf{av}} \mathbf{= ½\ VQ = ½\ V^2C = ½\ Q^2/C} \quad [J] \qquad (3.04)$$

Kenneth (2000)

3.2.3 Energy density of an electric field

The average energy stored in and electric charge transfer in a field of dielectric ε, area S and length l, subjected to voltage V is

$$\mathbf{E_{av} = ½\ VQ = ½\ \varepsilon\ \Phi^2 v = (½\ D^2 v)/\varepsilon} \qquad [J] \qquad (3.05)$$

Kenneth (2000)

Where D is the flux density on the charge surfaces v is the volume of the dielectric.

3.2.4 Energy dissipated in a resistor

For charges transmitted at steady rate per unit time, a steady current I and a steady voltage V in a time interval t, the time rate of energy conversion is given by Joules Law:

$$\mathbf{Power = E/t = VI = I^2R}. \qquad [W] \qquad (3.06)$$

Kenneth (2000)

In systems in which voltage and current vary with time according to simple Harmonic motion, the average value of power is

$$\mathbf{P_{av} = \tfrac{1}{2} V_m I_m Cos\theta = VI\ Cos\varphi} \qquad [W] \qquad (3.07)$$

φ is the phase difference between current and voltage, Cosφ power factor

Kenneth (2000)

3.2.5 Energy generated in fuel cells

Fuel cells convert part of the energy on reaction directly into electrical energy, The electric current in a cell may be related to the rate of reaction in the cell as:

$$I = jn_cF \qquad [A] \qquad (3.08)$$

And the instantaneous power delivered by the cell:

$$\mathbf{Energy/time = jn_cFV} \qquad [W] \qquad (3.09)$$

Where Faraday constant F = j x (electrons per mole) x (charge per electron)

Theoretical maximum work of an isothermal fuel cell is difference in Gibbs free energy of the reactants(r) and the products (p). The work leaving the control volume is:

$$\mathbf{W = H_r - H_p + Q} \qquad [J/gmole] \qquad (3.10)$$

Kenneth (2000)

For reversible isothermal process $Q = T(S_p - S_r)$ and the maximum work output of which a fuel cell is capable

$$W = H_r - H_p + T(S_p - S_r) = G_r - G_p \qquad [J/g\ mole] \qquad (3.11)$$

The maximum energy available from the cell in an adiabatic steady flow process is the difference in inlet and exit enthalpies. The cell thermal efficiency is the given as:

$$\mathbf{\eta_{th} = (G_r - G_p)/(H_r - H_p)} \qquad (3.12)$$

$$\mathbf{= 1 - T(S_r - S_p)/(H_r - H_p)}$$

Kenneth (2000)

3.2.6 Energy from magneto-hydrodynamic system:

The electrical power delivered to the load per unit volume of channel is given as:

$$\mathbf{Power = J.E = \sigma u^2 BK(1\text{-}K)} \qquad [W/m^2] \qquad (3.13)$$

$$\mathbf{H_2 = H_1 - w = H_1 - (Power|_{out})(volume)/m}$$

$$\mathbf{Energy/time = H_1 - \sigma u^2 BK(1\text{-}K)/\rho} \qquad [kW/kg] \qquad (3.12)$$

Kenneth (2000)

3.3 Mechanical Energy

3.3.1 Kinetic energy

The kinetic energy is the algebraic sum of the translating kinetic energy of the centre of gravity and the rotating kinetic energy about the centre of gravity.

$$\mathbf{E = ½\,\rho v^2 + ½\,I_o\omega^2} \qquad [J] \qquad (3.13)$$

The velocity v is the velocity of the centre of gravity and the moment of inertia I is the centroidal moment of inertia. Michael and Phillip (1995)

The Kinetic energy of a rigid body rotating about a fixed axis is

$$\mathbf{E = ½\,I_o\omega^2}$$

$$E = \mathbf{½(\rho r)\omega^2} \qquad [J] \qquad (3.14)$$

Where $\mathbf{I_o} = \boldsymbol{\rho}\mathbf{r}$ is the mass moment of inertia about the axis of rotation. r is the radius of rotational motion of the centre of mass. Richard et al (1965).

The frequency of uniform, perfectly flexible string of length l, fastened rigidly at the two ends stretched with tension T_o is:

$$\boldsymbol{\nu_n = nV/2l = n/2l\,(T_o/\rho_l)} \qquad [s^{-1}] \qquad (3.15)$$

The time average total energy in the string while it is vibrating in this mode is given by

$$\mathbf{E_n = \pi V^2 n^2 \rho_l A^2)/4l} \qquad (3.16)$$

Where $\mathbf{A = (8h/\pi^2 n^2)\ sin\ (n\pi/2)}$

The kinetic and potential energies balance each other in such a way that the total energy remains constant in time.

For the special case of plucked string:

$$\mathbf{E_n = 16h^2V^2\rho_l/\pi^{2n2}l\ sin^2(n\pi/2)} \qquad \text{when } \mathbf{n} \text{ is odd} \qquad [J] \qquad (3.17)$$

$$\mathbf{E_n = 16h^2V^2\rho_l/\pi^2n^2l} \qquad \mathbf{n} \text{ is even} \qquad [J] \qquad (3.18)$$

$$\mathbf{E_{tot} = 2h^2V^2\rho_l/l} \qquad \mathbf{n} \text{ takes all integral values} \qquad [J] \qquad (3.19)$$

Value of $\mathbf{E_{tot}}$ is equal to the original potential energy given to the string when it was plucked aside just before it was let go. Lindsay (1960)

3.3.3 Pressure energy

3.3.3.1 fluid at rest subject to only gravitational force:

For incompressible fluid the pressure-height equation integrates to:

$$\mathbf{(P_1\text{-}P_2) = \rho g\ (h_1\text{-}h_2)} \qquad [N/m^2] \qquad (3.20)$$

Perry et al (1997)

Pressure energy can be expressed as the work done in introducing fluid into an enclosure thus product of the prevailing pressure and the volume of space:

$$\mathbf{E = \Delta P.\ V} \qquad [J] \qquad (3.21)$$

3.3.3.2 Energy stored in adiabatic ally compressed gas:

Energy stored is equal to the work done in adiabatic compression

$$E = \gamma/(\gamma\text{-}1)(WRT_1/9806)[(P_2/P_1)^{(\gamma-1)/\gamma} - 1] \quad [J] \qquad (3.22)$$

Where W is the mass flow (kg/s),

R molar gas constant (J/kg.K),

k ratio of specific heat capacity at constant pressure to that at constant volume,

T_1 and T_2 are temperatures at the initial and final stages respectively. Perry et al (1997)

3.3.3.3 Energy stored in isothermally compressed gas:

$$E = ZRT.\ln(P_1/P_2) \qquad [J] \qquad (3.23)$$

Applicable only at constant temperature for ideal gas Z=1, for non ideal gases, correctional factor of compressibility is Z will depend on the gas in use

Perry et al (1997)

3.3.3.4 Energy stored in polytropically-compressed gas:

$$E = C_V \, \Delta T + P\Delta V \qquad [J] \qquad (3.24)$$

Perry et al (1997)

3.3.4 Potential energy

3.3.4.1 Due to mass potential

The total potential energy in a body by virtue of its position from another

$$\mathbf{E = force\ x\ distance\ apart}$$

$$= G.m_1.m_2/\, l^2 \times l$$

$$E = G.\, m_1.m_2/\, l \qquad [J] \qquad (3.25)$$

Where k is the gravitational constant with a value of $\mathbf{G=6.673x10^{-11}}$

3.3.4.2 Potential Energy due to gravitational pull with reference to a point.

The basic equation of static is obtained by consideration of particle at rest with respect to other particles at rest subject to only gravitational force.

Energy stored in the particle per unit volume is given by:

$$\mathbf{E = \rho g h} \qquad [J/m^3] \qquad (3.26)$$

where h is the height from a reference point in the gravitational field

Perry et al (1997)

3.3.4.3 Energy in a deflected magnet:

Energy stored in a magnet deflected from a position of balance may be equated to the work done in deflecting the magnet

$$\mathbf{E = mH(1- Cos\ \beta)} \qquad [J] \qquad (3.27)$$

Perry et al (1997)

3.3.4.4 Energy in a uniform magnetic field:

Total energy in a uniform magnetic field **B** of volume **V**

$$E= \frac{1}{2} kB^2V \qquad \mathbf{[J]}$$

(3.28)

Perry et al (1997)

3.3.4.5 Tensile energy

This refers to energy stored in a stretched elastic material due to applied force.

If elastic limit is not exceeded, extension is proportional to applied load so force in the wire has increased from **0** to **F**.

Energy stored in the wire is equal to the work done in stretching the wire.

$$\mathbf{E = \frac{1}{2} F.\Delta l} \qquad [J] \qquad (3.29)$$

Perry et al (1997)

The above equation 3.29 is strictly applicable only within the elastic limit of the stretched elastic material (ie when elongation is directly proposional to applied force)

3.3.4.6 Energy conversion in ejectors

The conversion of pressure energy in a compressible fluid to kinetic energy by allowing to sudden expanding is main principle of operation of this device. Kinetic energy of one fluid is used to pump another. The performance of this device can be computed by application of momentum equation.

This reveals pressure energy being converted to kinetic energy

$$(P_2 - P_1)g_c A = w_p(V_p - V_m) + w_s (V_s - V_m) \quad [J] \qquad (3.30)$$

Applicable for steam ejectors, using steam of quality not less than 97%

Perry et al (1997)

3.4 Chemical Energy

3.4.1 Fossil Fuel

Kinetic theory predicts an internal energy per atom of

$$u = 3kT/2 \quad [J] \qquad (3.31)$$

And an enthalpy of

$$h = u + pv = 3kT/2 + kT = 5kT/2 \quad [J] \qquad (3.32)$$

$$k = R/No = 8.32/(6.025 \times 10^{23}) = 1.38 \times 10^{-23}\ J/K \qquad (3.33)$$

Kenneth (2000)

3.4.2 Nuclear energy

For Uranium 235 fission reaction, it is

$$U^{235} + n \rightarrow \text{stable nuclei} + 1.65\text{x}10^{8} \text{ eV (average value)}$$

The average energy released per U^{235} atom is 1.65 x 10^{8} eV.

Energy per mole of Uranium 235 reaction is given by

$$E = N_m^{U235}\text{x } 1.65\text{x}10^{8}\text{x(eV/J)}$$

Generally for fission reactions the following equation 3.35 applies

$$E = N_{s.}N_m.N_A.H_r \qquad [J] \qquad (3.35)$$

where N_S is the stoichiometric coefficient per mole of neutrons in the fission reaction

N_m number of moles of radio-active material

N_A Avogadro number

H_r energy of reaction

For hydrogen fusion reactions it is

$$H^2 + H^2 \rightarrow He^3 + n + 3.2\text{ x}10^6 \qquad [eV]$$

$$\text{Energy} = 0.5N_m^{H2}\text{x } 3.2\text{x}10^6\text{x(eV/J)} \qquad [J] \qquad (3.36)$$

$$H^2 + H^2 \rightarrow H^3 + H^1 + 4\text{ x}10^6 \qquad eV$$

$$\text{Energy} = 0.5N_m^{H2}\text{x } 4\text{x}10^6\text{x(J/eV)} \qquad [J] \qquad (3.37)$$

$$H^3 + H^2 \rightarrow He^4 + n^1 + 17\text{ x}10^6 \quad eV$$

$$\textbf{Energy} = \mathbf{N_m^{H3} x\ 17x10^6 x(J/eV)} \qquad [J] \qquad (3.38)$$

Thus the average energy per deuteron is: **4.84 x 10^6 eV.**

Kenneth (2000)

3.4.3 Energy conversion in metabolism

For glucose molecule that enters the muscle, up to 36 ATPs can be generated.

The overall equation for ATP hydrolysis is usually written:

$$ATP + H_2O \leftrightarrow ADP + \text{inorganic phosphate (Pi)} \qquad (3.39)$$

$$\Delta G^{o'} = -30.66 \text{ kJ/ mol}$$

Energy generated by glucose in a metabolic process per unit time is therefore given by:

$$\textbf{Energy} = \mathbf{36N_m^{glucose} x(-\ 30.66)} \qquad [kW] \quad 3.40)$$

$$\textbf{Energy/time} = \mathbf{1.104x10^6\ N_m^{glucose}}$$

$$\mathbf{E = \ 1.104x10^6\ N_m^{glucose}} \qquad [J] \qquad (3.41)$$

Where N_m is the number of moles of glucose.

3.4.4 Photosynthetic energy conversion.

The synthesis of carbohydrate from carbon and water requires a large input of light energy. From the net equation of photosynthesis frequently written as:

$$6CO_2 + 12H_2O + \text{Light Energy} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

The standard free energy for the synthesis of glucose is +2,870 kJ/mol.

Energy converted per unit time to chemical form via photosynthesis is given by:

$$\mathbf{E = 478 \times N_m^{CO2}} \qquad [kW] \qquad (3.42)$$

Conversion Efficiency

If 8 red quanta are absorbed (8 mol of red photons are equivalent to 1,400 kJ) for each CO_2 molecule reduced (480 kJ/mol), the theoretical maximum energy efficiency for carbon reduction is 34%.

Under optimal conditions, plants can achieve energy conversion efficiencies within 90% of the theoretical maximum. However, under normal growing conditions the actual performance of the plant is far below these theoretical values. The factors that conspire to lower the quantum yield of photosynthesis include limitations imposed by biochemical reactions in the plant and environmental conditions that limit photosynthetic performance. Parson (1978)

3.4.5 Energy conversion in bio-luminescence:

In all cases, it involves a substrate (luciferin) and an enzyme (luciferase). Oxygen is always required.

FMNH2 + RCHO + O2 → FMN + H2O + RCOOH + light

Long chain aldehyde (3.43)

Reduced flavin mononucleotide

The quantity of light energy, E produced in the reaction can be evaluated using the 1st law of thermodynamics, by considering the change in total heat of formation of all reactants compared to total heat of formation of all products species.

$$E_{\text{light emmitted}} = (\Sigma E_{\text{formation}})_{\text{reactants}} - (\Sigma E_{\text{formation}})_{\text{products}}$$

[J] (3.44)

Yash (1993)

3.5 Thermal Energy

3.5.1 Change in thermal energy per unit volume:

$$\Delta E = \rho C_p \, \Delta T$$ [J]

(3.45)

Perry et al (1997)

3.5.2 In terms of enthalpy change

$$\Delta E = \rho \Delta H$$ [J] (3.46)

Kenneth (2000)

3.5.3 Solar Photovoltaic

$$\textbf{Photon energy} = \mathbf{h\upsilon} \qquad [s^{-1}] \qquad (3.47)$$

Where **h** is Planck's constant and υ is the frequency of the radiation. When a p-type material near a p-n junction is irradiated by an energetic photon,

The cell power output (energy per unit time) is the product of the current and cell potential difference:

$$\mathbf{P = IV = [I_{sc} - I_o (e^{qV/kT} - 1)]V} \qquad [W] \qquad (3.48)$$

$$\mathbf{I = I_{sc} - I_o(e^{qV/kT} - 1)} \qquad [A] \qquad (3.49)$$

Converting to non-dimensional form by dividing it by $I_{sc}V_{oc}$ gives

$$\mathbf{P/I_{sc}V_{oc} = [1 - (e^{qV/kT} - 1)/(e^{qVoc/kT} - 1)](V/Voc)} \qquad (3.50)$$

Kenneth(2000)

3.6 Energy in Waves

The power per unit area represented by the propagation of wave P is given by:

$$\mathbf{P = Y\,\underline{l}\,(\delta l / \delta x)} \qquad [W/m^2] \qquad (3.51)$$

$$\mathbf{P = -(YA^2\omega^2/V)\sin^s(\omega t - kx)} \qquad (3.52)$$

Robert (1960)

Since k=ω/v, where v is the velocity of the wave.

$$\mathbf{P' = \tfrac{1}{2}\, YA^2\omega^2/v} \qquad [W] \qquad (3.53)$$

$$\mathbf{P' = I = \varpi v} \qquad [W] \qquad (3.54)$$

Robert (1960)

The incident average power per unit area:

$$\mathbf{P'_i = \tfrac{1}{2}\, \rho_1 v_1 \omega^2 A_i^2} \qquad [W] \qquad (3.55)$$

And the transmitted average power:

$$\mathbf{P'_t = \tfrac{1}{2}\, \rho_2 v_2 \omega^2 A_t^2} \qquad [W] \qquad (3.56)$$

Consequently:

$$\mathbf{P'_t = ((4\rho_2 v_2/\rho_1 v_1)/(1+\rho_2 v_2/\rho_1 v_1)^2)\ P'_i} \quad [W] \qquad (3.57)$$

Robert (1960)

The coefficient of $\mathbf{P'_i}$ in equation 2.46 is called ‘Transmission Coefficient’ α.

The product $\mathbf{\rho v}$ controls the transmission of energy from one medium to the other,

The transmitted average power per unit area in terms of the incident power is expressed thus:

$$\mathbf{P' = (|A_t|^2/|A_i|^2)\ P'_i}$$

$$\mathbf{P' = [1/(\cos^2 k_1 l + ((r+1/r)^2/4)\ \sin^2 k_1 l)]\ P'_i}$$

$$[W/m^2] \qquad (3.58)$$

Robert (1960)

The reciprocal of the coefficient of $\mathbf{P'_i}$ on the right is the transmission coefficient T, $r=R_2/R_1$, k is the Boltzmann’s constant per molecule

3.6.1 Radiation from a radially vibrating sphere:

The average rate of energy dissipation is given by:

$$P' = \{R + (4\pi a^4 \omega \rho_o k)/(1 + k^2 a^2)\}\, f'^{2}_{a} \qquad [W] \qquad (3.59)$$

Robert (1960)

Where ρ_o is the density of the surrounding medium, ω is the frequency of the driving force, ω_{res} the angular resonance frequency

3.6.2 Energy in a vibrating string

$$E_n = 16h^2V^2\rho_l/\pi^{2n2}l\,\sin^2(n\pi/2) \qquad \text{when } \mathbf{n} \text{ is odd} \qquad (3.60)$$

$$E_n = 16h^2V^2\rho_l/\pi^2n^2l \qquad \mathbf{n} \text{ is even} \qquad (3.61)$$

$$E_{tot} = 2h^2V^2\rho_l/l \qquad \mathbf{n} \text{ takes all integral values} \qquad (3.62)$$

Robert (1960)

Value of E_{tot} is equal to the original potential energy given to the string when it was plucked aside just before it was let go.

3.6.3 Waves in membranes

Wave velocity, $v = \sqrt{(T/\sigma)}$ [m/s] (3.63)

The equation of motion is in the form:

$$\xi = (T/\sigma)\nabla^2\xi \qquad (3.64)$$

Evaluation of the two dimensional Laplacian depends on the shape of the membrane in the plain, assumption of **circular membrane** and using method of Raleigh(1955) for the approximate evaluation of the fundamental frequency in a complicated vibrating system in which the exact displacement cannot readily be determined, yields:

3.6.4 Wave propagation in crystal lattices

The total average energy density is:

$$\boldsymbol{\varpi = (fA^2/l)\sin^2 kl} \qquad [J/m^3] \qquad (3.65)$$

The average Power transmitted:

$$\mathbf{P' = 2A^2(\sqrt{f/m})\,Sin^2kl\;Cos\;kl} \qquad [W] \qquad (3.66)$$

Robert (1960)

The ratio $\boldsymbol{P'/\varpi}$ may be taken to represent physically the average velocity with which energy flows along the lattice due to wave propagation.

$$\boldsymbol{P'/\varpi = 2l(\sqrt{f/m})Cos\;kl} \qquad [m/s] \qquad (3.67)$$

Where the wave parameter $k=\omega/v$ and v is the wave front velocity. Robert (1960)

3.6.5 Light energy:

The energy of radiation is proportional to its frequency,

Planck (1900).

$$\mathbf{E = h\nu} \qquad [J] \qquad (3.68)$$

Energy of a photon is directly proportional to its wave frequency ν another form of equation 3.70

$$\mathbf{E = hc/\lambda} \qquad [J] \qquad (3.69)$$

The intensity of light is proportional to the square of amplitude of electric vector

$$\mathbf{I=ka^2} \qquad (3.70)$$

Van-overstraeten (1986)

CHAPTER 4

ENERGY EVALUATION IN ELECTRICAL ENERGY GENERATING PLANT

4.1 Introduction

Analyzing a typical energy conversion system using the equations of energy conversion and taking into account the other forms of energy generated, in a bid to produce a specific type will reveal the energy losses during such endeavor.

The aim here is to carry out a case study of evaluation of energy conversions in electricity generating system for Oil Mill Division of Sunseed Nigeria PLC, Zaria with a view to;

1. Test the usefulness of the energy conversion equations presented in Chapter 3 by carrying out quantitative energy conversion analysis of electrical energy generation.
2. Carry out first law analysis of electricity generation using internal combustion engine with a view to identify area of wastages and compare cost to electrical energy available for Power Holding Company of Nigeria

The energy conversion analysis is limited to conversion of chemical energy to electrical form. For the purpose of this analysis the following further limitations were in place:

1. **Chemical energy in diesel fuel is considered as initial form of energy, the electric energy generators are considered as energy conversion equipment, while the energy output is**

considered to be the sum of all accounted losses and the electrical energy accounted for useful work. The unaccounted losses are a limitation

2. Energy output is measured in form of electrical energy consumption of each equipment or machine within the complex, these are measured using electric power metering devices; ammeter and voltmeter.
3. Energy loss at the point of power generation only are taken into account, listed factors only account for significant ones.

4.2 Description of System Considered for Case Study

Sunseed Nigeria Public Liability Company is located about 7 kilometres from Zaria, along new Jos road, Zaria. It is surrounded by 'Zaria Industries Limited' (ZIL) and 'RigidPak' to the North, Dakace Primary School to the east and farmlands on the South and West boundaries.

The main activities of the Oil Mill are centered on processing variety of vegetable oil seeds namely: cottonseed, groundnut and soybean seed into edible oil and animal feeds.

The operation of the oil mill is divided into four main plants, each plant comprises of a variety of machines and equipment that use electrical energy.

Three main utilities are involved in operation of the plant

- Water for cooling
- Air for pneumatic actuators
- Steam for creating vacuum and heating purposes.

Sunseed Oil Mill has three, 1500 kVA 'PERKINS' diesel engine-powered electricity generators, of which two are in operation at any point in time. The generators were commissioned January 1998. the rated efficiency for each generator on commissioning was about 60%

ENERGY SOURCE ENERGY SINK

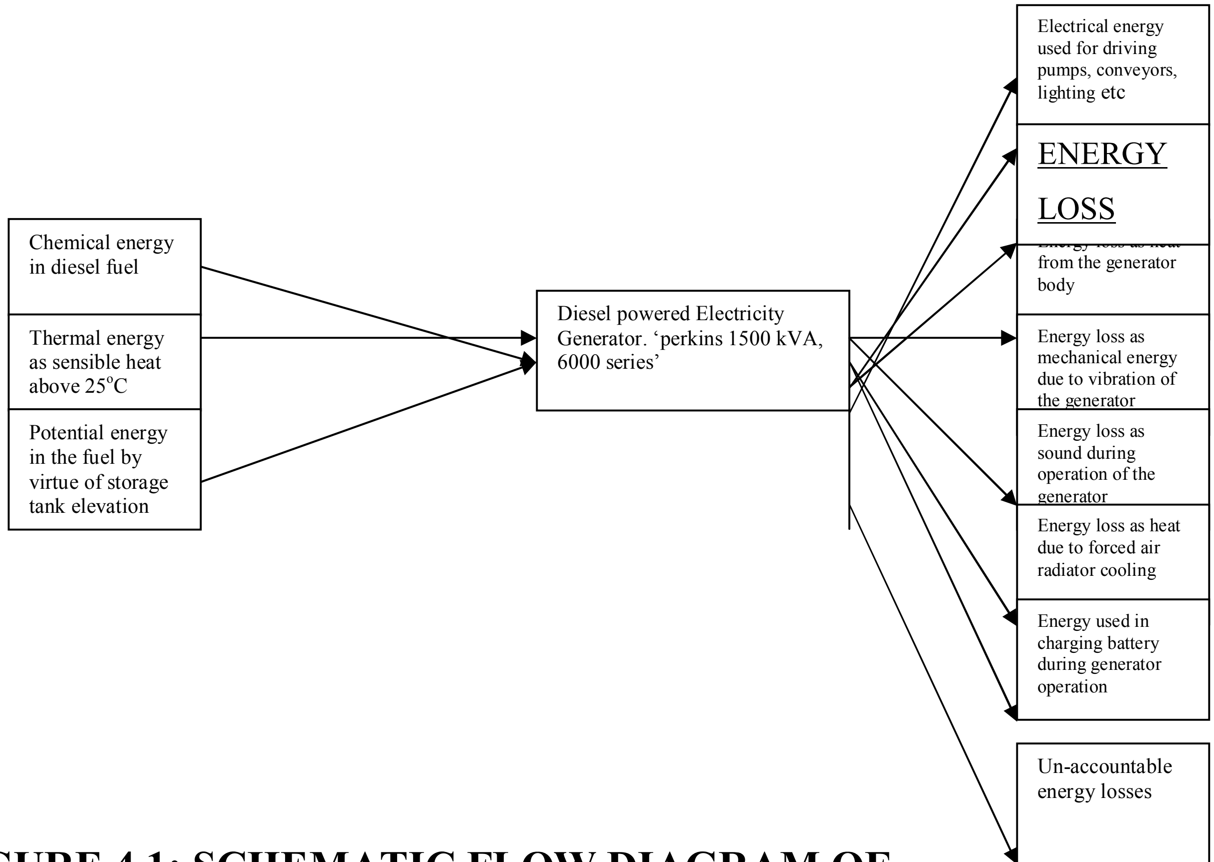


FIGURE 4.1: SCHEMATIC FLOW DIAGRAM OF ELECTRICAL ENERGY GENERATION AND USE IN PRODUCTION PROCESS OF SUNSEED NIGERIA PLC EDIBLE OIL DIVISION

4.2.1 Generating set description

The electrical energy generator is a four-cycle diesel engine in which high-pressure compression raises the air temperature to the ignition temperature of the injection fuel. It is fitted with accessories like speed governor, turbo charger, cartridge type air filter among others.

The engine cooling system is comprised of a radiator and a high capacity pusher fan with a thermostat. The alternator has its own internal fan to cool the alternator components.

The air circuit generally is in such a way that air is force-drafted so that the cooling air is drawn past the alternator, then past the engine and finally through the radiator.

Silencer/exhaust system is fitted to reduce the noise emission from the engine and direct exhaust gases to safe outlets.

Table C.1 in appendix C gives a technical overview of the generating set under study.

The specified rating is applicable for continuous electrical power supply.

4.3 Energy Source.

Table B.1 in Appendix B shows the characteristics of a typical Nigerian, Automotive Gas Oil (AGO) used as fuel, in generating plant

The calorific value of AGO suggests how much energy can be realized from complete combustion of a unit mass of the fuel to produce its combustion products.

4.3.1 Energy input as Chemical Energy

The details of calculation is given in Appendix D.1.1. The chemical energy converted as a result of combustion of 5,900 liters, over a period of 24 hours of operation is calculated as:

$$\mathbf{E_{chemical\ energy} = 225.262 \times 10^{3}\ MJ}$$

4.3.2 Thermal Energy in Diesel oil at the point of injection at temperature above 25^{o}C

The amount of energy added to the diesel as sensible heat is evaluated and accounted for as the thermal energy change of the AGO at the point of injection with reference to standard, conditions of 298 K and 1.013 Bar absolute pressure, calculation in appendix D.1.2.

$$\mathbf{E_{thermal\ energy} = 7.308 \times 10^{-3}\ MJ}$$

4.3.3 Potential Energy in fuel by Virtue of storage tank location above generator level

Detailed calculation presented in appendix D.1.3

$$\mathbf{E_{potential\ due\ to\ gravity} = 0.1919\ MJ}$$

Total energy input with Diesel Oil is the sum of 4.2.1 to 4.2.3, this gives;

$$\mathbf{E_{source} = 225262.1919\ MJ}$$

4.4 Energy Sink.

The energy sink here is considered to be end use of the energy either in the desired form or losses in the process of conversion from chemical energy in the fuel.

4.4.1 Energy for end use

The total energy consumption in form of electrical energy by plant machinery and appliances in 24 hours plant operation was calculated in details shown in appendix D.2.1. The details of individual machine consumption presented in appendix A

Total consumption **=170,936.871 MJ**

4.4.2 Energy losses at the generating station

The practical operation of the Generating set considered for this work goes un-avoidably with energy losses. Some of these losses can be estimated as follows

4.4.2.1 Loss as sound energy (in form of the noise by the generator when in operation)

Energy loss in form of noise was calculated in detail shown in appendix D2.2a.

Over 24 hours of operating two generators = 2.6kJ

4.4.2.2 Energy loss as heat with the combustion product at the generator exhaust.

Energy loss as heat with exhaust gas was calculated component-wise and finally summed up as follows, details of calculation presented in appendix D.2.2b

Heat loss with Nitrogen gas	24.12220x29.175x30.5= 21.464 kJ
Heat loss with Oxygen gas	5.77101x27.679x30.5=4.871 kJ
Heat loss with Carbon dioxide	0.52005x39.127x30.5=0.620 kJ
Heat loss with water vapor	0.23918x90.793x30.5=0.662.9 kJ
Heat loss with Sulphur-dioxide	0.00159x41.712x30.5=0.002 kJ

Total heat loss as sensible heat with exhaust gas for 100g diesel combustion = 27.619 kJ

Energy loss as heat for combustion of 5900 litres of diesel = 5900x0.86x276.19 kJ

= **1.401 MJ**

4.4.2.3 Energy loss as heat emitted from body of the generator

Energy loss in form of heat is mainly by radiation from the surface of the various parts like Radiator fins, turbo charger, Alternator body, main engine body etc

these calculation were carried out separately for main-manifold and turbo-charger, the heat loss was calculated using the approach of flue gas cooler with air on the other side, while energy loss as heat from other parts like main alternator body, engine body were estimated by assuming loss purely by radiation, details of calculations presented in appendix D.2.2c

= **4654.330 MJ**

4.4.2.4 Thermal energy dissipated for fan blowing radiator

Energy loss as heat through radiator was estimated using the approach to overall heat transfer coefficient for extended fin, air-cooled heat exchanger with water in the tube side on bare-tube basis. Details of the calculations presented in appendix D.2.2d

Energy loss as heat in 24 hours operation = **17,271.36 MJ**

4.4.2.5 Energy loss to generator vibration

Equations of energy in mechanically vibrating objects would be useful in estimating this aspect of energy loss, however the energy loss here was presumed negligible in order of magnitude to the other energy quantities in the system.

4.4.2.6 Energy consumption for charging battery of generator

While generator is in operation, part of the energy is used in form of mechanical energy to drive DC generator for charging the accumulators that remain on stand-by for kick starting and automation control current generation purposes. The energy consumed for re-charging the battery was estimated as shown in details appendix D2.2f

Energy loss in a day = **125.280 kJ**

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

This Chapter presents summary of the results, in line with the overall objective of collating and presenting energy content and energy conversion models. (Equations 3.1 to 3.70 in Chapter 3).

5.2 Models for Energy Forms and Conversions

Equations 3.1 to 3.3 were obtained from the fundamental definitions of electrostatics, while Equations 3.4 to 3.6 are various forms of expressions for Joules Law, the accuracy of which has been widely accepted.

Equations of kinetic energy as defined and proven to be accurate by Isaac Newton form the basis of the kinetic energy in object in linear motion and by analogy, the kinetic energy in object in rotational motion can be validated. Potential energy due to mass potential as presented in Equation 3.25 has been generally used and accepted as accurate. The Equations 2.1 to 2.3 for electrical potential have been considered to be valid by analogy to the mechanical potential.

The experiments of Galileo on simple pendulum and deductions from the findings can be considered as validation for Equations 3.15 to 3.19, the limitation are the assumption of no air or other medium resistance to the oscillation process.

Mathematical models for energy forms presented are for a limited few examples of each type practically known.

Some of the energy conversion equations that were deduced, especially in the cases of nuclear fusion and fission presented as Equations 3.35 to 3.39, metabolism, photosynthesis, bio-luminescence as presented as Equations 3.35 to 3.39, 3.41, 3.42 and 3.44 respectively were deduced from theories available in literature and were formulated based on the stoichiometry and the heat of reaction of the chemical reactions that express the transformation. Theses models can be applied to practical situations once the basic measurable variables are known. Results obtained when these models are used are expected to be accurate considering fact that they are based on the well established fundamentals of heat of reaction and the concept of first law of thermodynamics.

Equations of energy stored in compressed gas under adiabatic, isothermal and poly-tropic conditions presented as equations 3.22 to 3.24 respectively have been established in wide literature. Perry et al (1997)

5.3 Electrical Energy Generation Case Study

A case study of energy conversion and use by Sunseed oil mill led to the following deductions:

This approach has accounted for **192,864.090 MJ** which is only 85.61% of energy expected as output based on the concept of first law of thermodynamics, hence the first law efficiency of energy conversion process from point of diesel intake into generator to the point of transmission in electrical transmission to plant equipment.

The efficiency is given by:

$$= (170,936.511/225269.5)x100$$

$$= 75.88\%$$

TABLE 5.1 ENERGY CONVERSION SUMMARY

ENERGY INPUT		ENERGY OUTPUT	
Description	Quantity	Description	Quantity
Energy input as chemical energy	225,262.071 MJ	Electrically powered induction motors and other appliances	170,936.871 MJ
Thermal Energy in the fuel as sensible heat at the point of injection	0.007318 MJ	Thermal energy dissipated for fan blowing radiator	17,271.360 MJ
Energy in fuel by virtue of storage location above generator level	0.192 MJ	Energy lost as sound energy at the powerhouse	0.0026 MJ
		Heat loss with the combustion product at the Generator exhaust.	1.401 MJ
		Energy loss as heat from body of the Generators	4654.330 MJ
		Energy loss to generator vibration	Ignored as negligible
		Energy loss due to rated in – efficiency of the Generators	
		Power driving the battery re-charging alternator.	0.125 MJ
		Un-accounted losses	32,398.109 MJ
TOTAL	**225,262.199**		**225,262.199**

5.3.1 Efficiency analysis

From table 5.1 above, total energy put to desirable use =170,936.871 MJ

Total energy lost based on first law of thermodynamics =225,269.500- 170,936.511

= 54332.989 MJ

Diesel quantity equivalent based on calorific value gives: = (54,332.989/46) kg

= 1562.370 kg

= 1905.330 liters of diesel in a day

= 55,254.561 liters in a month

Considering the present average cost of diesel per liter at ₦ 98, the naira value of energy paid for but never available for use is ₦ 5,414,947.06 in a month.

An estimate of total power generation cost was also made with the aim of crystallizing the problems and prospects of the present approach to electrical energy generation. This reveals

average amount expended on maintenance of one generator per month ₦ 650,000,

This cost comprises of cost of routine maintenance parts, major overhaul parts wages of the operating and special maintenance unit.

Given that two generators are operational at any point in time gives

Total cost of N1, 300,000.00 per month

Total cost of diesel in a month = 5900 liters x 98 x 29 ₦ 16,767,800.00

Total cost of power generation ₦ N18,067,800.00

Percentage of spending not expected to yield any out put eventually:

₦ 5,414,947.06 / 18,067,800.00x

100%

= **29.97%**

Another approach to revealing the inefficiency is by considering cost of power generation per unit of electricity.

Using the electrical energy generation efficiency as basis for comparison, analysis of electrical energy generation efficiency were evaluated as follows:

Rate of electrical energy generation = (170,936.871x1000/(24x60x60)) kW

Electrical energy generation per day = 47,482.464 kWh

Theoretically expected electrical energy generation efficiency per liter of fuel = 8.05 kWh/l

Generation efficiency per liter of fuel for new generators is 4.0 kWh/l

Actual present generation efficiency of each generator per liter of diesel is 2.6 kWh/l.

1. It can be inferred that generation efficiency of a new generator is 50% of theoretical expectation from first law analysis.
2. Actual efficiency of the generator (10 years old) has dropped by 35%.
3. By taking into account the two factors above, the actual avoidable monetary loss per month was calculated as 0.5x0.35x ₦ 5,414,947.06 = ₦ 1,759,857.80

5.3.2 Comparison to PHCN

Summing up the actual values of electrical energy generation 15340 kWh

In a month totaling 444860 kWh

Cost of power generation per unit	=18067800/444860
	₦ 40.62 per kWh
This by far exceeds the rate charged by PHCN	₦ 8.5 per kWh

Generation cost is 4.77 times the cost of available electricity to buy from PHCN.

CHAPTER 6

6.1 Conclusions

Practically most, if not all human activities are centered on energy conversion.
Design and Analysis of energy conversion systems could not be possible without energy conversion models, the energy expressions and expressions of energy conversions presented are a necessary and useful tool to engineers and scientist working on energy conversion systems

Energy forms and types have been presented in form of mathematical expressions, conversion from one form or type of energy to others have been resented in terms of measurable parameters.

Analysis of SUNSEED electrical energy generation using mathematical models presented was carried out and the following deductions were made:

1. The sum of =N= **5,414,947.06** representing 29.97 % of the spending on power generation is going as waste.
2. Cost comparison of a unit of electricity =N=40.62 when generated in the present manner against =N=8.50, price sold by PHCN, indicating option of buying electricity as more economical than present operating mode.

6.2 Recommendations

More scenarios of energy conversion should be explored with a view to generating expressions of energy conversion for as many as possible.

Ultimate aim should be a situation where an expression should be found for any scenario that an engineer may encounter in the course of design.

APPENDIX A

ELECTRICAL POWER CONSUMPTION DATA OF SUNSEED NIG PLC, ZARIA (VEGETABLE OIL PROCESSING DIVISION)

TABLE A.1 DETAILS OF ELECTRICAL ENERGY CONSUMPTION BY ALL MACHINES AND EQUIPMENT

Electrical Equipment Name	Phase Current (A)	Voltage (V)	power consumption (kW)	Hours Daily (hours)	Energy Cons. (Mj)
COTTONSEED PREPARATION PLANT					
Screw conv silo A	5.9	415	3392.741	21	256.491
Screw conv silo A	6.2	415	3565.253	0	0.000
Screw conv silo B	5.2	415	2990.213	0	0.000
Screw conv silo B	9.2	415	5290.376	0	0.000
Silo output conveyor C1	4.9	415	2817.700	24	243.449
Bucket elevator BE2	5.8	415	3335.237	24	288.164
Bucket discharge conveyor	4.3	415	2472.676	24	213.639
Inclined conveyor	6.5	415	3737.766	24	322.943
Bucket elevator BE3	4.9	415	2817.700	24	243.449
Cleaners feed conveyor C3	5.9	415	3392.741	24	293.133
Four tray seed cleaner drive	3.4	415	1955.139	24	675.696
Seed cleaner fan drive	7.3	415	4197.798	24	1450.759
Clean seed conv. Gear drive	0.8	415	460.033	24	158.987
Seed return conveyor	5.2	415	2990.213	24	516.709
Clean seed conv. Gear drive	8.2	415	4715.335	24	407.405
Clean seed rotolift RHL1	6.6	415	3795.270	24	327.911
Delinters feed conveyor C6&C8	2.3	415	1322.594	24	228.544
Cross conveyor	2.1	415	1207.586	24	104.335
Delinters main drive	12.8	415	7360.523	24	5087.594
Delinters brush drive	11.6	415	6670.474	24	4610.632
Delinters feeder	1.7	415	977.569	18	506.772
Mechanical fan drive F4 &F5	24.3	415	13973.493	24	2414.620
Saw roll sharpener (Gummer)	3.1	415	1782.627	22	141.184
Delinted seed conveyor C9&C10	2.9	415	1667.619	24	288.164
Fan 1	16.8	415	9660.687	24	834.683
Fan 2	18.1	415	10408.240	24	899.272
Lint cleaner	2.8	415	1610.114	24	139.114
Shaker (yellow)	1.9	415	1092.578	24	94.399
Bale Press	13.5	415	7763.052	8	223.576

Delinted seed conveyor C11	6.5	415	3737.766	24	322.943
Bucket elevator for Funtua cleaners	7.5	415	4312.807	10	155.261
Funtua seed cleaners SC5&6	5.3	415	3047.717	10	219.436
Clean seed conveyor form SC5&6	5.6	415	3220.229	10	231.856
Husk blower	26.9	415	15468.599	24	1336.487
Husk rotary valve	5.2	415	2990.213	24	258.354
Rotolift RHL2	8.5	415	4887.847	24	422.310
Hullers feed conveyor C12	8.2	415	4715.335	24	407.405
Excess seed return conveyor C13	13.2	415	7590.539	24	655.823
Huller main drive	2.5	415	1437.602	24	745.253
Huller shaker	5.6	415	3220.229	24	1669.367
Husk + +meat conveyor C14	6.8	415	3910.278	24	337.848
Meat conveyor C15	5.9	415	3392.741	24	293.133
Husk + meat rotolift RHL3	4.9	415	2817.700	24	243.449
Husk+ meat conveyor to HSS	5.8	415	3335.237	24	288.164
HSS feed conveyor C16	5.8	415	3335.237	24	288.164
HSS Main drive	2.7	415	1552.610	24	670.728
Husk conveyor from all HSS	5.8	415	3335.237	24	288.164
Husk + seed Rotolift RHL4	4.8	415	2760.196	24	238.481
Material return to Hullers Conveyor	6.5	415	3737.766	24	322.943
Meat conveyor from all HSS	1.9	415	1092.578	24	94.399
Meat cross conveyor	3.1	415	1782.627	24	154.019
HSS fan F6, 7 & F 10	11.5	415	6612.970	24	1714.082
HSS fan F8 & F 9	9.7	415	5577.896	24	963.861
DDB fan F11 A	8.2	415	4715.335	24	407.405
DDB fan F11 B	14.1	415	8108.076	24	700.538
Conveyor from DDB fan cyclones	3.4	415	1955.139	24	168.924
Cross conveyor from DDB fan cyclones	3.8	415	2185.155	24	188.797
DDBS feed conveyor	6.2	415	3565.253	24	308.038
Meat recovery conveyor	1.8	415	1035.074	24	89.430
DDB main drive DDB 1,2,3&4	4.2	415	2415.172	24	834.683
Shaker motor for DDB 3&4 only	2.5	415	1437.602	24	248.418
Meat rotolift RHL6	6.1	415	3507.749	24	303.070
Husk rotolift RHL5	4.6	415	2645.188	24	228.544
Conveyor of Husk to 'roots' blower C27	4.4	415	2530.180	24	218.608
Meat to bin conveyor	3.4	415	1955.139	24	168.924
Meat bin vibrator	2.2	415	1265.090	2	9.109
Meat from bin (under) conveyor	3.4	415	1955.139	24	168.924
Bucket elevator	3.5	415	2012.643	24	173.892
Conditioner compartment main drive	4.2	415	2415.172	24	834.683
Conditioned meat conveyor	3.1	415	1782.627	24	154.019

Rotolift RHL7	15.6	415	8970.638	24	775.063
Rotolift RHL8	6.8	415	3910.278	24	337.848
Flaker feed conveyor	2.4	415	1380.098	24	119.240
Flaker rotary feeder	1.3	415	747.553	24	64.589
Flaker roll main drives	35.8	415	20586.463	24	3557.341
Flake conveyor	2.2	415	1265.090	24	109.304
Press feed conveyor C34	3.2	415	1840.131	24	158.987
Press screw feeder	2.3	415	1322.594	24	114.272
Press main drive	196.7	415	113110.539	24	9772.751
Press oil conveyor	0.8	415	460.033	24	39.747
Vibro screen	1.5	415	862.561	24	74.525
Filtration pump	9.6	415	5520.392	12	238.481
Filtered oil pump to tank farm	8.7	415	5002.856	12	216.123
Cake breaker	6.2	415	3565.253	24	308.038
Expelled cake conveyor (radilar)	2.3	415	1322.594	24	114.272
Radilar conveyor for cake cooler feed	3.5	415	2012.643	24	173.892
Radilar conveyor for cooled cake	3.4	415	1955.139	24	168.924
Radilar for cake to solvent plant (708)	4.8	415	2760.196	24	238.481
Foots conveyor	2.9	415	1667.619	24	144.082
Internal plant lighting	10.2	220	1795.200	11	1421.798
Apparatus lighting	25.8	220	4540.800	24	12554.404
EXTRACTION PLANT					
Extractor feed rotary valve	2.5	415	1437.602	24	124.209
Extractor main drive	3.2	415	1840.131	18	119.240
Extractor spray pumps	4.6	415	2645.188	24	1371.265
Slurry hopper pumps 2A & 2B	2.3	415	1322.594	24	228.544
Cake breaker	1.4	415	805.057	24	69.557
Inclined radilar for feeding Toaster	4.6	415	2645.188	24	228.544
De-solventizer/toaster main drive	15.8	415	9085.646	24	785.000
Toaster discharge conveyor	1.6	415	920.065	14	46.371
Radilar conveyor to pelletizing item 9	6.8	415	3910.278	24	337.848
Hot oil pump	4.2	415	2415.172	24	208.671
Cold oil pump	4.2	415	2415.172	24	208.671
Distillation miscella pump P8	1.5	415	862.561	24	74.525
Distillation process pump	3.4	415	1955.139	24	168.924
Final oil pump p22	3.2	415	1840.131	9	59.620
Hexane pump p63	2.6	415	1495.106	6	32.294
Hexane pump p1	5.6	415	3220.229	24	278.228
Hot water pump	4.1	415	2357.668	24	203.702
Condensate return pump	3.5	415	2012.643	24	173.892
Cool water pump for condensers	24.9	415	14318.518	24	1237.120

Chilled water pump	7.8	415	4485.319	24	387.532
Chiller Freon 22 compressor	2.9	415	1667.619	24	144.082
Internal plant lighting	4.2	220	739.200	11	526.902
Apparatus lighting	4.5	220	792.000	24	752.717
PELLETIZING PLANT					
Powder Radilar conveyor	4	415	2300.163	24	198.734
Conveyor for powder transfer to CPM	2.7	415	1552.610	24	134.146
Elevator for excess powder return	3.4	415	1955.139	24	168.924
Conveyor for excess powder return	3.4	415	1955.139	24	168.924
Expander conditioner drive		415	0.000		0.000
CPM feed conveyor	2.1	415	1207.586	22	95.641
CPM conditioner	8.9	415	5117.864	22	405.335
CPM main drive	76	415	43703.106	22	3461.286
Radilar conveyor of pellet from CPM	3.4	415	1955.139	24	168.924
Bucket elevator BE3	3.2	415	1840.131	24	158.987
Pellet radilar conveyor to cooler	3.2	415	1840.131	24	158.987
Pellet cooler main drive	1.3	415	747.553	24	64.589
Cooled pellet Radilar (under)	3.2	415	1840.131	24	158.987
Cooled pellet elevator to pellet bin BE4	3.3	415	1897.635	24	163.956
Stitching machine	1.5	220	264.000	16	15.206
Internal plant lighting	10.5	220	1848.000	11	2049.062
Apparatus lighting	2.8	220	492.800	24	340.623
REFINERY PLANT					
Refinery short mix oil and water pumps	9	415	5175.368	24	2235.759
Hermetic separators	7.1	415	4082.790	24	1058.259
Mixers M1, M3, M4	4.5	415	2587.684	24	670.728
Mixer M2	0.8	415	460.033	24	39.747
Caustic lye pumps	2.1	415	1207.586	24	208.671
Caustic metering pump	1.8	415	1035.074	24	89.430
Phosphoric acid metering pump	0.8	415	460.033	24	39.747
Cooling tower fan drive	4.8	415	2760.196	24	238.481
Cooling water pumps drive	13.5	415	7763.052	24	1341.455
Soap stock pump drive	3.6	415	2070.147	24	178.861
Soft water pump drive	5.3	415	3047.717	24	263.323
Raw caustic pump	2.7	415	1552.610	2	11.179
Neutralized oil pump to storage P5	2.8	415	1610.114	24	139.114
Neutralized oil transfer pump	4.1	415	2357.668	20	169.752
Bleached oil pump	2.7	415	1552.610	10	55.894
Deodorized oil transfer pump	3.4	415	1955.139	10	70.385

Bleaching slurry filtration pump	9.9	415	5692.905	24	491.867
De-aerated oil pump	13.4	415	7705.548	24	665.759
Deodorizer pump	12.5	415	7188.011	24	621.044
Distilled fatty acid pump	8.5	415	4887.847	24	422.310
Thermal oil circulation pump	6.9	415	3967.782	24	342.816
Thermal oil heater oil & air blower drive	1	415	575.041	20	41.403
Soap stock loading gear pump drive	8.4	415	4830.343	3	104.335
Recovered oil pump	1.2	415	690.049	3	7.453
Internal plant lighting	8.5	220	1496.000	11	888.624
Apparatus lighting	9	220	1584.000	24	1642.291
BOILER PLANT					
Boiler feed water pump drive	16.5	415	9488.174	16	546.519
Induced draft fan drive	24.6	415	14146.005	18	916.661
Secondary air fan drive	4.5	415	2587.684	16	149.051
Forced draft fan drive	4.3	415	2472.676	16	142.426
Mechanical dust collector gear drive	1.4	415	805.057	24	69.557
Husk feeding radilar conveyor drive	5.6	415	3220.229	16	185.485
Husk screw conveyor feeder	1.5	415	862.561	24	74.525
Service water transfer pump drive	10.5	415	6037.929	24	521.677
Fire service water pump	39.9	415	22944.131	0	0.000
Plant lighting 4 ft fluorescents tubes	4.8	220	844.800	11	501.811
60w pin bulb	1.2	220	211.200	24	36.495
Apparatus lighting	9.6	220	1689.600	24	1167.852
Aerator drive	9.2	415	5290.376	24	1.00
Raw effluent pump drive	2.8	415	1		914.1
Primary concentrator drive	1.5	415	862.561	24	139.114
Acid metering pump	1.3	415	747.553	24	74.525
Lime metering pump drive	1.5	415	862.561	24	64.589
Alum metering pump drive	1.3	415	747.553	24	74.525
Flocculation agitator drive	1	415	575.041	24	64.589
Secondary concentrator main drive	1	415	575.041	24	49.684
Sludge pumps	2	415	1150.082	3	49.684
Sand filter pump drive	2.9	415	1667.619	18	24.842
Plant lighting 4ft fluorescents tubes	1.6	220	281.600	11	108.062
Apparatus lighting	2	220	352.000	0	111.514
POWER HOUSE					529.958
GA22 atlas cop co air compressor	16	415	9200.654	16	17.803
Diesel transfer pump	4.3	415	2472.676	2	139.392

Building lighting	2	220	352.000	11	17.803
	220	220			
TANK FARM					
Crude oil transfer pump	12.3	415	7073.003	3	76.388
Refined oil transfer pump	10	415	5750.409	2.5	51.754
Ceiling fan	0	220	0.000	11	0.000
Building lighting	1	220	176.000	24	91.238
LABORATORY					
Heating mantle	0.8	220	140.800	11	11.151
Hot plate	7.8	220	1372.800	24	118.610
Flash point apparatus	0.5	220	88.000	2	0.634
Hot water bath	7.5	220	1320.000	24	114.048
Water distiller	7.7	220	1355.200	2	9.757
Hot air oven	8.6	220	1513.600	24	261.550
Lighting	2	220	352.000	24	486.605
Ceiling fans	2	220	352.000	24	182.477
OFFICES					
Air conditioners 2hp	2.7	220	475.200	10	68.429
Air conditioners 1.5hp	1	220	176.000	10	101.376
Ceiling fans	1	220	176.000	10	25.344
Table /standing fans	1	220	176.000	10	25.344
4 ft fluorescents lighting	25.1	220	4417.600	11	7872.163
2ft fluorescents lighting		220	0.000		0.000
60w pin bulb		220	0.000		0.000
Desk top computers	2.3	220	404.800	10	364.320
Laptop computers	1.5	220	264.000	11	10.454
STAFF CANTEEN					
2ft fluorescents	0.25	220	44.000	0	0.000
4ft fluorescents	0.5	220	88.000	24	60.826
Ceiling fans	2	220	352.000	11	55.757
Fridge	0.6	220	105.600	24	9.124
Freezer	0.8	220	140.800	24	12.165
Hot plate	7.1	220	1249.600	3	13.496
Baking oven	5	220	880.000	3.5	11.088
250 W halogen lamps	20.3	220	3572.800	11	11.088
250w mercury vapor lamps	43.5	220	7656.000	205	1131.863
4 ft fluorescents lamps	2.1	220	369.600	11	56087.856
2 ft fluorescents lamps		220	0.000		58.545

Power consumption summary:

COTTON SEED PREPARATORY PLANT: **69,201.722 MJ**

SOLVENT EXTRACTION PLANT	**7,767.458 MJ**
PELLETIZING PLANT	**15,679.769 MJ**
REFINERY PLANT	**12,038.687 MJ**
BOILER PLANT	**4,312.059 MJ**
EFFLUENT TREATMENT PLANT	**1,676.228 MJ**
POWER HOUSE	**704.956 MJ**
TANK FARM	**219.380 MJ**
LABORATORY	**1,184.832 MJ**
OFFICES	**8,467.430 MJ**
STAFF CANTEEN	**57,451.808 MJ**
Total Power consumption in 24 hour period:	**170,936.871 MJ**

APPENDIX B

DATA ON AUTOMOTIVE GAS OIL

Table B.1 shows average characteristics of A typical Nigerian, Automotive Gas oil (AGO) used as fuel (Othmar 1992: Jessen, 1977; Spalding,1973; Cremer, 1960)

TABLE B.1 PROPERTIES OF AUTOMOTIVE GAS OIL

Property	
Composition, % mass Carbon Hydrogen Sulfur Oxygen Ash Sediment	 86.1 13.2 0.7 - - -
Water Content	-
Minimum Handling temperature, K	283
Flash point, K	343
Density, kg/m^3	830
Vapor pressure, Bar at 318 K	0.0013 0.0033
Critical parameters: Pressure, Bar Temperature, K	 15.2 711
Gross Calorific Value, Mj/kg	46

Source: *Othmar (1992), Jessen, (1977), Spalding (1973), Cremer (1960)*

The calorific value of AGO suggests how much energy can be realized from complete combustion of a unit mass of the fuel to produce its combustion products.

APPENDIX C

‘PERKINS’ 1500 kVA GENERATING SET CONFIGURATION

Technical overview of the generating set under study. The specified rating is applicable for continuous electrical power supply.

TABLE C.1 GENERATING SET CONFIGURATION

Model	P1500
Rated power kVA kW	1500 1200
Power factor (Cos Φ)	0.8
Rated voltage (V)	400/230
Rated frequency (Hz)	50
Rated current (A)	2165.1
Rated RPM	1500
Maximum Altitude (m)	152.5
Maximum ambient temperature (^{o}C)	30
Excitation Voltage	64
Excitation Current	3.8

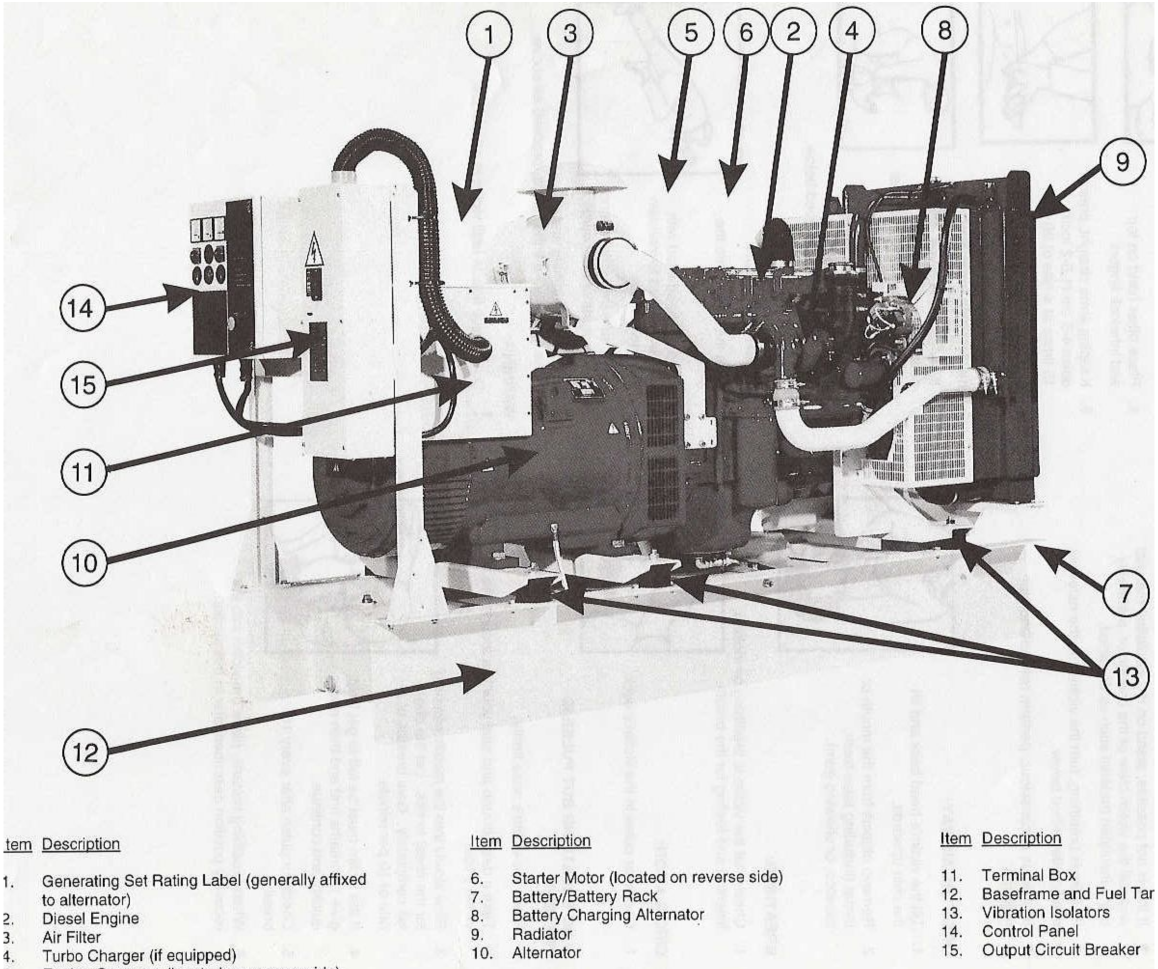


FIGURE C.1: 'PERKINS' 1500kVA 5000 SERIES ELECTRICITY GENERATOR

APPENDIX D

CALCULATIONS

D.1.0 ENERGY SOURCE CALCULATIONS

D.1.1 Energy input as Chemical Energy

Chemical energy converted as a result of combustion of 5,900 liters, over a period of 24 hours of operation is calculated thus:

= (5,900 litres) x (0.83 kg/litre) x (46 MJ/kg)

=**225.262 x 10^3 MJ**

D.1.2 Thermal Energy in Diesel oil at the point of injection at temperature above 25^{o}C

The amount of energy added to the diesel as sensible heat is evaluated and accounted for as the thermal energy change of the AGO at the point of injection with reference to standard, conditions. From equation 3.61

Energy added **= m C_p.ΔT**

= 211.416 x 2.659 x (311.16-298.16)

= 7308.14 Joules

= 7.308x10^{-3} MJ

D.1.3 Potential Energy in fuel by Virtue of storage tank location above generator level

Potential energy of fuel in storage in a tank 4m above flow level of the Generating set

Based on the principle of energy conservation, it is converted into kinetic energy when it flows down from the storage to the generator

From equation 3.37

Potential Energy (per unit mass) = **ρgh**

For a given mass, m = mgh

= (5900 ltres x 0.83 kg/litre) x (9.8 m/s^2) x (4m)

= 0.1919 MJ

D.2.0 ENERGY SINK CALCULATIONS

The energy sink here is considered to be end use of the energy either in the desired form or losses in the process of conversion from chemical energy in the fuel.

D.2.1 Energy used in driving machinery

The end use is mainly in form of electrical energy consumption of machines and appliances that comprise the operations. Some are power consumption by 3-phase Induction Motors that drive conveying systems, Agitators, Pumps, Cake breakers

The energy consumption is calculated using equation 3.05,

$$\mathbf{Power = I_{line} . V_{line} . Cos\ \varphi}$$

$$= \mathbf{\sqrt{3}\ I_{phase} . V_{line} \times 0.8}$$

[J/s]

Other electrical appliances like communication systems, air conditioners, computers, fans, lighting, all laboratory equipment and canteen electrical appliances to mention a few, use single-phase electric power supply, power consumption is calculated from equation 3.05:

$$\textbf{Power} = \mathbf{I.V.Cos}\ \boldsymbol{\varphi} \qquad [J/s]$$

Details of machines and appliances energy consumption computation given in appendix A.

D.2.2 Energy loss at the Generating station

D.2.2a Loss as Sound Energy (in form of the noise by the generator when in operation)

The noise level in the powerhouse measured average **83 dB** was taken for the purpose of energy accounting.

Using equation 2.21 the rate of sound energy dissipated per unit time is given by

$$\text{Energy loss as sound (kW)} = \mathbf{2x10^{-10}\ (e^{\delta/20})} \text{ x Volume of Room}$$

$$= 2x10^{-10}x(e^{83/20}) \text{ x 20m x 20m x 6m}$$

$$= 3x\ 10^{-5} \text{ kW}$$

Over a 24 hours operation, **Energy loss = 2.6 kJ**

D.2.2b Energy loss as heat with the combustion product at the Generator exhaust.

This loss is in form of sensible heat content of the exhaust gas at the temperature of discharge compared to the reference temperature 298 K.

The total energy loss is calculated by summing up the sensible heat of the component gases comprising the exhaust gas at temperature of discharge.

Nitrogen, carbon dioxide, sulphur-dioxide and excess oxygen comprise about 99.8% of the exhaust gas.

Each specie contribution was calculated using a modified form of equation 3.61

$$= \mathbf{m}\ \mathbf{C_p dT}$$

where: **m** is the molar flow rate of the component gas in the exhaust stream. C_p is the molar specific heat capacity of the gas at constant pressure, values each of the specie gases is calculated from

$$C_p = a + (b \times 10^{-3})T + (c \times 10^{-6})T^2 + (d \times 10^5)/T^2 \qquad \text{[cal/mol.K]}$$

$$= 4.184x(a + (b \times 10^{-3})T + (c \times 10^{-6})T^2 + (d \times 10^5)/T^2) \qquad \text{[J/mol.K]}$$

Values of a, b and c for species as presented by: WEAST C. Robert 'CRC Handbook of Chemistry and Physics', CRC press Incorporated 1977-78, page D-61 to D66.

TABLE D.1: SPECIFIC HEAT CAPACITIES OF SPECIES IN GENERATOR EXHAUST GAS AT 298K, 359K AND AVERAGE 328.5K

	Nitrogen		
T (K)	298	359	328.5
a	6.760	6.760	6.760
b	0.606	0.606	0.606
c	0.130	0.130	0.130
d	0.000	0.000	0.000
Specific heat capacity Cp	**29.088**	**29.264**	**29.175**
% increase in Cp with ref to 298 K	0.00%	0.61%	0.30%
	Oxygen		
T (K)	298	359	328.5
a	8.270	8.270	8.270
b	0.258	0.258	0.258
c	0.000	0.000	0.000
d	-1.877	-1.877	-1.877
Specific heat capacity Cp	**26.080**	**28.896**	**27.679**
% increase in Cp with ref to 298 K	0.00%	10.80%	6.13%

	Carbondioxide		
T (K)	298	359	328.5
a	7.700	7.700	7.700
b	5.300	5.300	5.300
c	-0.830	-0.830	-0.830
d	0.000	0.000	0.000
Specific heat capacity Cp	**38.517**	**39.730**	**39.127**
% increase in Cp with ref to 298 K	0.00%	3.15%	1.58%
	Carbonmonoxide		
T (K)	298	359	328.5
a	6.600	6.600	6.600
b	1.200	1.200	1.200
c	0.000	0.000	0.000
d	0.000	0.000	0.000
Specific heat capacity Cp	**29.111**	**29.417**	**29.264**
% increase in Cp with ref to 298 K	0.00%	1.05%	0.53%
	Sulphurdioxide		
T (K)	298	359	328.5
a	11.400	11.400	11.400
b	1.414	1.414	1.414
c	0.000	0.000	0.000
d	-2.045	-2.045	-2.045
Specific heat capacity Cp	39.826	43.183	41.712
% increase in Cp with ref to 298 K	0.00%	8.43%	4.74%
	water vapor		
T (K)	298	359	328.5
a	21.700	21.700	21.700
b	0.000	0.000	0.000
c	0.000	0.000	0.000
d	0.000	0.000	0.000
Specific heat capacity Cp	90.793	90.793	90.793
% increase in Cp with ref to 298 deg	0.00%	0.00%	0.00%

Considering variation (0.6% to 8%) in value of specific heat capacity due to change in temperature from 298K to 359K, a calculated value at an average temperature of 328.5K between exhaust discharge temperature 359K and the ambient temperature 298K was generally used for each of the species:

Table D.2 Exhaust gas composition per 100g of diesel consumed for combustion

EXHAUST GAS SPECIE	mol	mol %
Carbon-dioxide	0.52005	1.70%
excess oxygen	5.77101	18.83%
Sulphur dioxide	0.00159	0.01%
Water vapor	0.23918	0.78%
Nitrogen	24.12220	78.69%

Heat loss with Nitrogen gas 24.12220x29.175x30.5= 21.464 kJ

Heat loss with Oxygen gas 5.77101x27.679x30.5=4.871 kJ

Heat loss with Carbon dioxide 0.52005x39.127x30.5=0.620 kJ

Heat loss with water vapor 0.23918x90.793x30.5=0.662.9 kJ

Heat loss with Sulphur-dioxide 0.00159x41.712x30.5=0.002 kJ

Total heat loss as sensible heat with exhaust gas for 100g diesel combustion = 27.619 kJ

Energy loss as heat for combustion of 5900 litres of diesel = 5900x0.86x276.19 kJ

= **1.401 MJ**

D.2.2c Energy loss as heat emitted from Body of the generator and all other parts

Equations of heat transmission by radiation is used to estimated heat loss from the generator surface

Energy loss as heat from main manifold and turbo-charger:

using equation for air cooled flue gas heat exchangers, the heat loss is calculated thus:

Energy loss = Uac.Am.ΔT_{LMTD}

U=170.349 $Jm^2.s^{-1}.K^{-1}$ is the overall heat transfer coefficient for air-cooled flue gas heat exchanger for operating pressure of about $6.9x10^5Nm^{-2}$ and pressure drop 20.68 to

34.47×10^3 Nm^{-2} .(presented in **Robert H. Perry, Don W. Green, James O. Maloney, "PERRY 'S CHEMICAL ENGINEERS 'HANDBOOK",** seventh edition, table 11-5)

energy loss = 170.449x2.039x155

= 53.8696 kJ/s = **4654.330 MJ**/day

Energy loss as heat from main alternator body:

Using Equation 2.61, blackbody radiation law gives the maximum possible rate of energy emission per unit area of surface:

$$\mathbf{E = \sigma T^4} \qquad [W/m^2]$$

where T is the temperature of the surface,σ Stefan Boltzmann constant $=5.67 \times 10^{-8}$ $Wm^{-2}K^{-4}$

Total surface area of various parts of the generator at temperature slightly above ambience 298K energy loss as heat radiation for the parts in question calculated as follows:

Main alternator body $= A_{alt}\boldsymbol{\sigma} \mathbf{T^4}$

$= (\pi.0.8^2/4) \times 5.67 \times 10^{-8} \times (20)^4$

$=4.56 \times 10^{-3}$ J/s = **393.99 J/day**

D.2.2d Thermal energy dissipated by radiator

Energy loss as heat from Radiator:

Energy loss = $Uac.A_R.\Delta T_{LMTD}$

Uac is the overall heat transfer coefficient for extended fin air-cooled heat exchanger with water in the tube side on bare-tube basis.

$= 709.788 \times A_R \times .\Delta T_{LMTD}$

$= 709.788 \times 22 \times 12.8$

$= 1.999 \times 10^5$ J/s

in a 24 hour day operation, energy loss as heat = 0.1999x60x60x24 = **17,271.36 MJ**

D.2.2e Energy loss due to generator vibration

Vibration of entire generator results in energy losses. Equations of energy loss in mechanically vibrating objects will be used in estimating these losses

D.2.2f Power Consumption for driving Engine Battery Charger

An estimate of the energy used to drive a battery-charging alternator, which generates DC current while the engine is in operation was made using another form of equation 3.09 will be used.

For reversible isothermal process $Q = T(S_p - S_r)$ and the maximum work output of which a fuel cell is capable

$$W = H_r - H_p + T(S_p - S_r) = G_r - G_p \qquad \text{[J/g mole]} \qquad (3.09)$$

Considering the batteries operation is represented by the chemical equations 2.53 and 2.54, work done recharging the battery is equivalent to energy taken from generator for this purpose.

The reverse of equation 2.54

$$\mathbf{Pb(s) + PbO_2\,(s) + 2H_2SO_4\,(aq) \leftrightarrow 2PbSO_4\,(s) + 2H_2O\,(l)}$$

Energy used = work done, $W = H_r - H_p + T(S_p - S_r)$

Assuming isothermal battery operation and using the heats of formation difference for products less those of reactants we have:

= {((0-65-2x212.03)-(-2x218.5-2 x 68.3174))/2} x 4.12

[kJ/mol]

= 1451.99 kJ/mol of H_2SO_4 in solution

in 10 litres of 20% sulphuric acid solution, 0.0204 mols of H_2SO_4

= 29.63 kJ

Energy used for both generators = **59.260 kJ**

D.3 FINAL ANALYSIS

Energy available through combustion = **225,262 MJ**

Energy added through heat content of fuel **= 7.308 MJ**

Energy added by virtue of fuel storage location **= 0.1919 MJ**

Total **225,269.500 MJ**

The total average Energy used up for machine and appliances operation **= 171,889.137 MJ**

Energy loss due to sound energy at point of generation = **2.6 x 10^{-3} MJ**

Energy loss as heat with combustion products =**1.401 MJ**

Energy lost as heat from body of generators = **0.393x10^{-3}J +4654.330 MJ+17,271.36MJ**

Energy loss due to generator vibration = ignored as negligible

Energy loss as work done for battery charging alternator = **59.26x10^{-3} MJ**

Total Energy utilized or lost in 24 hours of operation **193816.290 MJ**

Energy loss due to inefficiency of conversion = 225,269.500-193816.290 = 31,453.320 MJ

This is equivalent to 683.76 liters of diesel in a day

20,512.8litres in a month