VELOPMENT OF A PREDICTIVE MODEL ON A SUSTAINABLE BIOMASS CONSUMPTION)CESS (A CASE STUDY OF NIGERIAN MIDDLE BELT)

BY

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NOVEMBER, 2005

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A RESEARCH PROJECT SUBMITTED TO THE DEPARTMENT OF CHEMICAL ENGINEERING, SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE, NIGERIA

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B. ENG.) DEGREE IN CHEMICAL ENGINEERING

NOVEMBER, 2005

DECLARATION

I, Salihu Mohammed (99/8363EH) hereby declare that this research project, "Development of a Predictive Model on a Sustainable Biomass Consumption Process (A Case Study of Nigerian Middle Belt)", carried out under the supervision of Engineer Alhassan Muhammad and presented in partial fulfilment of the requirement for the award of Bachelor of Engineering (B. Eng.) Degree in Chemical Engineering has not been presented for any degree elsewhere, to the best of my knowledge.

Salihu Mohammed

Date

CERTIFICATION

This is to certify that this research project titled "Development of a Predictive Model on a Sustainable Biomass Consumption Process (A Case Study of Nigerian Middle Belt)" was carried out by Salihu Mohammed (99/8363EH) and submitted to the Department of Chemical Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Minna, Niger State, in partial fulfilment of the requirement for the award of Bachelor of Engineering (B. Eng.) Degree in Chemical Engineering.

Engr. Alhassan Muhammad (Project Supervisor)	6/12/05 Date
Dr. F. Aberuagba (Head of Department)	Date
External Examiner	Date

DEDICATION

I dedicate this project work to The Almighty Allah, The Lord of all creatures, The Compassionate, the Merciful, The Lord of the world. Then, to my parents, Alhaji Salihu and Mrs Aishat (Naomi) Salihu for their loves, care and support from my birth to date.

ACKNOWLEDGEMENT

My gratitude to Almighty Allah, whom nobody can be linked, the protector and the author, the finisher of my life. I acknowledge and appreciate my parents Alhaji Salihu and Hajiya Aishat (Naomi) Salihu, you both did everything possible to get me educated. I love you mum, you are a mother with example worthy of emulation, your children excel is your highest priority, there is no way I could you back but to show you my appreciation and Almighty Allah will reward you with Aljannatul Firdaus.

Dad, you are father, a friend and a mentor you do everything to get me educated and say me through good life. This achievement is more of celebration of you, dad and mums achievement rather than mine. I appreciate the effort of my supervisor Engr. Alhassan Muhammed for his encouragement and assistance during the work. Also to my colleague Mal. Abdulwahab Giwa for his guide and wisdom that saw the completion of this work.

My gratitude to my grand father (Maternal) late Mr. Alabila Ekele for his foresight towards education for my mummy's family may God in his infinite mercy grant your soul rest Amen. I am grateful to Arc. Patrick Alabila for his support, Mr. Isaiah, Miss Ojochenemi Alabila for their care.

I am ever grateful to my elder brother Arc. Jibrin Salihu Alabila for his love, caring and word of inspiration, also to my siblings Mr. Salisu Salihu, Miss Fatima, Bilkisu, Umar, Nafisat and Farida Salihu. I acknowledge my late Jnr. Brother Lawal Salihu who the cold hand of death caught him, I miss you Lawal may your gentle soul rest in perfect peace.

Last but not the least, I'm grateful to my dear friend Miss H. Netume Ayuba for her love care, and encouragement in my life, (I love you). Also Awal Danjuma, his dad

Alhaji Danjuma Akuh and entire family for their guidance and parental care, with due respect I thank you very much.

Not forgetting my Buddies, A.K Muhammed, Peter Wisdom, Kenneth, Jerry boy, Sadeeq Guru, Abdulsalam, Zak mopol, S Traore, Uthman others too numerous to mentioned. I say " NUFF RESPECT".

On my part I feel great to Almighty Allah the must Honourable beyond Human comprehension.

TABLE OF CONTENT

ABSTRACT

This research work was carried out to model an equation for predicting biomass consumption and desertification rate in the middle belt of Nigeria. The data used for the modelling were obtained from questionnaires and the model equations are

(i) Biomass consumption rate = $\text{bcrate} := 5 \times 10^{-12} \cdot ck + 3 \cdot fur + 1 \cdot dis$

(ii) Biomass regeneration rate =

$$\text{deserrate} = (0.9999 \cdot hf + 1.0013 \cdot nf) - \left(5 \times 10^{-12} \cdot ck + 3 \cdot fur + 1 \cdot dis\right)$$

These were developed using empirical method of the least square starting from the equation derived by Odigure and Adeniyi (1998). The developed model equation was then simulated using MathCAD 2000 Professional. Both the simulated and experimental results showed that the rate of generation of biomass is less than that of biomass consumption leading to desertification process in the middle belt of Nigeria. The comparison of the results revealed close fittings because the calculated errors were almost equal to zero. Hence, the model equation can be used to predict biomass consumption rate as well as the desertification process in the middle belt of Nigeria.

CHAPTER ONE

1.0 INTRODUCTION

1.1 General Introduction

Biomass is the name given to any recent organic matter that has been derived from plants as a result of the photosynthetic conversion process. Biomass energy is derived from plant and animal material, such as wood from forests, residues from agricultural and forestry processes, and industrial, human or animal wastes (Ramage & Scurlock, 1996).

Biomass as the solar energy stored in chemical form in plant and animal materials is among the most precious and most promising alternative fuels not only for power generation but also for other industrial and domestic applications on earth. It provides not only food but also energy, building materials, paper, fabrics, medicines and chemicals. Biomass has been used for energy purposes ever since man discovered fire (Miro & Sohif, 2003).

Biomass energy will continue to play an important role in energy consumption in sub-Saharan Africa during the next decades given its level - reaching over 95% in some places - and the relatively slow economic growth and rapid urbanization trends (Ekouevi, 2001). Biomass use is expected to provide nearly 80% of the total energy used in the sub-Saharan African region even in 2010 (Global Environment Outlook, 2000). In fact biomass energy consumption is expected to grow by 2.4% per annum in the period 1995–2020 (Lambert, 1998). Given these trends, an urgent need for relevant policies to inform future rural energy security in the region is implied. Such a process calls for high quality data on biomass production, conversion, distribution and utilization.

As much traditional energy use occurs outside the commercial sector, data on it is geographically patchy and discontinuous. In many countries, the state of biomass resources is unknown and data collection efforts are rather weak or non-existent (Ekouevi, 2001). This statistical invisibility of much rural energy use reinforces its neglect and hampers the development of effective policy. In addition, the enormous variety of energy use patterns, even within quite short distances, makes extrapolation dangerous (WEC, 2000)

There is a need to improve the quality of country level data on biofuels, and to strengthen national and institutional capacities to collect, analyze and disseminate the information (Gustafson, 2001).

Whereas significant strides have been made in the quantification of biomass production - using various techniques including remote sensing - a lot still remains to be understood in as far as biomass consumption is concerns. Previous methods to estimate biomass fuel consumption in Africa have been patchy, sectoral and involving incoherent methods. Recent studies - albeit country based (Marufu et al, 1997 and Kituyi et al, 2001) - have attempted to seal some of the major loopholes, including improving our understanding of factors such as stove types, fuel composition and tree species, diet types, demographic factors, cost and source distance, biofuel availability and interfuel substitution patterns on the biofuel consumption rates and patterns. Also understood for some areas are the temporal patterns of biofuel utilization and the inclusion of other biofuel consumers including communal institutions and commercial enterprises (Kituyi et al, 2001).

A key shortcoming in almost all previous national and regional studies is the "spot" approach used in data collection. Data collected on a special day is assumed to be representative of all other days across the month or year for a given household, institution or commercial enterprise. However, the significantly high fuel demand by some food types and the wide variations in food preferences across cultures implies that this could in fact be a key factor influencing fuel wood consumption. Previous studies have only given this aspect a qualitative treatment, only using the reported diet patterns to speculate on fuel consumption. There's need to incorporate aspects of food types into fuel measurement formulae in future fuel use surveys taking into consideration temporal food consumption patterns.

Mathematical models are currently employed in almost all aspects of process design and operation (chemical, biochemical and petrochemical industries). Models can be algebraic equations (steady state models as well as property or kinetic models), DAE - ordinary differential algebraic equations (dynamic or steady state models with respect to position), PDE - partial differential equations (dynamic or two-position dimension steady state models) with boundary conditions and PDAE - partial differential algebraic equations systems.

This study aims to develop a methodology for accurate estimation of biofuels used in Nigerian Middle Belt with the aid of a predictive mathematical model. The study builds upon a recent "spot" study on biofuel use in Nigerian middle belt to examine the relationship between the diet patterns and fuel consumption.

1.2 Aim and Objectives

The aim of this project is development of a predictive sustainable biomass consumption models; a case study of Nigerian middle belt. This aim can only be achieved through the realization of the following objectives:

(i) Developing the predictive model for the sustainable biomass consumption.

(ii) Testing the model using available data on biomass consumption in the Nigerian Middle Belt.

(iii) Comparing the experimental with the model results to see the validity of the model.

1.3 Scope of the work

This work is limited to developing a mathematical model to predict the sustainable biomass consumption in Nigerian middle belt.

1.4 Justification

It is important to say, that biomass absorbs the same amount of CO_2 in growing that it releases when burned as a fuel in any form. This means that biomass contribution to global warming is zero. In addition, biomass fuels contain negligible amount of sulphur, so their contribution to acid rain is minimal. It is, therefore, a fuel which is worthy of investigating of it is consumed so that proper consumption can be encouraged and unnecessary consumption discouraged (Ramage & Scurlock, 1996).

So, the predictive model to be developed will be used to determine the rate at which biomass is being consumed in the Nigerian Middle Belt.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Biomass

Biomass was the first household energy source used by human beings, and for nearly all-human life history, wood has been our dominant energy source. According to Diebold (Solar Energy Research Institute), until the discovery of low cost petroleum and natural gas in the early 1900's, wood was the most significant energy and heat supplier. Combustion of wood in different scales of boilers produced steam for heating purposes, for power industrial machinery, and, even for transportation vehicles such as trains, ships and farm machinery. Present trends show that biomass will continue the most significant energy source for human kind in the future (Simpson, 2005).

Biomass is the term used to name material derived from plants, (grass, trees and crops) and animals. Plant derived biomass is mainly composed by carbon, oxygen and hydrogen (50:43:6%) and traces of mineral elements such as nitrogen, potassium, phosphorus, sulphur and some others. The predominant organic compounds are cellulose and hemi-cellulose or just carbohydrates polymers (75%) and lignin (25%), the last, acting as "glue" to hold the cellulose fibbers together (Simpson, 2005).

Carbon dioxide from the atmosphere and water from the earth (hydrosphere) are combined through photosynthesis, driven by the solar energy, to produce carbohydrates that build the organic matter of vegetable biomass. The solar energy is transformed into chemical energy in the chemical bonds of the structural components of biomass. When burning biomass (extracting the energy stored in the chemical bonds) efficiently, oxygen from the atmosphere combines with the carbon from biomass to produce carbon dioxide and water. Both water and carbon dioxide are the basic compounds that, together with inorganic nutrients from the lithosphere, driven by the solar energy, build up new biomass "organism" through the process known as photosynthesis. Thus, biomass is a renewable resource!

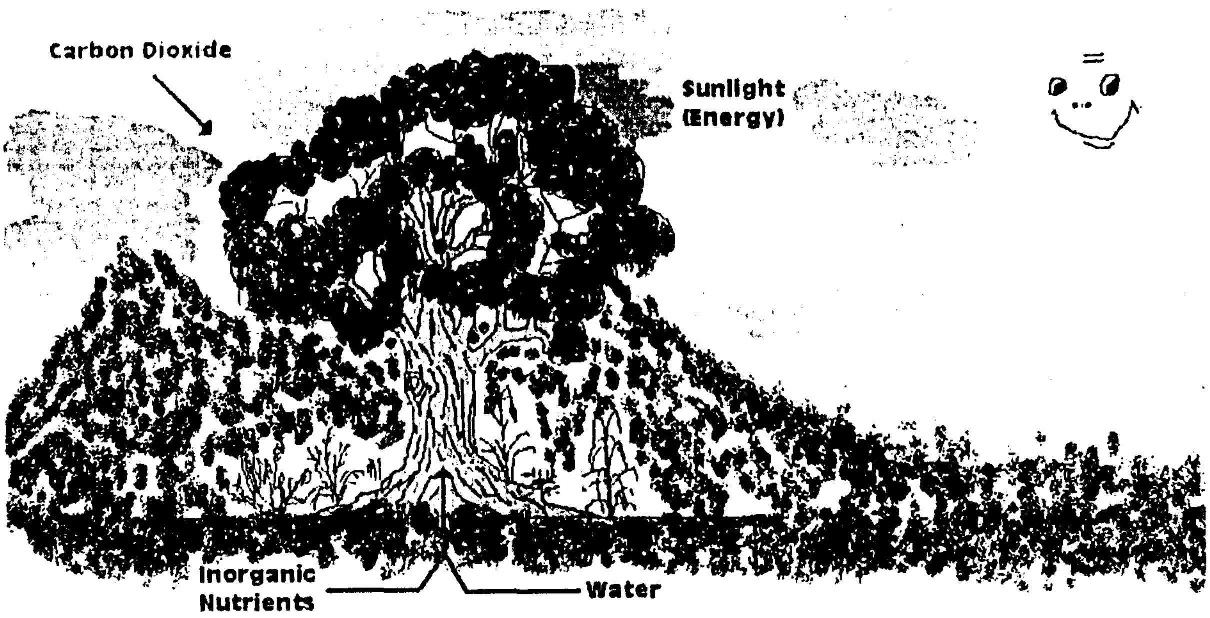

Figure 2.1: Diagram of a tree (a source of biomass)

Biomass from animals comes from animal excreta (waste), which still contains carbon (or organic material) and, therefore, can be submitted to fermentation (anaerobic/aerobic digestion), converting it into biogas or light alcohols. In the other hand, the animal excreta, i.e., cow dung, can be dried and burnt directly as a solid fuel. The carbon present in these wastes comes principally from vegetable mater that composes the animal (herbivorous) diet. This could be the reason why biomass is mainly regarded just as from plants (Simpson, 2005).

Biomass as the solar energy stored in chemical form in plant and animal materials is among the most precious and most promising alternative fuels not only for power generation but also for other industrial and domestic applications on earth. It provides not only food but also energy, building materials, paper, fabrics, medicines and chemicals. Biomass has been used for energy purposes ever since man discovered fire (Miro et al, 2003).

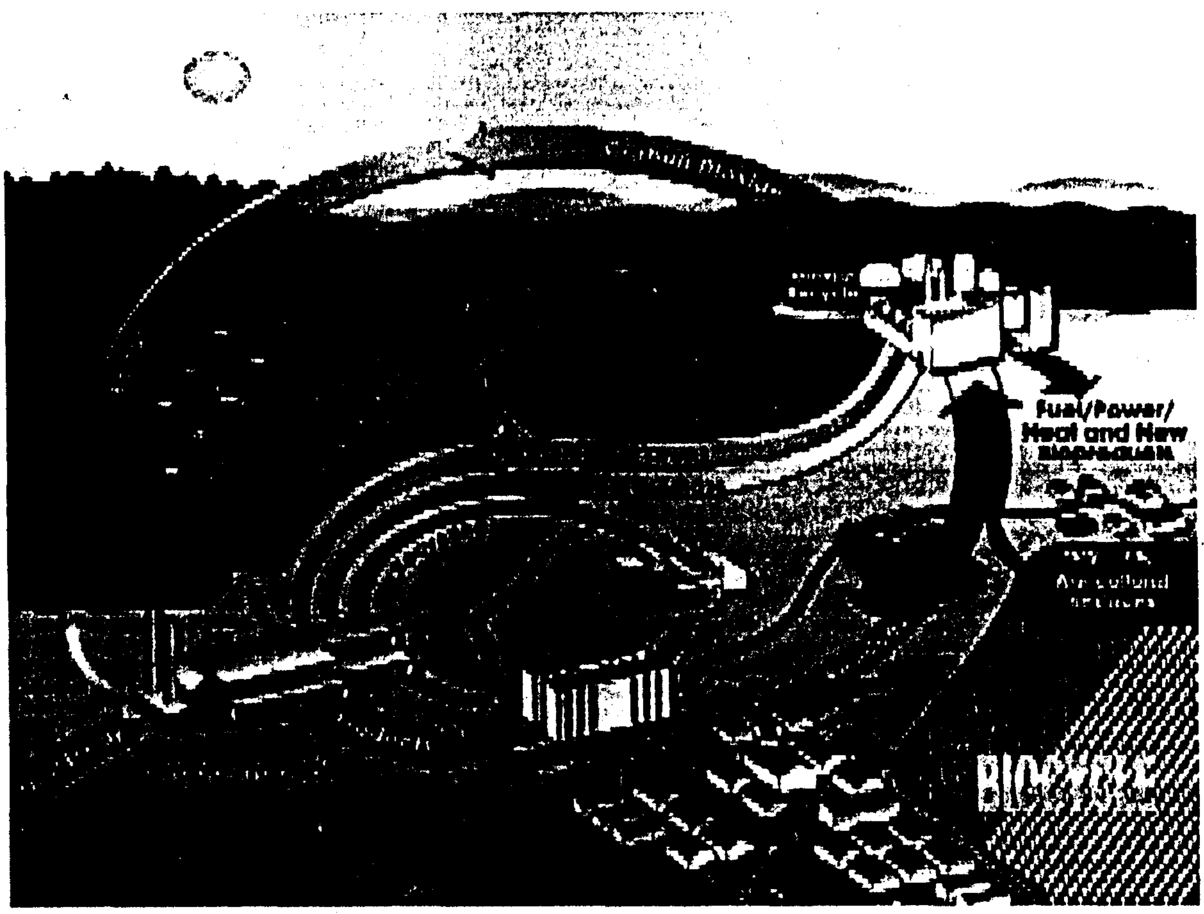

Figure 2.2: Biocycle

It is important to say, that biomass absorbs the same amount of CO_2 in growing that it releases when burned as a fuel in any form. This means that biomass contribution to global warming is zero. In addition, biomass fuels contain negligible amount of sulphur, so their contribution to acid rain is minimal.

Over millions of years, natural processes in the earth transformed organic matter into today's fossil fuels: oil, natural gas and coal.

In contrast, biomass fuels come from organic matter in trees, agricultural crops and other living plant material (Miro et al, 2003).

CO_2 from the atmosphere and water from the earth are combined in the photosynthetic process to produce carbohydrates that form the building blocks of biomass. The solar energy that drives photosynthesis is stored in the chemical bonds of the structural components of biomass.

If we burn biomass efficiently, oxygen from the atmosphere combines with the carbon in plants and produces CO2 and water. The process is cyclic because the carbon dioxide is then available to produce new biomass (Miro, 2003).

Fossil fuels are not renewable. The oil, natural gas and coal we use today are gone forever. However, biomass fuels are renewable because the growth of new plants and trees replenishes the supply.

Unlike any other energy resource, using biomass to produce energy is often a way to dispose of biomass waste materials that otherwise would create environmental risks.

2.2 *Biomass Applications*

2.2.1 *Biofuels*

The production of biofuels such as ethanol and biodiesel has the potential to replace significant quantities of fossil fuels in many transport applications. The widespread use of ethanol in Brazil has shown that biofuels are technically feasible on a large scale. In the USA and Europe biofuel production (ethanol and biodiesel) is increasing, with most of the products being marketed in fuel blends, e.g. E20 is 20% ethanol and 80% petrol and has been found to be suitable for most spark ignition engines without any modifications. At present this production is supported by government incentives, but in the future, with the increased growth of energy crops, and economies of scale, cost reductions may make biofuels competitive in their own right (Serena, 1999).

2.2.2 *Electricity Generation*

Electricity can be generated from a number of biomass sources and being a form of renewable energy can be marketed as "Green Power". The production of electricity from renewable biomass sources does not contribute to the greenhouse effect as the carbon dioxide released by the biomass when it is combusted, (either directly or after a biofuel is produced) is equal to the carbon dioxide absorbed by the biomass material during its growth. Where forest crops are grown on existing pasture land a forest sink is also provided (Serena, 1999).

2.2.3 Heat & Steam

The combustion of biomass or biogas can be used to generate heat and steam. Heat can be the main product, in applications such as home heating and cooking, or it can be a by-product of electricity generation in combined heat and power plants. Steam generated by biomass can be used to drive steam turbines for electricity generation, used for process heat in a manufacturing or processing plant, or used to service a hot water load (Serena, 1999).

2.2.4 Combustible Gas

The biogas produced from anaerobic digestion or pyrolysis has a number of uses. It can be used in internal combustion engines to drive turbines for electricity generation, to produce heat for commercial and domestic needs, and in specially modified vehicles as a transport fuel (Serena, 1999).

2.3 Biomass Resources

Biomass resources that can be used for energy production cover a wide range of materials. The use of biomass energy can be separated into two categories, namely modern biomass and traditional biomass. Modern biomass usually involves large-scale uses and aims to substitute for conventional fossil fuel energy sources. It includes forest wood and agricultural residues; urban wastes; and biogas and energy crops. Traditional biomass is generally confined to developing countries and small-scale uses. It includes fuel wood and charcoal for domestic use, rice husks other plant residues, and animal dung (Serena, 1999).

Typical biomass resources include (Miro, 2003):

The forest	Residues from logging operations and other forest wooden waste
Waste from wood processing industry	sawdust, cut-offs, bark, etc.
Agricultural waste	Palm oil residues, rice husks, sugarcane, coconut shells, coffee & cocoa husks, cotton & maize residues, etc.
Organic waste	Animal manure, food processing wastes.
Urban wood waste	Wooden pallets, packing material, etc.
Wastewater & landfill	Municipal sewage, landfill gas, etc.
Other natural resources	Straw, peat, bagasse

2.3.1 Agricultural Crops

There are many agricultural crops that can be grown specifically as energy sources, including sugar cane, corn (maize), wheat, sorghum, and vegetable oil-bearing crops such as sunflowers, rapeseed (canola), and soya beans. The majority of these crops are grown as liquid fuel sources, that is, they are harvested and processed, into fuels such as ethanol (a petrol substitute) or biodiesel. The most widely grown energy crops are sugar cane (a special type known as 'energy cane') and corn (maize). In Brazil over 4 million vehicles have been run on pure ethanol produced by these crops, with over 100 billion litres produced since 1975 (Ramage & Scurlock, 1997). There is also large-scale use of these crops in the USA and Europe where the production of liquid biofuels is subsidised. Currently in Australia agricultural crops are not grown specifically as energy sources because it is uneconomic to do so, but there is some use of crop wastes as fuel sources, as covered in the next section (Serena, 1999).

Seed crops, which contain a high proportion of oil, can be crushed and the oils extracted and used directly or after esterfication, to replace diesel (called biodiesel) or as a heating oil (see Table 1). There are a wide range of crops that can be used for biodiesel production, but the most common used is rapeseed. Other raw materials used are palm-oil, sunflower-oil, soya bean-oil, tallow (animal fat) and recycled frying oils. The cost of the raw material is the most important factor affecting the overall cost of production. There are currently 85 biodiesel plants around the world (including one in Malaysia using palm-oil) with a combined capacity of over 1.28 million tonnes (Korbitz 1998). In the Philippines, diesel is blended with coconut oil and used in tractors and lorries.

There are a number of benefits associated with biodiesel, including a reduction in greenhouse gases of at least 3.2kg of carbon dioxide-equivalent per kilogram of biodiesel, a 99% reduction of sulphur oxide emissions, a 39% reduction in particulate matter, a high biodegradability, and energy supply security (Korbitz 1998).

2.3.2 Agricultural Residues

Large quantities of crop residues are produced annually worldwide, and are vastly under-utilised. A common agricultural residue is the rice husk, which makes up 25% of rice by mass. Other plant residues include sugar cane fibre (known as bagasse), coconut husks and shells, palm oil fibre, groundnut shells, and cereal straw (Serena, 1999).

In Australia the major residues produced are those from winter cereals, sugar cane and sorghum. Current farming practice is usually to plough these residues back into the soil, or they are burnt, left to decompose, or grazed by stock. A number of agricultural and biomass studies, however, have concluded that it may be appropriate to remove and utilise a portion of crop residue for energy production, providing large volumes of low cost material (ERDC). These residues could be processed into liquid fuels or combusted/gasified to produce electricity and heat (Serena, 1999).

2.3.3 Animal Waste

There are a wide range of animal wastes that can be used as sources of biomass energy. The most common sources are manures from pigs, chickens and cattle (in feed lots) because these animals are reared in confined areas generating a large amount of waste in a small area. In the past this waste has been recovered and sold as a fertilizer or simply spread onto agricultural land, but the introduction of tighter environmental controls on odour and water pollution means that some form of waste management is now required, which provides further incentives for waste-to-energy conversion (Serena, 1999).

A common method of converting these waste materials is via anaerobic digestion, described in a later section of this information page. The product from anaerobic digestion is a 'biogas' that can be used as a fuel for internal combustion engines to generate electricity, or burnt directly for cooking, or for space and water heating. Food processing and abattoir wastes are also a potential anaerobic digestion feedstock.

2.3.4 Black Liquor

Black liquor is a waste product generated by the paper and pulp making industry. Black liquor can be pyrolysed or gasified as a biomass energy source. The University of Melbourne has developed a fluidised bed fast pyrolysis process that can convert black liquor into a "bio-oil". The bio-oil can be processed into transport fuel substitutes such as biodiesel.

2.3.5 Sugar Industry Wastes

The sugar cane industry produces large volumes of bagasse (sugar cane fibre) each year. Bagasse is potentially a major source of biomass energy as it can be used as boiler feedstock to generate steam for process heat and electricity production. Most sugar cane mills utilise bagasse to produce electricity for their own needs, but recently a few of these plants have been expanded and upgraded to allow the exportation of large quantities of electricity to the grid (Serena, 1999).

In Australia, many sugar mills in Queensland and New South Wales have good potential to are export increased quantities of renewable electricity. These mills have an installed generating capacity of over 250 MWe, but the bagasse resource could supply a much greater capacity. The Rocky Point Green Energy Corporation was recently awarded a $3 million Renewable Energy Showcase Grant to develop a 30MWe biomass cogeneration plant at its Beenleigh Mill, Queensland. This plant will use wood waste outside the normal 20 week cane crushing season, and it is expected to reduce CO_2 emissions by over 220,000 tonnes per year (CADDET, 1999).

2.3.6 Forestry Crops

Wood is a major energy source in many parts of the world including Asia, Africa and South America, and the potential exists for it to become a significant renewable source all over the world. The best type of trees for these wood crops are those which are fast growing and suitable for coppicing. Coppicing involves harvesting the tree after a few years and then allowing the tree to sprout again from the stump, followed by subsequent harvesting on a 2 - 5 year period. The wood can be burnt to generate steam for electricity, or heat for cooking, water and space heating, or used in charcoal manufacture.

Growing energy forestry crops on a large scale has received renewed interest in Australia and other parts of the developed world recently. There is a over 1 million hectares of land which is marginal for intensive agriculture in Australia that could be used for this purpose. It has the potential to improve agricultural productivity, conserve land, and diversify farm income, but the financial viability for farmers is currently unproven (ERDC) (Serena, 1999).

2.3.7 Forestry Residues

Forestry residues are generated by operations such as thinning of plantations, clearing for logging roads, extracting stemwood for pulp and timber, and natural attrition. Wood processing also generates significant volumes of residues usually in the form of sawdust, off-cuts, bark and woodchip rejects. This waste material is often not utilised, with forest arisings often left to rot on site, but it can be collected and used as a fuel source, in the same way that traditional wood or forestry crops can.

2.3.8 Industrial Waste

The food industry produces a large number of residues and by-products that can be used as biomass energy sources. These waste materials are generated from all sectors of the food industry with everything from meat production to confectionery producing waste that can be utilised as an energy source (Serena, 1999).

Solid wastes include peelings and scraps from fruit and vegetables, food that does not meet quality control standards, pulp and fibre from sugar and starch extraction, filter sludges and coffee grounds. These wastes are usually disposed of in landfill dumps with the food company paying for their disposal (Serena, 1999).

Liquid waste streams are generated by washing meat, fruit and vegetables, blanching fruit and vegetables, pre-cooking meats, poultry and fish, cleaning and processing operations and wine making. These waste waters contain sugars, starches and other dissolved and solid organic matter, but in a fairly dilute form (ERDC). The potential exists for these industrial wastes to be anaerobically digested to produce biogas, or fermented to produce ethanol, and several commercial examples of waste-to-energy conversion already exist.

2.3.9 Municipal Solid Waste (MSW)

Millions of tonnes of household waste are collected each year with the vast majority disposed of in landfill dumps. The composition of MSW varies according to the location and type of the collection service. In 1994 the average composition of Australian MSW was found to be 46% putrecibles (decaying organic matter), 24% paper, 26% plastic, glass and metal, and 4% "other" (ERDC). The biomass resource in this MSW comprises the putrecibles, paper and plastic and averages 80% of the total MSW collected (Serena, 1999).

Municipal solid waste can be converted into energy by direct combustion, or by natural anaerobic digestion in the landfill. In Australia there are a number of landfill gas plants. At these landfill sites the gas produced by the natural decomposition of MSW (approximately 50% methane and 50% carbon dioxide) is collected from the stored material and scrubbed and cleaned before feeding into internal combustion engines or gas turbines to generate heat and power.

2.3.10 Sewage

Sewage is a source of biomass energy that is very similar to the other animal wastes previously mentioned, the only difference being that it has been treated in developed countries for many years. Energy can be extracted from sewage using anaerobic digestion to produce biogas. The sewage sludge that remains can then be incinerated or undergo pyrolysis to produce more biogas and 'bio-oil' (Serena, 1999).

2.4 Biomass Conversion Technologies

2.4.1 Anaerobic Digestion

Anaerobic digestion is the decomposition of wet and green biomass through bacterial action in the absence of oxygen to produces a mixed gas output of methane and carbon dioxide known as biogas. The anaerobic digestion of municipal solid waste buried in landfill sites produces a gas known as landfill gas which occurs naturally as the bacterial decomposition of the organic matter continues over time. The methane gas produced in landfill sites eventually escapes into the atmosphere. However, the landfill gas can be extracted from existing landfill sites by inserting perforated pipes into the landfill. In this way, the gas will travel through the pipes under natural pressure to be used as an energy source, rather than simply escaping into the atmosphere to contribute to greenhouse gas emissions.

Biogas is most commonly produced using animal manure, mixed with water, which is stirred and warmed inside an air-tight container, known as a digester. Digesters range in size from around 1m3 for a small household unit to as large as 2000m^3 for a large commercial installation (Ramage & Scurlock 1996). The biogas produced can be burnt directly for cooking and space heating, or used as fuel in internal combustion engines to generate electricity (Serena, 1999).

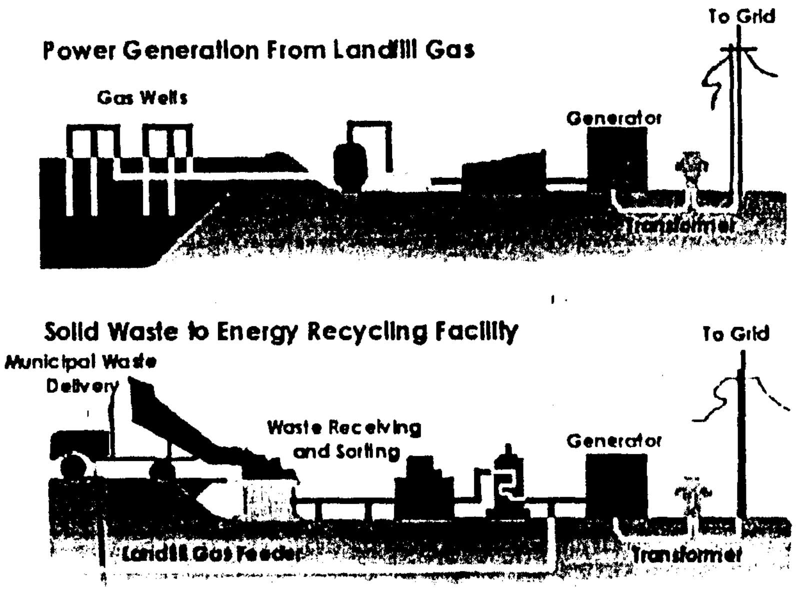

Figure 2.3: Power generation from landfill gas and solid waste to energy recycling

Alternatively, new landfill sites can be specially developed in a configuration which encourages anaerobic digestion. In these new sites, the pipe system for gas collection is laid down before the waste is deposited, thus optimising the gas output, which can be as high as 1000m^3 per hour and last up to 20 years. The landfill gas is generally used for electricity generation, using large internal combustion engines to drive generators of around 500kWe generators to match the normal gas supply rates of around 10GJ per hour (depending on the size of the landfill). One of the largest landfill gas plants in the world is a 46MWe plant in California (Ramage & Scurlock 1996). In Australia increasing emphasis is being placed on recycling, so in the future the amount of landfill generated per person will decrease, lowering the size of the landfill gas resource (Serena, 1999).

2.4.2 Briquetting & Pelletising

Briquetting and pelletising involves the compaction of biomass at high temperatures and very high pressures. The biomass particles are compressed in a die to produce briquettes or pellets. These products have significantly smaller volume than the original biomass and thus have a higher volumetric energy density (VED) making them a more compact source of energy. They are also easier to transport and store than natural biomass.

The briquettes and pellets can be used directly on a large scale as direct combustion feed, or on a small scale in domestic stoves or wood heaters. They can also be used in charcoal production.

2.4.3 Direct Combustion & Cogeneration

Direct combustion is the main process adopted for utilising biomass energy. The energy produced can be used to provide heat and/or steam for cooking, space heating and industrial processes; or for electricity generation.

Small-scale applications, such as domestic cooking and space heating, can be very inefficient with heat transfer losses of 30 - 90%. This problem can be addressed through the use of more efficient stove technology.

On a larger scale biomass, such as fuelwood, forestry residues, bagasse and municipal solid waste, can be combusted in furnaces and boilers to produce process heat (figure 3), or steam to feed steam turbine generators. Power plant size is constrained by the local feedstock availability and is generally less than 25MW. However, by using dedicated feedstock supplies, such as short-rotation plantations or herbaceous energy crops, the size can be increased to 50 -75 MW, gaining significant economies of scale (Overend 1998). In developing countries, power generation is usually required in smaller increments, and feedstock requirements can easily be met by agricultural residues, such as rice husks and nut shells (Serena, 1999).

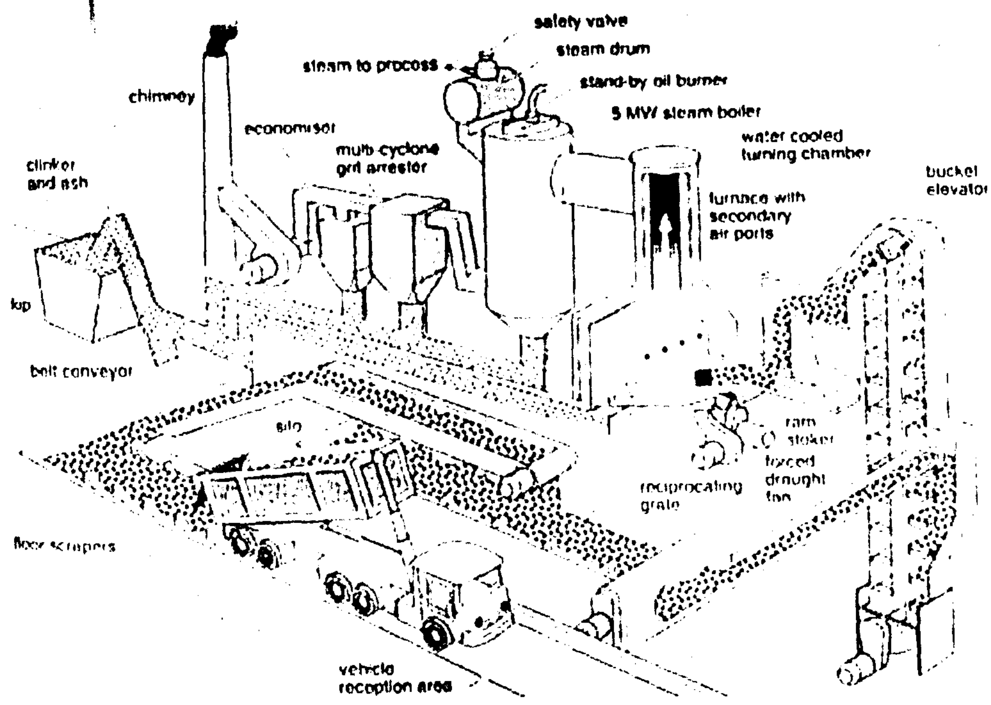

Figure 2.4: A large scale plant for generating process heat from woodchips

(Copyright Ramage & Scurlock, 1996)

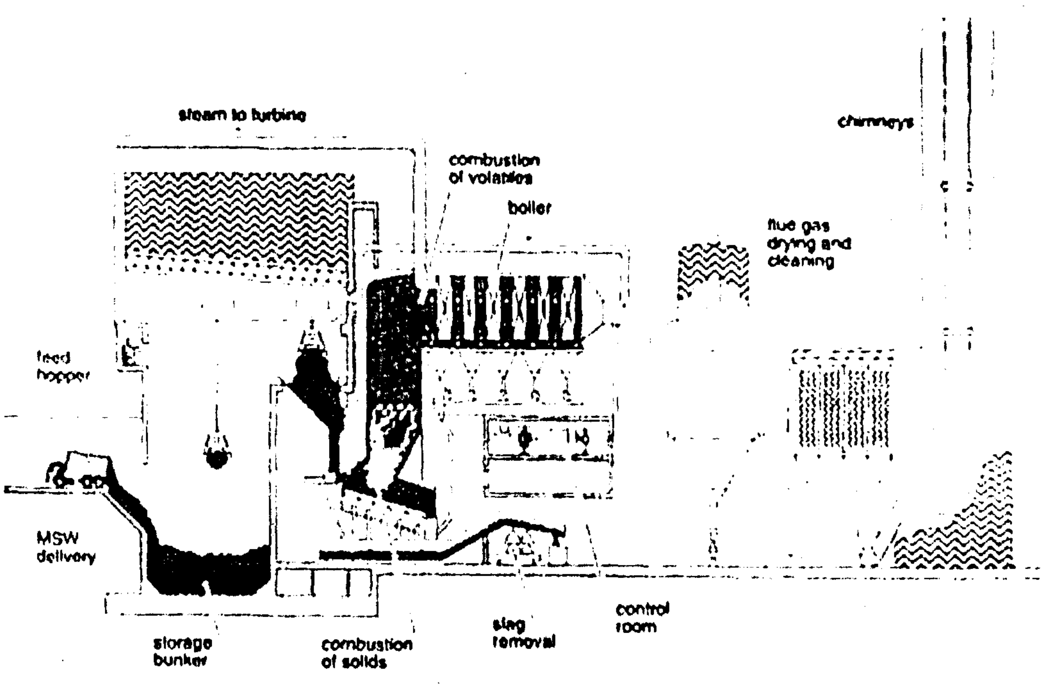

Figure 2.5: A large MSW combustion plant

(Copyright Ramage & Scurlock, 1998)

The basic technology is proven for selected feedstocks in the 10 -50MW size range. For example, the McNeil Generation Station in Vermont, USA, is a typical wood-fired power plant with a capacity of 50MW (see figure 5). There are currently over 7,000MW of biomass power generation in the United States based on steam turbine technology.

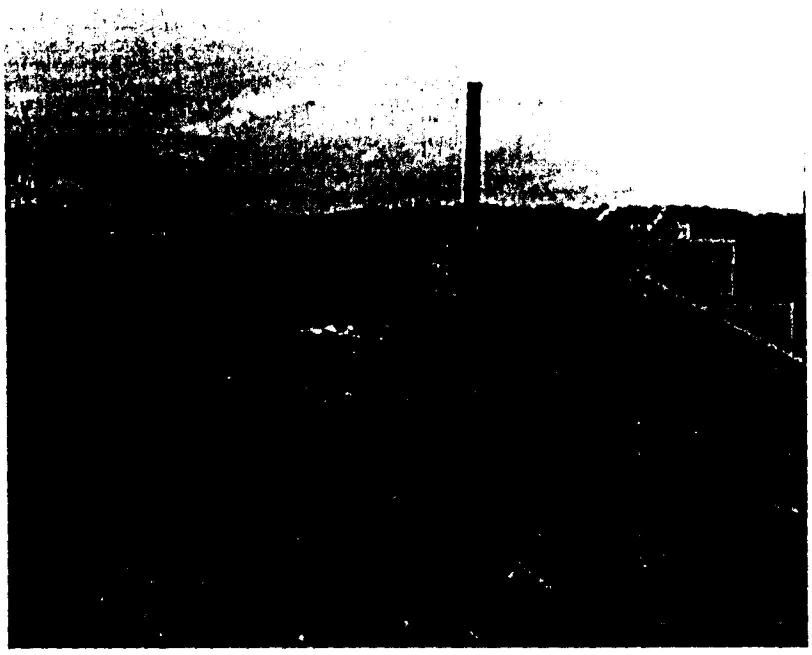

Figure 2.6: Photo of the McNeil Generation Station, Vermont

Chicken litter, a mixture of straw, wood chips and poultry droppings, is another source of biomass and the Fibro Thetford project in England will soon be the largest biomass power station in Europe. The plant, which is based on he design of two existing 12.7MWe and 13.5MWe plants, will have a capacity of 38.5MWe and will be fuelled by poultry litter.

Large biomass power generation systems can have comparable efficiencies to fossil fuel systems, but this comes at a higher cost due to the design of the burner to handle the higher moisture content of biomass. However, by using the biomass in a combined heat and electricity production system (or cogeneration system), the economics are significantly improved. Cogeneration is viable in area where there is a local demand for the heat as well as the electricity, though this can be more easily exported off the site to a distant user.

2.4.4 *Pyrolysis*

Pyrolysis is the basic thermochemical process for converting solid biomass to a more useful liquid fuel. Biomass is heated in the absence of oxygen, or partially combusted in a limited oxygen supply, to produce a hydrocarbon rich gas mixture, an oil-like liquid and a carbon rich solid residue. Traditionally in developing countries, the solid residue produced is charcoal, which has a higher energy density than the original fuel, and is smokeless and thus ideal for domestic use. The traditional charcoal kilns are simply mounds of wood covered with earth, or pits in the ground. However, the process of carbonisation is very slow and inefficient in these kilns, and more sophisticated kilns are replacing the traditional ones. The pyrolitic or "bio-oil" produced can be easily transported and refined into a series of products similar to refining crude oil.

2.4.5 *Gasification*

Gasification is a form of pyrolysis, carried out with more air, and at high temperatures in order to optimise the gas production. The resulting gas, known as producer gas, is a mixture of carbon monoxide, hydrogen and methane, together with carbon dioxide and nitrogen. The gas is more versatile than the original solid biomass (usually wood or charcoal): it can be burnt to produce process heat and steam, or used in internal combustion engines or gas turbines to produce electricity, or even as a vehicle fuel as was common in Australia and Germany in World War II.

Biomass gasification is the latest generation of biomass energy conversion processes, and is being used at a scale of up to 50 MWe to improve the efficiency, and to reduce the investment costs of biomass electricity generation through the use of gas turbine technology. High efficiencies (up to about 50%) are achievable using combined-cycle gas turbine systems, where waste heat from the gas turbine is recovered to produce steam for use in a steam turbine. Economic studies show that biomass gasification plants can be as economical as conventional coal-fired plants (Badin & Kirschner 1998, p.45). However gas cleanup to an acceptable standard remains the major challenge yet to be overcome.

Commercial gasifiers are available in a range of size and types, and can be run on a variety of fuels, including wood, charcoal, coconut shells and rice husks. Power output is determined by the economic supply of biomass, which is limited to a maximum of 80MWe in most regions (Overend 1998). The first gasification combined-cycle power plant in the world is a 6MW facility at Varnamo, Sweden, which is fuelled by wood residues. The proposed 75MW alfalfa gasification combined-cycle power plant in Minnesota, USA, when completed, will be the first dedicated crop-fuel plant of its size in the world. Other installations have been built and tested but several have proven to be unacceptable.

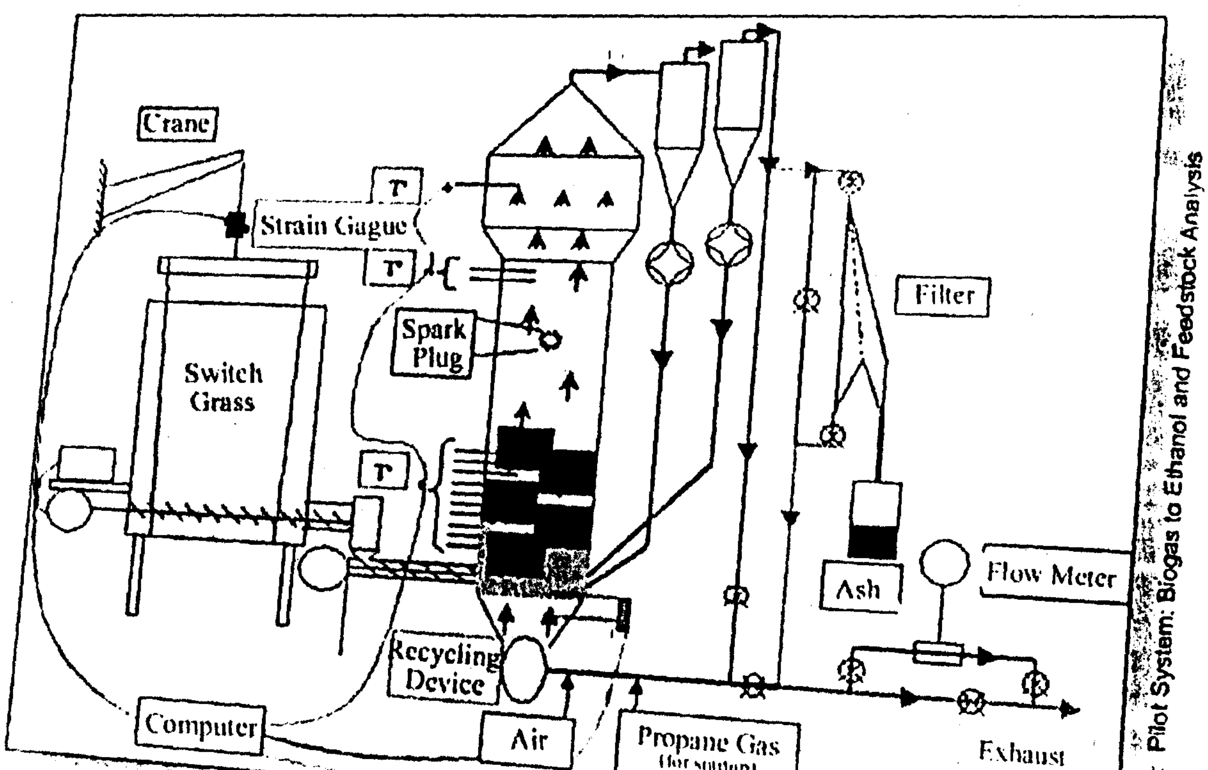

Diagram of the experimental setup of the biomass gasifier tested by researchers at Oklahoma State University.

Figure 2.7: Charcoal Production

Charcoal production is a form of pyrolysis with very limited available oxygen, where the vapours and gases are driven off. Modern charcoal retorts (furnaces) operating at about 600° C produce 25 - 35% of the dry biomass feed as charcoal, and the gases can be used for kiln drying. Traditional earthen kilns (as used in many developing countries) have yields closer to 10% as there is less control (Twidell). The charcoal produced is 75 - 85% carbon and is useful as a compact, controllable fuel. It can be burnt to provide heat on a large and small scale. High-grade charcoal is used in laboratory and industrial chemical applications.

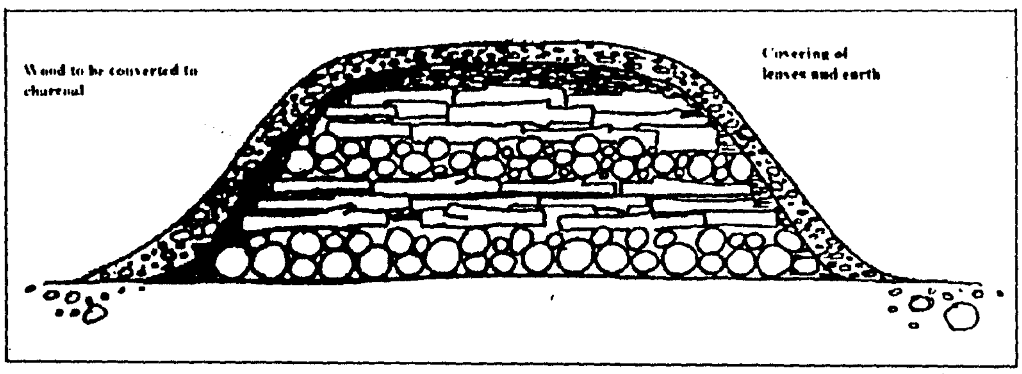

Figure 2.8: Traditional Earth Kiln for Charcoal Production

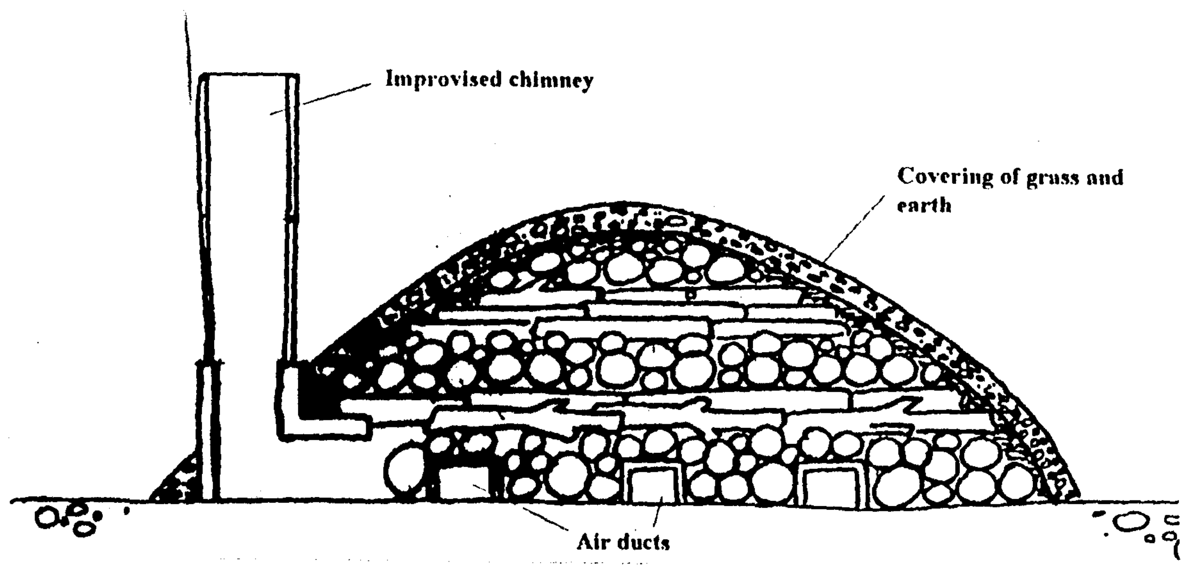

Figure 2.9: Improved Charcoal Kiln Found in Brazil, Sudan and Malawi

2.4.6 *Co-firing*

Co-firing involves the use of biomass material in conjunction with fossil fuels, usually coal. The biomass is commonly chipped wood which is added to the feed coal (wood is 5 - 15% of total) and combusted to produce steam in a coal power plant. Co-firing is currently well developed in the USA but also in a stage of research and development as electricity companies examine the effect of the addition of wood to the coal, in terms of specific power plant performance and potential problems. It is hoped that co-firing will become economically viable in the future, allowing coal power stations to produce a small portion of renewable energy.

2.4.7 *Ethanol Production*

Ethanol can be produced from certain biomass materials that contain sugars, starch or cellulose. The best-known feedstock for ethanol production is sugar cane, but other materials can be used, including wheat and other cereals, sugar beet, jerusalem artichoke, and wood. The choice of biomass is important as feedstock costs typically make up 55 - 80% of the final alcohol selling price (World Energy Council 1994). Starch-based biomass is usually cheaper than sugar-based materials, but requires additional processing. Similarly, cellulose materials, such as wood and straw, are readily available but require expensive preparation. The lignin by-product, which is around 50% of the material, can be combusted to provide the energy to drive the process.

2.5 *Benefits of Biomass*

Biomass is a renewable source of energy and its use does not contribute to global warming. In fact, it an reduce the atmospheric levels of carbon dioxide, as it acts as a sink and soil carbon can also increase.

Biomass fuels have negligible sulphur content and therefore do not contribute to sulphur dioxide emissions which cause acid rain. The combustion of biomass generally produces less ash than coal combustion, and the ash produced can be used as a soil additive on farm land to recycle material such as phosphorous and potassium.

The conversion of agricultural and forestry residues, and municipal solid waste for energy production is an effective use of waste products that also reduces the significant problem of waste disposal, particularly in municipal areas.

Biomass is a domestic resource, which is not subject to world price fluctuations or the supply uncertainties of imported fuels. In developing countries in particular, the use of liquid biofuels, such as biodiesel and ethanol, reduces the economic pressures of importing petroleum products.

Perennial energy crops (grasses and trees) have lower environmental impacts than conventional agricultural crops.

Constraints to Biomass Use

In nature, biomass has relatively low energy density and so transportation increases the costs and reduces the net energy production. Biomass has a low bulk density (large volumes are needed compared to fossil fuels), which makes transportation and handling difficult and costly. The key to overcoming this problem is locating the energy conversion process close to a concentrated source of biomass, such as a sawmill, sugar mill or pulp mill.

The incomplete combustion of fuelwood produces organic particulate matter, carbon monoxide and other organic gases. If high temperature combustion is used, oxides of nitrogen will be produced. At a smaller domestic scale, the health impact of air pollution inside buildings is a significant problem in developing countries, where fuelwood is burnt inefficiently in open fires for domestic cooking and space heating.

There is the potential for the widespread use of natural forests to cause deforestation and localised fuelwood scarcity, with serious ecological and social ramifications. This is currently occurring in Nepal, parts of India, South America and in sub-saharan Africa. The conversion of forest land into agricultural land and urban areas is a major cause of deforestation. In addition, in many Asian countries much of the woodfuel used for energy purposes comes from indigenous forest areas.

There is a potential conflict over the use of land and water resources for biomass energy and other uses, such as food and fibre production. However, the use of modern agricultural production techniques means that there is land available for all uses, even in densely populated regions like Europe.

Some biomass applications are not fully competitive at this stage. In electricity production for example, there is strong competition from new, highly efficient natural gas-fired combined-cycle plants. However, the economics of biomass energy production are improving, and the growing concern about greenhouse gas emissions is making biomass energy more attractive.

The production and processing of biomass can involve a significant energy input, such as fuel for agricultural vehicles and fertilisers, resulting in a reduced energy balance for the biomass application. Biomass processes need to minimise the use of energy-intensive and fossil-fuel based inputs, and maximise waste conversion and energy recovery.

There are often political and institutional constraints to biomass use, such as energy policies, taxes and subsidies that encourage the use of fossil fuels. Energy prices often do not reflect the environmental benefits of biomass or other renewable energy resources.

2.6 *Uses of Biomass*

Modern biomass now represents only 3% of primary energy consumption in industrialised countries (Ramage & Scurlock 1996). However, much of the rural population in developing countries, which represents about 50% of the world's population, is still reliant on traditional biomass, mainly in the form of wood, for fuel. Traditional biomass accounts for 35% of primary energy consumption in developing countries, raising the world total to 14% of primary energy consumption (Ramage & Scurlock 1996).

The Earth's natural biomass replacement represents an energy supply of around 3,000EJ (3 x 1021 J) a year, of which just under 2% is currently (1998) used as fuel. It is not possible, however, to use all of the annual production of biomass in a sustainable manner. One analysis carried out by the United Nations Conference on Environment and Development (UNCED) estimates that biomass could potentially supply about half of the present world primary energy consumption by the year 2050 (Ramage & Scurlock 1996).

2.7 *The Future for Biomass*

In the future, biomass has the potential to provide a cost-effective and sustainable supply of energy, while at the same time aiding countries to meet their greenhouse gas reduction targets. By the year 2050, it is estimated that 90% of the world population will live in developing countries (Ramage & Scurlock 1996). It is critical therefore that the biomass processes used in these countries are sustainable. The modernisation of biomass technologies, leading to more efficient biomass production and conversion, is one possible direction for biomass use in developing countries.

In industrialised countries, the main biomass processes utilised in the future are expected to be the direct combustion of residues and wastes for electricity generation, bio-ethanol and biodiesel as liquid fuels, and combined heat and power production from energy crops. In the short to medium term, biomass waste and residues are expected to dominate biomass supply, to be substituted by energy crops in the longer term. The future of biomass electricity generation lies in biomass integrated gasification/gas turbine technology, which offers high energy conversion efficiencies and will be further developed to run on biomass produced fuels.

2.8 Status of Biomass Utilization

The development of biomass energy utilization can be considered from its sources and technology for transformation and utilization. Biomass is mainly collected from residues or by-products of crops, food and other production. Being essential an agro-industry economy, Thailand has a fairly large biomass resource base of about 60 million tons generated each year that could be utilized for energy purposes.

Technologies for transformation and utilization of biomass cover a wide range, from well-established technologies to those in the research stage. All of these technologies have been improved and the cumulative experiences are also important. The biomass conversion technologies have been concentrated in gasification technology, densification technology, pyrolysis technology, and combustion technology and biogas technology. Co-generation system is also attractive to many industries from combined heat and power facilities providing process heating and electricity for their own consumption and sell surplus electricity to grid.

However, the major constrains of biomass utilization are difficulty in assessment of resources, low bulk density and high moisture content, problems of collection, transportation and storage, and availability and reliability concerns.

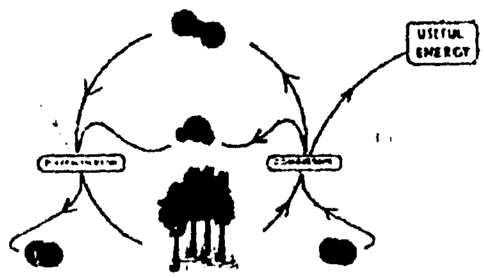

Figure 2.10: Biomass

2.9 *Modelling*

2.9.1 Conceptualization of mathematical modelling

Mathematical modelling is the general characterization of a process or concept in mathematical terms, thus enabling the relatively simple manipulation of variables to be accomplished in order to determine how these processes or concept would behave in different situations (Ajibade, 2004). It attempts to describe the functional relationship of the variables and parameters by a set of equations and thus, showing more clearly the cause and effect relationships of the variables.

Mathematical modelling is versatile and is widely used in practice. It is a recognised and valuable adjunct and usually a precursor of computer simulation. In developing a mathematical model, you need to determine the mathematical expression that will relate what is known to what you intend to determine. In developing a mathematical system that models the system, when values are input into the model, it will act upon this input and produce an output. The major goal is to have this output be of reasonable approximation of the corresponding response or output of the actual system. Many mathematical models that are difficult or tedious to solve by normal hand calculations can be solved efficiently with the computer. However, the solution will only be as good as the mathematical model (Ajibade, 2004).

2.9.2 Principles of mathematical formulation

The principles involved in the formulation of mathematical models are as stated below:

1. Basis: The basis for the mathematical models are the fundamental physical and chemical laws, such as the law of mass, energy and momentum conservation stated in their time derivative forms. Others include parameters such as mass transfer coefficient, diffusivity constant, reaction rates which are either obtained experimentally or from process operating data.
2. Assumptions: There is need to make simplifying but reasonable assumptions about the system while modelling. The outcome of the model is dependent on the assumptions as they impose limitation on the model.
3. Mathematical consistency of model: Care must be taken not to under specify or over specify the number of variables or equations describing the system because in order to obtain a solution, the numbers of variables must equal the number of equations, that is, the degree of freedom of the system must be zero.
4. Solution of the model equation: Available solution techniques and tools must be kept in mind as the model is being developed, as a model that contains unknown and immeasurable parameters is unsolvable and amount to a waste of time and energy. In the search for a method of solution,

possible approximations for the defining equations, boundary and initial conditions and acceptable final solutions are considered.

5. Verifications: The need to prove the validity of a model is an important part of mathematical modelling. Because of the complex nature of verifying the models, it is often neglected. However, one way of achieving this objective is by comparing average experimental result for similar operating conditions to the computed results (Ajibade, 2004).

2.9.3 Simulation

Martin Shubik defines simulation of a system as the operation of a model, which is a representation of the system, the model being amenable to manipulations which would be impossible, too expensive or impractical or perform on the system it portrays.

Simulation is used for two principal reasons:

i. To give greater understanding and insight into the behaviour of the physical system and the principles upon which its design is based.
ii. To provide a convenient, inexpensive and time saving means of gaining this understanding and insight under a variety of operating conditions (Ajibade, 2004).

2.9.4 Computer simulation

Computer simulation however means the running of a special program on a suitable type of computer which generates time response of the model that imitates the behaviour of the process being studies. There are two types of simulation methods, namely, analogue and digital simulation. However, digital simulation is more frequently used because of the enhanced capabilities and operational speed of modern electronic computers which are used in executing computer algorithm of the models.

Modelling and simulation can be carried out with the aid of the computer using some powerful software packages like Excel, Polymath, MathCAD, SPSS and so on.

2.9.4.1 Importance of mathematical modelling

It is quite often the case that we have to design the control system for a chemical process before the process is being constructed. In such as case, we cannot rely on the experimental procedures and we need a different representation of the chemical process in order to study its dynamic behaviour. This representation is usually a set of mathematical equation whose solution yields the dynamics or static behaviour of the chemical process we examine.

Mathematical modelling and simulation can result in considerable saving of both time and money. When it is impractical to experiment with the real system, mathematical modelling and simulation can be used to explore the effect of changes on a system. It can also result in an increase in the fundamental knowledge about a system since it usually involves a considerable analysis of the system (Ajibade, 2004).

Many chemical process developments in the recent years were undertaken through model development. A typical example of a developed model using pH as the optimization criteria was reported in the work of Adeniyi and Odigure (2002).

In the work, the pH was modelled using the empirical method of the least square method (Carnahan et al, 1969, Himmelblau, 1987) of the form

$$pH = f(Temperature, TSS, COD, hardness, Ca, Mg, Cl)$$

which becomes

$$pH = f(a \cdot T + b \cdot t + c \cdot C_1 + d \cdot H + e \cdot C_2 + f \cdot M + g \cdot C_3)$$

I represents the square of the error between the observed pH and its predicted value, P.

$$I = \left[P - (a \cdot T + b \cdot t + c \cdot C_1 + d \cdot H + e \cdot C_2 + f \cdot M + g \cdot C_3)\right]^2$$

For n experimental values of P and other variable,

$$nI = \sum (P_i - a \cdot T_i - b \cdot t_i - c \cdot C_{1i} - d \cdot H_i - e \cdot C_{2i} - f \cdot M_i - g \cdot C_{3i})^2$$

The condition for a minimum was obtained and a set of linear equations was derived, after which basic program was used to obtain the sum from the experimental data. They used the summation to form a 7 x 7 matrix and the constant coefficients were obtained with a computer program using Gauss-Jordan elimination method.

The model equation obtained in this work was

$$P_m = (0.1137949399 \cdot T + 0.022099205 \cdot t + 0.0832652449 \cdot C_1 + 0.0937238337 \cdot H) \cdot \ldots$$
$$+ -0.080762186 \cdot C_2 - 0.035212731 \cdot M + 0.0034813083 \cdot C_3$$

The percentage error was calculated using the modelled and experimental value.

The comparative values of their experimental results and the modelled pH values were presented in Table 2.1 below.

Table 2.1: Comparative pH values for experimental and developed model

Month	Observed pH value	Model pH value	Percentage error (%)
January	9.50	9.52	0.21
February	9.20	9.25	0.54
March	9.00	9.00	0.00
April	8.90	8.70	2.25
May	9.00	9.08	0.88
June	9.80	9.53	2.76

July	9.50	9.52	0.21
August	9.20	9.25	0.54
September	9.00	9.00	0.00
October	8.90	8.70	0.25
November	9.00	9.07	0.77
December	9.80	9.50	3.06

They then concluded that the developed model showed that the pH value is a reflection of the physio-chemical and technological parameters. They also concluded that the parametric coefficients in the model equation obtained showed the effect of some of the measured parameters on the overall pH value (i.e. increasing acidity and alkalinity).

CHAPTER THREE

3.0 METHODOLOGY

3.1 General Procedure

The methodology adopted in this project is the use of questionnaire. 20 questionnaires were distributed to the people of each state of the middle belt including Abuja (i.e. Benue, Kwara, Niger, Plateau, Kogi, Nasarawa, Abuja) each. At the end of the day, only 120 questionnaires out of 140 were recovered. This means that 20 questionnaires were not recovered. A sample of the questionnaire used is presented in the appendix A.

CHAPTER FOUR

4.0 MATHEMATICAL MODELLING ALGORITHM

4.1 MODELLING OF BIOMASS CONSUMPTION RATE

4.1.1 EMPIRICAL MODELLING OF BIOMASS CONSUMPTION RATE

The biomass consumption rate is a function of biomass consumed by cooking, furniture and natural

disaster

Denoting

cooking by ck

furniture by fur

natural disaster by dis

and

biomass consumption rate by bcrate

it can be written that

$$bcrate = f(ck, fur, dis) \quad ---(4.1)$$

The expression above can be written as

$$bcrate = f(a \cdot ck + b \cdot fur + c \cdot dis) \quad ---(4.2)$$

where the bcrate is the dependent variable; ck, fur and dis are the independent variables for

the biomass consumption rate and a, b and c are the coefficients to be determined.
If the the square of the error between the experimental biomass consumption rate (ebcrate)and

its predicted value is represented by I, using the experimentally obtained data of ck, fur and dis

$$(ebcrate - bcrate)^2 \quad ---(4.3)$$

and, since,

$$bcrate = f(a \cdot ck + b \cdot fur + c \cdot dis) \quad ---(4.4)$$

$$I = [ebcrate - (a \cdot ck + b \cdot fur + c \cdot dis)]^2 \quad ---(4.5)$$

For n experimental values of P and ck, fur and dis,

$$nI = \sum\left[ebcrate_i - \left(a \cdot ck_i + b \cdot fur_i + c \cdot dis_i\right)\right]^2 \quad ---(4.6)$$

$$nl = \sum \left(ebcrate_i - a \cdot ck_i - b \cdot fur_i - c \cdot dis_i\right)^2 \qquad ---(4.7)$$

To minimize nl with respect to the coefficients a, b and c, using the first partial derivatives of nl

with respect to these constants and equating these to zero, the necessary conditions for a

minimum are obtained. So from equation (4.7),

$$\frac{\partial}{\partial a}(nl) = -2 \cdot \sum ck_i \cdot \left(ebcrate_i - a \cdot ck_i - b \cdot fur_i - c \cdot dis_i\right) = 0 \qquad ---(4.8)$$

$$\frac{\partial}{\partial b}(nl) = -2 \cdot \sum ck_i \cdot \left(ebcrate_i - a \cdot ck_i - b \cdot fur_i - c \cdot dis_i\right) = 0 \qquad ---(4.9)$$

$$\frac{\partial}{\partial c}(nl) = -2 \cdot \sum ck_i \cdot \left(ebcrate_i - a \cdot ck_i - b \cdot fur_i - c \cdot dis_i\right) = 0 \qquad ---(4.9)$$

When rearranged, these sets of linear equations become

$$\sum\left(ck_i \cdot ebcrate_i\right) = \left[a \cdot \sum\left(ck_i\right)^2 + b \cdot \sum\left(ck_i \cdot fur_i\right) + c \cdot \sum\left(ck_i \cdot dis_i\right)\right] \qquad ---(4.10)$$

$$\sum\left(fur_i \cdot ebcrate_i\right) = \left[a \cdot \sum\left(ck_i \cdot fur_i\right) + b \cdot \sum\left(fur_i\right)^2 + c \cdot \sum\left(fur_i \cdot dis_i\right)\right] \qquad ---(4.11)$$

$$\sum\left(dis_i \cdot ebcrate_i\right) = \left[a \cdot \sum\left(dis_i \cdot fur_i\right) + b \cdot \sum\left(dis_i \cdot fur_i\right)^2 + c \cdot \sum\left(ck_i \cdot dis_i\right)\right] \qquad ---(4.11)$$

where $\Sigma = \Sigma^n{}_{i=1}$

and n = 120 and the sums are obtained from the experimental data using MathCAD 2000

Values :=

	1	2	3	4
1	0.38	0.19	0.1	0.67
2	0.38	0.19	0.04	0.6
3	0.38	0.19	0.04	0.6
4	0.38	0.19	0.04	0.6
5	0.38	0.19	0.04	0.6
6	0.38	0.19	0.04	0.6
7	0.38	0.19	0.04	0.6
8	0.38	0.19	0.04	0.6
9	0.38	0.19	0.04	0.6
10	0.38	0.19	0.04	0.6
11	0.38	0.19	0.04	0.6
12	0.38	0.19	0.04	0.6
13	0.38	0.19	0.04	0.6

With reference to the table above, the superscripts refer to the column

$ck_i := Values^{\langle 1 \rangle}$ $\quad fur_i := Values^{\langle 2 \rangle}$ $\quad dis_i := Values^{\langle 3 \rangle}$ $\quad ebcrate_i := Values^{\langle 4 \rangle}$

$$\text{Biomass} := \begin{pmatrix} \sum\overrightarrow{(ck_i)^2} & \sum\overrightarrow{(ck_i \cdot fur_i)} & \sum\overrightarrow{(ck_i \cdot dis_i)} \\ \sum\overrightarrow{(fur_i \cdot ck_i)} & \sum\overrightarrow{(fur_i)^2} & \sum\overrightarrow{(fur_i \cdot dis_i)} \\ \sum\overrightarrow{(dis_i \cdot ck_i)} & \sum\overrightarrow{(dis_i \cdot fur_i)} & \sum\overrightarrow{(dis_i)^2} \end{pmatrix} \qquad \text{Muhammad} := \begin{pmatrix} \sum\overrightarrow{(ck_i \cdot ebcrate_i)} \\ \sum\overrightarrow{(fur_i \cdot ebcrate_i)} \\ \sum\overrightarrow{(dis_i \cdot ebcrate_i)} \end{pmatrix}$$

Symmetricity of the matrix,

$$\text{Biomass} - \text{Biomass}^T = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

solution := lsolve(Biomass, Muhammad)

$$\text{solution} = \begin{pmatrix} 5 \times 10^{-12} \\ 3 \\ 1 \end{pmatrix}$$

$a := \text{solution}_1$ $\qquad a = 5 \times 10^{-12}$

$b := \text{solution}_2$ $\qquad b = 3$

$c := \text{solution}_3$ $\qquad c = 1$

If it is known that,

$ck := ck_i$ $\qquad fur := fur_i$ $\qquad dis := dis_i$ $\qquad$ and $\qquad ebcrate := ebcrate_i$

The model equation can thus be written as

$$bcrate := 5 \times 10^{-12} \cdot ck + 3 \cdot fur + 1 \cdot dis$$

4.1.2 SIMULATION OF MODEL EQUATION

The model equation is simulated using the MathCAD software and the simulated results are as

shown in the table below.

bcrate =

	1
1	0.667
2	0.604
3	0.604
4	0.604
5	0.604
6	0.604
7	0.604
8	0.604
9	0.604
10	0.604
11	0.604
12	0.604
13	0.604

4.1.3 CALCULATION OF ERRORS

The errors between the experimental and predicted values were also calculated with the MathCAD

software and the results are as shown in the table below.

Errors := ebcrate − bcrate

Errors =

	1
1	$-1.895 \cdot 10^{-12}$
2	$-1.875 \cdot 10^{-12}$
3	$-1.875 \cdot 10^{-12}$
4	$-1.875 \cdot 10^{-12}$
5	$-1.875 \cdot 10^{-12}$
6	$-1.875 \cdot 10^{-12}$
7	$-1.875 \cdot 10^{-12}$
8	$-1.875 \cdot 10^{-12}$
9	$-1.875 \cdot 10^{-12}$
10	$-1.875 \cdot 10^{-12}$
11	$-1.875 \cdot 10^{-12}$
12	$-1.875 \cdot 10^{-12}$
13	$-1.875 \cdot 10^{-12}$

4.1.4 CALCULATION OF PERCENTAGE ERRORS

The percentage errors between the experimental and predicted values were also calculated with the

MathCAD software and the results are as shown in the table below.

$$\%Errors := \overrightarrow{\left(\frac{Errors}{ebcrate} \cdot 100\%\right)}$$

%Errors =

	1
1	$-2.842 \cdot 10^{-10}$
2	$-3.103 \cdot 10^{-10}$
3	$-3.103 \cdot 10^{-10}$
4	$-3.103 \cdot 10^{-10}$
5	$-3.103 \cdot 10^{-10}$
6	$-3.103 \cdot 10^{-10}$
7	$-3.103 \cdot 10^{-10}$
8	$-3.103 \cdot 10^{-10}$
9	$-3.103 \cdot 10^{-10}$
10	$-3.103 \cdot 10^{-10}$
11	$-3.103 \cdot 10^{-10}$
12	$-3.103 \cdot 10^{-10}$
13	$-3.103 \cdot 10^{-10}$

%

4.2 MODELLING OF BIOMASS REGENERATION RATE

4.2.1 EMPIRICAL MODELLING OF BIOMASS REGENERATION RATE

The biomass regeneration rate is a function of trees planted by human beings and those grown naturally.

Denoting

trees planted by human beings by hf

and trees planted by naturally by nf

it can be written that

$$regenrate = f(hf, nf)$$

The expression above can be written as

$$regenrate = f(a \cdot hf + b \cdot nf)$$

where the regenrate is the dependent variable; hf and nf are the independent variables for

the biomass regeneration rate and a and b are the coefficients to be determined.

If the the square of the error between the experimental biomass regeneration rate (regenrate)and its

predicted value is represented by I, using the experimentally obtained data of hfand nf

$$l = (eregenrate - regenrate)^2$$

and, since,

$$regenrate = f(a \cdot hf + b \cdot nf)$$

$$l = [eregenrate - (a \cdot hf + b \cdot nf)]^2$$

For n experimental values of P and hf and nf,

$$nl = \sum\left[eregenrate - \left(a \cdot hf_i + b \cdot nf_i\right)\right]^2$$

$$nl = \sum\left(eregenrate - a \cdot hf_i - b \cdot nf_i\right)^2$$

To minimize nl with respect to the coefficients a and b, using the first partial derivatives of nl

with respect to these constants and equating these to zero, the necessary conditions for a

minimum are obtained. So from equation (4.7),

$$\frac{\partial}{\partial a}(nl) = -2 \cdot \sum hf_i \cdot \left(eregenrate_i - a \cdot hf_i - b \cdot nf_i\right) = 0$$

$$\frac{\partial}{\partial b}(nl) = -2 \cdot \sum nf_i \cdot \left(eregenrate_i - a \cdot hf_i - b \cdot nf_i\right) = 0$$

When rearranged, these sets of linear equations become

$$\sum\left(hf_i \cdot eregenrate_i\right) = \left[a \cdot \sum\left(hf_i\right)^2 + b \cdot \sum\left(hf_i \cdot nf_i\right)\right]$$

$$\sum\left(nf_i \cdot eregenrate_i\right) = \left[a \cdot \sum\left(nk_i \cdot hf_i\right) + b \cdot \sum\left(nf_i\right)^2\right]$$

where $\Sigma = \Sigma^n_{i=1}$

and n = 120 and the sums are obtained from the experimental data using MathCAD 2000.

Values :=

	1	2	3
1	0.37	0.08	0.44
2	0.37	0.03	0.4
3	0.37	0.03	0.4
4	0.37	0.03	0.4
5	0.37	0.03	0.4
6	0.37	0.03	0.4
7	0.37	0.03	0.4
8	0.37	0.03	0.4
9	0.37	0.03	0.4
10	0.37	0.03	0.4
11	0.37	0.03	0.4
12	0.37	0.03	0.4
13	0.37	0.03	0.4

With reference to the table above, the superscripts refer to the column

$hf_i := Values^{\langle 1 \rangle}$ $nf_i := Values^{\langle 2 \rangle}$ $eregenrate_i := Values^{\langle 3 \rangle}$

$$Biomass := \begin{pmatrix} \sum \overrightarrow{(hf_i)^2} & \sum \overrightarrow{(hf_i \cdot nf_i)} \\ \sum \overrightarrow{(nf_i \cdot hf_i)} & \sum \overrightarrow{(nf_i)^2} \end{pmatrix} \qquad Muhammad := \begin{pmatrix} \sum \overrightarrow{(hf_i \cdot eregenrate_i)} \\ \sum \overrightarrow{(nf_i \cdot eregenrate_i)} \end{pmatrix}$$

$solution := lsolve(Biomass, Muhammad)$

$$solution = \begin{pmatrix} 0.9999 \\ 1.0013 \end{pmatrix}$$

$a := solution_1$ $a = 0.9999$

$b := solution_2$ $b = 1,0013$

If it is known that,

$hf := hf_i$ $nf := nf_i$ $eregenrate := eregenrate_i$

The model equation can thus be written as

$$regenrate := 0.9999 \cdot hf + 1.0013 \cdot nf$$

4.3 DESERTIFICATION RATE

This is the difference between the biomass consumption rate and the biomass regeneration rate.

That is,

$$deserrate = bcrate - regenrate$$

and, since

$$bcrate = \left(5 \times 10^{-12} \cdot ck + 3 \cdot fur + 1 \cdot dis\right)$$

and

$$regenrate = (0.9999 \cdot hf + 1.0013 \cdot nf)$$

Then,

$$deserrate = (0.9999 \cdot hf + 1.0013 \cdot nf) - \left(5 \times 10^{-12} \cdot ck + 3 \cdot fur + 1 \cdot dis\right)$$

Thus, the predictive model for desertification is given as

$$deserrate = (0.9999 \cdot hf + 1.0013 \cdot nf) - \left(5 \times 10^{-12} \cdot ck + 3 \cdot fur + 1 \cdot dis\right)$$

4.2.2 SIMULATION OF MODEL EQUATION

The model equation is simulated using the MathCAD software and the simulated results are as

shown in the table below.

regenrate =

	1
1	0.444
2	0.397
3	0.397
4	0.397
5	0.397
6	0.397
7	0.397
8	0.397
9	0.397
10	0.397
11	0.397
12	0.397
13	0.397

4.1.3 CALCULATION OF ERRORS

The errors between the experimental and predicted values were also calculated with the MathCAD

software and the results are as shown in the table below.

Errors := eregenrate − regenrate

Errors =

	1
1	$3.503 \cdot 10^{-5}$
2	$-4.13 \cdot 10^{-6}$
3	$-4.13 \cdot 10^{-6}$
4	$-4.13 \cdot 10^{-6}$
5	$-4.13 \cdot 10^{-6}$
6	$-4.13 \cdot 10^{-6}$
7	$-4.13 \cdot 10^{-6}$
8	$-4.13 \cdot 10^{-6}$
9	$-4.13 \cdot 10^{-6}$
10	$-4.13 \cdot 10^{-6}$
11	$-4.13 \cdot 10^{-6}$
12	$-4.13 \cdot 10^{-6}$
13	$-4.13 \cdot 10^{-6}$

4.1.4 CALCULATION OF PERCENTAGE ERRORS

The percentage errors between the experimental and predicted values were also calculated with the

MathCAD software and the results are as shown in the table below.

$$\%Errors := \overrightarrow{\left(\frac{Errors}{eregenrate} \cdot 100\%\right)}$$

%Errors =

	1
1	$7.893 \cdot 10^{-3}$
2	$-1.041 \cdot 10^{-3}$
3	$-1.041 \cdot 10^{-3}$
4	$-1.041 \cdot 10^{-3}$
5	$-1.041 \cdot 10^{-3}$
6	$-1.041 \cdot 10^{-3}$
7	$-1.041 \cdot 10^{-3}$
8	$-1.041 \cdot 10^{-3}$
9	$-1.041 \cdot 10^{-3}$
10	$-1.041 \cdot 10^{-3}$
11	$-1.041 \cdot 10^{-3}$
12	$-1.041 \cdot 10^{-3}$
13	$-1.041 \cdot 10^{-3}$

%

DESERTIFICATION RATE

This is the difference between the biomass consumption rate and the biomass regeneration rate.

That is,

$$deserrate = bcrate - regenrate$$

and, since

$$bcrate = \left(5 \times 10^{-12} \cdot ck + 3 \cdot fur + 1 \cdot dis\right)$$

and

$$regenrate = (0.9999 \cdot hf + 1.0013 \cdot nf)$$

Then,

$$deserrate = \left(5 \times 10^{-12} \cdot ck + 3 \cdot fur + 1 \cdot dis\right) - (0.9999 \cdot hf + 1.0013 \cdot nf)$$

Projection by year December 2006 =

$(0.9999*62.8125+1.0013*6.4375)*24*12*30*223916=1.22*10^{11}$

Projection by the year Dec 2006= $(5*10^{-12} * 41.8750 +3* 20.9375 + 1* 6.4375) * 24 *12 * 30\ 223916 = 1.34* 10^{11}$

Area deserted will be = $1.34*10^{11} - 1.22*10^{11} = 1.4 *10^{11}$

Therefore, $223916 - 1.4*10^{11} = -1.4*10^{12}$

$-1.4*10^{12}$ = Area deserted by December 2006.

This modeling has also been used to project the area that will be deserted in Dec 2006.

Hence, to alert government to take appropriate measure in the middle belt region of Nigeria

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION OF RESULTS

5.1 RESULTS

5.1.1 Experimental Results

The results of this project are as outlined below.

Table 5.1 Experimental results

S/N	Cooking (kg/hr)	Furniture (kg/hr)	Disaster (kg/hr)	Experimental rate (kg/hr)
1	0.3750	0.1875	0.1042	0.6667
2	0.3750	0.1875	0.0417	0.6042
3	0.3750	0.1875	0.0417	0.6042
4	0.3750	0.1875	0.0417	0.6042
5	0.3750	0.1875	0.0417	0.6042
6	0.3750	0.1875	0.0417	0.6042
7	0.3750	0.1875	0.0417	0.6042
8	0.3750	0.1875	0.0417	0.6042
9	0.3750	0.1875	0.0417	0.6042
10	0.3750	0.1875	0.0417	0.6042
11	0.3750	0.1875	0.0417	0.6042
12	0.3750	0.1875	0.0417	0.6042
13	0.3750	0.1875	0.0417	0.6042
14	0.3750	0.1875	0.1042	0.6667
15	0.3750	0.1875	0.1042	0.6667
16	0.3750	0.1875	0.1042	0.6667
17	0.3750	0.1875	0.1042	0.6667
18	0.3750	0.1875	0.1042	0.6667
19	0.3750	0.1875	0.1042	0.6667

20	0.3750	0.1875	0.1042	0.6667
21	0.3750	0.1875	0.0417	0.6042
22	0.3750	0.1875	0.0417	0.6042
23	0.3750	0.1875	0.0417	0.6042
24	0.2500	0.125	0.1042	0.4792
25	0.3750	0.1875	0.1042	0.6667
26	0.3750	0.1875	0.0417	0.6042
27	0.3750	0.1875	0.1042	0.6667
28	0.3750	0.1875	0.0417	0.6042
29	0.3750	0.1875	0.1042	0.6667
30	0.3750	0.1875	0.0417	0.6042
31	0.3750	0.1875	0.1042	0.6667
32	0.3750	0.1875	0.1042	0.6667
33	0.3750	0.1875	0.1042	0.6667
34	0.3750	0.1875	0.1042	0.6667
35	0.3750	0.1875	0.0417	0.6042
36	0.3750	0.1875	0.0417	0.6042
37	0.3750	0.1875	0.0417	0.6042
38	0.2500	0.125	0.1042	0.4792
39	0.3750	0.1875	0.0417	0.6042
40	0.1250	0.0625	0.0417	0.2292
41	0.2500	0.125	0.0417	0.4167
42	0.3750	0.1875	0.0417	0.6042
43	0.1250	0.0625	0.0417	0.2292
44	0.3750	0.1875	0.0417	0.6042
45	0.3750	0.1875	0.0417	0.6042

46	0.3750	0.1875	0.0417	0.6042
47	0.3750	0.1875	0.0417	0.6042
48	0.3750	0.1875	0.0417	0.6042
49	0.3750	0.1875	0.0417	0.6042
50	0.2500	0.125	0.0417	0.4167
51	0.2500	0.125	0.0417	0.4167
52	0.3750	0.1875	0.0417	0.6042
53	0.2500	0.125	0.0417	0.4167
54	0.2500	0.125	0.0417	0.4167
55	0.3750	0.1875	0.0417	0.6042
56	0.3750	0.1875	0.0417	0.6042
57	0.3750	0.1875	0.0417	0.6042
58	0.3750	0.1875	0.0417	0.6042
59	0.3750	0.1875	0.0417	0.6042
60	0.3750	0.1875	0.0417	0.6042
61	0.3750	0.1875	0.0417	0.6042
62	0.3750	0.1875	0.0417	0.6042
63	0.3750	0.1875	0.0417	0.6042
64	0.3750	0.1875	0.0417	0.6042
65	0.3750	0.1875	0.0417	0.6042
66	0.3750	0.1875	0.0417	0.6042
67	0.3750	0.1875	0.0417	0.6042
68	0.3750	0.1875	0.0417	0.6042
69	0.3750	0.1875	0.0417	0.6042
70	0.3750	0.1875	0.0417	0.6042
71	0.3750	0.1875	0.0417	0.6042

72	0.3750	0.1875	0.0417	0.6042
73	0.3750	0.1875	0.0417	0.6042
74	0.3750	0.1875	0.0417	0.6042
75	0.3750	0.1875	0.0417	0.6042
76	0.3750	0.1875	0.0417	0.6042
77	0.3750	0.1875	0.0417	0.6042
78	0.3750	0.1875	0.0417	0.6042
79	0.3750	0.1875	0.0417	0.6042
80	0.3750	0.1875	0.0417	0.6042
81	0.3750	0.1875	0.1042	0.6667
82	0.3750	0.1875	0.0417	0.6042
83	0.3750	0.1875	0.0417	0.6042
84	0.3750	0.1875	0.0417	0.6042
85	0.3750	0.1875	0.0417	0.6042
86	0.2500	0.125	0.0417	0.4167
87	0.3750	0.1875	0.0417	0.6042
88	0.1250	0.0625	0.1042	0.2917
89	0.3750	0.1875	0.1042	0.6667
90	0.3750	0.1875	0.1042	0.6667
91	0.3750	0.1875	0.0417	0.6042
92	0.3750	0.1875	0.1042	0.6667
93	0.3750	0.1875	0.0417	0.6042
94	0.3750	0.1875	0.0417	0.6042
95	0.3750	0.1875	0.0417	0.6042
96	0.3750	0.1875	0.0417	0.6042
97	0.3750	0.1875	0.0417	0.6042

98	0.3750	0.1875	0.0417	0.6042
99	0.3750	0.1875	0.0417	0.6042
100	0.3750	0.1875	0.1042	0.6667
101	0.2500	0.125	0.0417	0.4167
102	0.3750	0.1875	0.0417	0.6042
103	0.3750	0.1875	0.0417	0.6042
104	0.3750	0.1875	0.0417	0.6042
105	0.3750	0.1875	0.0417	0.6042
106	0.3750	0.1875	0.0417	0.6042
107	0.2500	0.125	0.0417	0.4167
108	0.3750	0.1875	0.0417	0.6042
109	0.3750	0.1875	0.0417	0.6042
110	0.3750	0.1875	0.0417	0.6042
111	0.2500	0.125	0.0417	0.4167
112	0.3750	0.1875	0.0417	0.6042
113	0.1250	0.0625	0.0417	0.2292
114	0.1250	0.0625	0.0417	0.2292
115	0.1250	0.0625	0.0417	0.2292
116	0.3750	0.1875	0.0417	0.6042
117	0.3750	0.1875	0.0417	0.6042
118	0.3750	0.1875	0.0417	0.6042
119	0.3750	0.1875	0.0417	0.6042
120	0.1250	0.0625	0.0417	0.2292

5.1.2 Simulated Results

Table 5.2 Simulated results

S/N	Cooking (kg/hr)	Furniture (kg/hr)	Disaster (kg/hr)	Simulated rate (kg/hr)
1	0.3750	0.1875	0.1042	0.6667
2	0.3750	0.1875	0.0417	0.6042
3	0.3750	0.1875	0.0417	0.6042
4	0.3750	0.1875	0.0417	0.6042
5	0.3750	0.1875	0.0417	0.6042
6	0.3750	0.1875	0.0417	0.6042
7	0.3750	0.1875	0.0417	0.6042
8	0.3750	0.1875	0.0417	0.6042
9	0.3750	0.1875	0.0417	0.6042
10	0.3750	0.1875	0.0417	0.6042
11	0.3750	0.1875	0.0417	0.6042
12	0.3750	0.1875	0.0417	0.6042
13	0.3750	0.1875	0.0417	0.6042
14	0.3750	0.1875	0.1042	0.6667
15	0.3750	0.1875	0.1042	0.6667
16	0.3750	0.1875	0.1042	0.6667
17	0.3750	0.1875	0.1042	0.6667
18	0.3750	0.1875	0.1042	0.6667
19	0.3750	0.1875	0.1042	0.6667
20	0.3750	0.1875	0.1042	0.6667
21	0.3750	0.1875	0.0417	0.6042
22	0.3750	0.1875	0.0417	0.6042
23	0.3750	0.1875	0.0417	0.6042

24	0.2500	0.125	0.1042	0.4792
25	0.3750	0.1875	0.1042	0.6667
26	0.3750	0.1875	0.0417	0.6042
27	0.3750	0.1875	0.1042	0.6667
28	0.3750	0.1875	0.0417	0.6042
29	0.3750	0.1875	0.1042	0.6667
30	0.3750	0.1875	0.0417	0.6042
31	0.3750	0.1875	0.1042	0.6667
32	0.3750	0.1875	0.1042	0.6667
33	0.3750	0.1875	0.1042	0.6667
34	0.3750	0.1875	0.1042	0.6667
35	0.3750	0.1875	0.0417	0.6042
36	0.3750	0.1875	0.0417	0.6042
37	0.3750	0.1875	0.0417	0.6042
38	0.2500	0.125	0.1042	0.4792
39	0.3750	0.1875	0.0417	0.6042
40	0.1250	0.0625	0.0417	0.2292
41	0.2500	0.125	0.0417	0.4167
42	0.3750	0.1875	0.0417	0.6042
43	0.1250	0.0625	0.0417	0.2292
44	0.3750	0.1875	0.0417	0.6042
45	0.3750	0.1875	0.0417	0.6042
46	0.3750	0.1875	0.0417	0.6042
47	0.3750	0.1875	0.0417	0.6042
48	0.3750	0.1875	0.0417	0.6042
49	0.3750	0.1875	0.0417	0.6042

50	0.2500	0.125	0.0417	0.4167
51	0.2500	0.125	0.0417	0.4167
52	0.3750	0.1875	0.0417	0.6042
53	0.2500	0.125	0.0417	0.4167
54	0.2500	0.125	0.0417	0.4167
55	0.3750	0.1875	0.0417	0.6042
56	0.3750	0.1875	0.0417	0.6042
57	0.3750	0.1875	0.0417	0.6042
58	0.3750	0.1875	0.0417	0.6042
59	0.3750	0.1875	0.0417	0.6042
60	0.3750	0.1875	0.0417	0.6042
61	0.3750	0.1875	0.0417	0.6042
62	0.3750	0.1875	0.0417	0.6042
63	0.3750	0.1875	0.0417	0.6042
64	0.3750	0.1875	0.0417	0.6042
65	0.3750	0.1875	0.0417	0.6042
66	0.3750	0.1875	0.0417	0.6042
67	0.3750	0.1875	0.0417	0.6042
68	0.3750	0.1875	0.0417	0.6042
69	0.3750	0.1875	0.0417	0.6042
70	0.3750	0.1875	0.0417	0.6042
71	0.3750	0.1875	0.0417	0.6042
72	0.3750	0.1875	0.0417	0.6042
73	0.3750	0.1875	0.0417	0.6042
74	0.3750	0.1875	0.0417	0.6042
75	0.3750	0.1875	0.0417	0.6042

76	0.3750	0.1875	0.0417	0.6042
77	0.3750	0.1875	0.0417	0.6042
78	0.3750	0.1875	0.0417	0.6042
79	0.3750	0.1875	0.0417	0.6042
80	0.3750	0.1875	0.0417	0.6042
81	0.3750	0.1875	0.1042	0.6667
82	0.3750	0.1875	0.0417	0.6042
83	0.3750	0.1875	0.0417	0.6042
84	0.3750	0.1875	0.0417	0.6042
85	0.3750	0.1875	0.0417	0.6042
86	0.2500	0.125	0.0417	0.4167
87	0.3750	0.1875	0.0417	0.6042
88	0.1250	0.0625	0.1042	0.2917
89	0.3750	0.1875	0.1042	0.6667
90	0.3750	0.1875	0.1042	0.6667
91	0.3750	0.1875	0.0417	0.6042
92	0.3750	0.1875	0.1042	0.6667
93	0.3750	0.1875	0.0417	0.6042
94	0.3750	0.1875	0.0417	0.6042
95	0.3750	0.1875	0.0417	0.6042
96	0.3750	0.1875	0.0417	0.6042
97	0.3750	0.1875	0.0417	0.6042
98	0.3750	0.1875	0.0417	0.6042
99	0.3750	0.1875	0.0417	0.6042
100	0.3750	0.1875	0.1042	0.6667
101	0.2500	0.125	0.0417	0.4167

102	0.3750	0.1875	0.0417	0.6042
103	0.3750	0.1875	0.0417	0.6042
104	0.3750	0.1875	0.0417	0.6042
105	0.3750	0.1875	0.0417	0.6042
106	0.3750	0.1875	0.0417	0.6042
107	0.2500	0.125	0.0417	0.4167
108	0.3750	0.1875	0.0417	0.6042
109	0.3750	0.1875	0.0417	0.6042
110	0.3750	0.1875	0.0417	0.6042
111	0.2500	0.125	0.0417	0.4167
112	0.3750	0.1875	0.0417	0.6042
113	0.1250	0.0625	0.0417	0.2292
114	0.1250	0.0625	0.0417	0.2292
115	0.1250	0.0625	0.0417	0.2292
116	0.3750	0.1875	0.0417	0.6042
117	0.3750	0.1875	0.0417	0.6042
118	0.3750	0.1875	0.0417	0.6042
119	0.3750	0.1875	0.0417	0.6042
120	0.1250	0.0625	0.0417	0.2292

5.1.3 Experimental and Simulated Results

Table 5.3 Comparison between the experimental and simulated results

S/N	Experimental rate (kg/hr)	Simulated rate (kg/hr)	Errors (kg/hr)
1	0.666666666666667	0.666666666668542	-0.000000000001875
2	0.604166666666667	0.604166666668542	-0.000000000001875
3	0.604166666666667	0.604166666668542	-0.000000000001875
4	0.604166666666667	0.604166666668542	-0.000000000001875
5	0.604166666666667	0.604166666668542	-0.000000000001875
6	0.604166666666667	0.604166666668542	-0.000000000001875
7	0.604166666666667	0.604166666668542	-0.000000000001875
8	0.604166666666667	0.604166666668542	-0.000000000001875
9	0.604166666666667	0.604166666668542	-0.000000000001875
10	0.604166666666667	0.604166666668542	-0.000000000001875
11	0.604166666666667	0.604166666668542	-0.000000000001875
12	0.604166666666667	0.604166666668542	-0.000000000001875
13	0.604166666666667	0.604166666668542	-0.000000000001875
14	0.666666666666667	0.666666666668542	-0.000000000001875
15	0.666666666666667	0.666666666668542	-0.000000000001875
16	0.666666666666667	0.666666666668542	-0.000000000001875
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20	0.666666666666667	0.666666666668542	-0.000000000001875
21	0.604166666666667	0.604166666668542	-0.000000000001875
22	0.604166666666667	0.604166666668542	-0.000000000001875
23	0.604166666666667	0.604166666668542	-0.000000000001875

24	0.479166666666667	0.479166666667917	-0.000000000001250
25	0.666666666666667	0.666666666668542	-0.000000000001875
26	0.604166666666667	0.604166666668542	-0.000000000001875
27	0.666666666666667	0.666666666668542	-0.000000000001875
28	0.604166666666667	0.604166666668542	-0.000000000001875
29	0.666666666666667	0.666666666668542	-0.000000000001875
30	0.604166666666667	0.604166666668542	-0.000000000001875
31	0.666666666666667	0.666666666668542	-0.000000000001875
32	0.666666666666667	0.666666666668542	-0.000000000001875
33	0.666666666666667	0.666666666668542	-0.000000000001875
34	0.666666666666667	0.666666666668542	-0.000000000001875
35	0.604166666666667	0.604166666668542	-0.000000000001875
36	0.604166666666667	0.604166666668542	-0.000000000001875
37	0.604166666666667	0.604166666668542	-0.000000000001875
38	0.479166666666667	0.479166666667917	-0.000000000001250
39	0.604166666666667	0.604166666668542	-0.000000000001875
40	0.229166666666667	0.229166666667292	-0.000000000000625
41	0.416666666666667	0.416666666667917	-0.000000000001250
42	0.604166666666667	0.604166666668542	-0.000000000001875
43	0.229166666666667	0.229166666667292	-0.000000000000625
44	0.604166666666667	0.604166666668542	-0.000000000001875
45	0.604166666666667	0.604166666668542	-0.000000000001875
46	0.604166666666667	0.604166666668542	-0.000000000001875
47	0.604166666666667	0.604166666668542	-0.000000000001875
48	0.604166666666667	0.604166666668542	-0.000000000001875
49	0.604166666666667	0.604166666668542	-0.000000000001875

50	0.416666666666667	0.416666666667917	-0.000000000001250
51	0.416666666666667	0.416666666667917	-0.000000000001250
52	0.604166666666667	0.604166666668542	-0.000000000001875
53	0.416666666666667	0.416666666667917	-0.000000000001250
54	0.416666666666667	0.416666666667917	-0.000000000001250
55	0.604166666666667	0.604166666668542	-0.000000000001875
56	0.604166666666667	0.604166666668542	-0.000000000001875
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63	0.604166666666667	0.604166666668542	-0.000000000001875
64	0.604166666666667	0.604166666668542	-0.000000000001875
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67	0.604166666666667	0.604166666668542	-0.000000000001875
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73	0.604166666666667	0.604166666668542	-0.000000000001875
74	0.604166666666667	0.604166666668542	-0.000000000001875
75	0.604166666666667	0.604166666668542	-0.000000000001875

76	0.604166666666667	0.604166666668542	-0.000000000001875
77	0.604166666666667	0.604166666668542	-0.000000000001875
78	0.604166666666667	0.604166666668542	-0.000000000001875
79	0.604166666666667	0.604166666668542	-0.000000000001875
80	0.604166666666667	0.604166666668542	-0.000000000001875
81	0.666666666666667	0.666666666668542	-0.000000000001875
82	0.604166666666667	0.604166666668542	-0.000000000001875
83	0.604166666666667	0.604166666668542	-0.000000000001875
84	0.604166666666667	0.604166666668542	-0.000000000001875
85	0.604166666666667	0.604166666668542	-0.000000000001875
86	0.416666666666667	0.416666666667917	-0.000000000001250
87	0.604166666666667	0.604166666668542	-0.000000000001875
88	0.291666666666667	0.291666666667292	-0.000000000000625
89	0.666666666666667	0.666666666668542	-0.000000000001875
90	0.666666666666667	0.666666666668542	-0.000000000001875
91	0.604166666666667	0.604166666668542	-0.000000000001875
92	0.666666666666667	0.666666666668542	-0.000000000001875
93	0.604166666666667	0.604166666668542	-0.000000000001875
94	0.604166666666667	0.604166666668542	-0.000000000001875
95	0.604166666666667	0.604166666668542	-0.000000000001875
96	0.604166666666667	0.604166666668542	-0.000000000001875
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98	0.604166666666667	0.604166666668542	-0.000000000001875
99	0.604166666666667	0.604166666668542	-0.000000000001875
100	0.666666666666667	0.666666666668542	-0.000000000001875
101	0.416666666666667	0.416666666667917	-0.000000000001250

102	0.604166666666667	0.604166666668542	-0.000000000001875
103	0.604166666666667	0.604166666668542	-0.000000000001875
104	0.604166666666667	0.604166666668542	-0.000000000001875
105	0.604166666666667	0.604166666668542	-0.000000000001875
106	0.604166666666667	0.604166666668542	-0.000000000001875
107	0.416666666666667	0.416666666667917	-0.000000000001250
108	0.604166666666667	0.604166666668542	-0.000000000001875
109	0.604166666666667	0.604166666668542	-0.000000000001875
110	0.604166666666667	0.604166666668542	-0.000000000001875
111	0.416666666666667	0.416666666667917	-0.000000000001250
112	0.604166666666667	0.604166666668542	-0.000000000001875
113	0.229166666666667	0.229166666667292	-0.000000000000625
114	0.229166666666667	0.229166666667292	-0.000000000000625
115	0.229166666666667	0.229166666667292	-0.000000000000625
116	0.604166666666667	0.604166666668542	-0.000000000001875
117	0.604166666666667	0.604166666668542	-0.000000000001875
118	0.604166666666667	0.604166666668542	-0.000000000001875
119	0.604166666666667	0.604166666668542	-0.000000000001875
120	0.229166666666667	0.229166666667292	-0.000000000000625

5.2 Discussion of Results

The data used for this modelling were obtained from the questionnaires in which the factors influencing biomass consumption process were outlined for the people to respond to in the states of the middle belt of Nigeria.

As said earlier, the questionnaires were shared among the people of the seven states in the middle belt region of Nigeria, which comprises of Niger, Kogi, Abuja, Plateau, Benue and Nasarawa States. At the end of successful filling of the questionnaire, only 120questionnaire were recovered from 140 questionnaires.

From the results of the questionnaires, it was discovered that the factors influencing the biomass consumption rate in the middle belt region of Nigeria are cooking, furniture and natural disaster while that responsible for biomass regeneration are natural germination of plant and tree planted by human beings.

After obtaining the data from the questionnaire; the total human consumption rate per hour was added to the total natural consumption rate per hour to obtain, the total consumption rate used in the proposed modelling which is empirical method of the least square

The biomass consumption rate is written as

$$bcrate = f(ck, fur, dis)$$

while biomass regeneration rate is written as

$$regenrate = (hf, nf)$$

and the expression is further written as

$$bcrate = f(a \cdot ck + b \cdot fur + c \cdot dis)$$

and regeneration is given as

$$regenrate = (a \cdot hf + b \cdot nf)$$

The biomass consumed by cooking, furniture and natural disaster is denoted by ck, fur and dis respectively, where the biomass consumption rate is the dependent variable and ck, fur and dis are the independent variables for the biomass consumption. Further, the coefficients a, b and c were determined to be given in matrix form as

$$\begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} 5 \times 10^{-12} \\ 3 \\ 1 \end{pmatrix}$$

Now, fixing the coefficients gave the model equation for the biomass consumption rate to be

$$bcrate := 5 \times 10^{-12} \cdot ck + 3 \cdot fur + 1 \cdot dis$$

The model equation obtained was simulated and the results are as presented in Table 5.2.

The comparisons between the experimental and simulated results are shown in Table 5.3. It could be observed from the table that the results are in good agreement with each other.

In an attempt to further determine the concord between the experimental and simulated results, the errors between the experimental and simulated results were both calculated to be in the order of exponential -12. The results of the errors revealed that there is very insignificant errors between the experimental and simulated results between the errors are in the order of 10^{-12} while the percentage errors are in the order of 10^{-10}.

Having obtained a model equation for the biomass consumption rate, it is necessary to obtain another equation for the biomass regeneration rate. The equation for the biomass regeneration was also obtained using the same empirical method of the least square and the equation is given as

$$regenrate = (0.9999 \cdot hf + 1.0013 \cdot nf)$$

The difference between the biomass regeneration rate and biomass consumption rate gave the desertification in terms of a model to be

$$deserrate = (0.9999 \cdot hf + 1.0013 \cdot nf) - (5 \times 10^{-12} \cdot ck + 3 \cdot fur + 1 \cdot dis)$$

In conclusion, considering the range of the errors between the experimental and simulated biomass consumption rate, it was clear that the equation modelled for the biomass consumption rate which is given as

$$\text{bcrate} := 5 \times 10^{-12} \cdot \text{ck} + 3 \cdot \text{fur} + 1 \cdot \text{dis}$$

can be used to predict the biomass consumption rate as well as desertification rate in the middle belt of Nigeria.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The model equation for biomass consumption rate in the middle belt of Nigeria is given as

$$\text{bcrate} := 5 \times 10^{-12} \cdot ck + 3 \cdot fur + 1 \cdot dis$$

While that of the desertification rate is given as

$$\text{deserrate} = (0.9999 \cdot hf + 1.0013 \cdot nf) - \left(5 \times 10^{-12} \cdot ck + 3 \cdot fur + 1 \cdot dis\right)$$

Considering the insignificant errors between the experimental and simulated biomass consumption rate, it is concluded that the model equation can be used to predict the rate of biomass consumption in the middle belt of Nigeria.

6.2 Recommendation

It is recommended that a model equation should be obtained (modelled) for the biomass consumption rate in the northern part of Nigeria so that the rate of biomass consumption in the middle belt of Nigeria can be compared with that of the northern part of the country.

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APPENDICES

APPENDIX A:

A1 Questionnaire

A sample of the questionnaire used for this project is shown below:

DEPARTMENT OF CHEMICAL ENGINEERING

SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE

RESEARCH QUESTIONNAIRE

I am a student of the above named institution wishing to carry out a research work on the "Development of a Predictive Model on Sustainable Biomass Consumption Process, a Case Study of Nigeria Middle Belt".

Please kindly respond to the questions given below to enable the researcher embark on this research work. I assure you that every information given will be treated confidentially, as the research work is strictly academics.

Tick ✓ where appropriate.

Section A: Bio Data

(1) Name: ______________________________ Locality: ______________

(2) Marital Status: i. Single [ ] ii. Married [ ]

(3) Educational Qualification:

i. Primary [ ] ii. Secondary [ ] iii. Adult Education [ ]

iv. Others [ ]

Section B:

(4) Occupation i. Farming ☐ ii. Civil servant ☐

iii. Business man/woman ☐

(5) What are your main sources of fuel for domestic cooking/heating?

i. Wood ☐ ii. Gas cooker ☐ iii. Electricity ☐

(6) How often do you use wood for cooking daily?

i. Once ☐ ii. Twice ☐ iii. Thrice ☐

(7) What is the estimated percentage of your furniture that are made from wood?

20% ☐ 50% ☐ 80% ☐ 100% ☐

(8) How often do you experience natural disaster that result into cutting or felling of trees in a year? i. Once ☐ ii. Twice ☐ iii. Thrice ☐

(9) What is the estimated number of trees in tonnes that are brought down by the disaster? Between 10 – 50 tonnes ☐ Between 50 – 100 tonnes ☐

Section C:

If you are a farmer, please fill this section.

(10) How often do you plant trees in your locality per year?

Every month ☐ Every year ☐ None ☐

(11) Do you burn agricultural waste?

Yes ☐ No ☐

(12) Do you allow your agricultural waste to decompose naturally?

Yes ☐ No ☐

Section D:

If you are a civil servant and others, please fill this section.

(13) What are the factors affecting the area as a result of cutting down of the trees?

i.

ii.

iii.

iv.

v.

(14) Did the consumption of wood as a source of fuel affects your soil fertility?

Yes ☐ No ☐

(15) Did the cutting down of trees causes natural disasters in your areas?

Yes ☐ No ☐

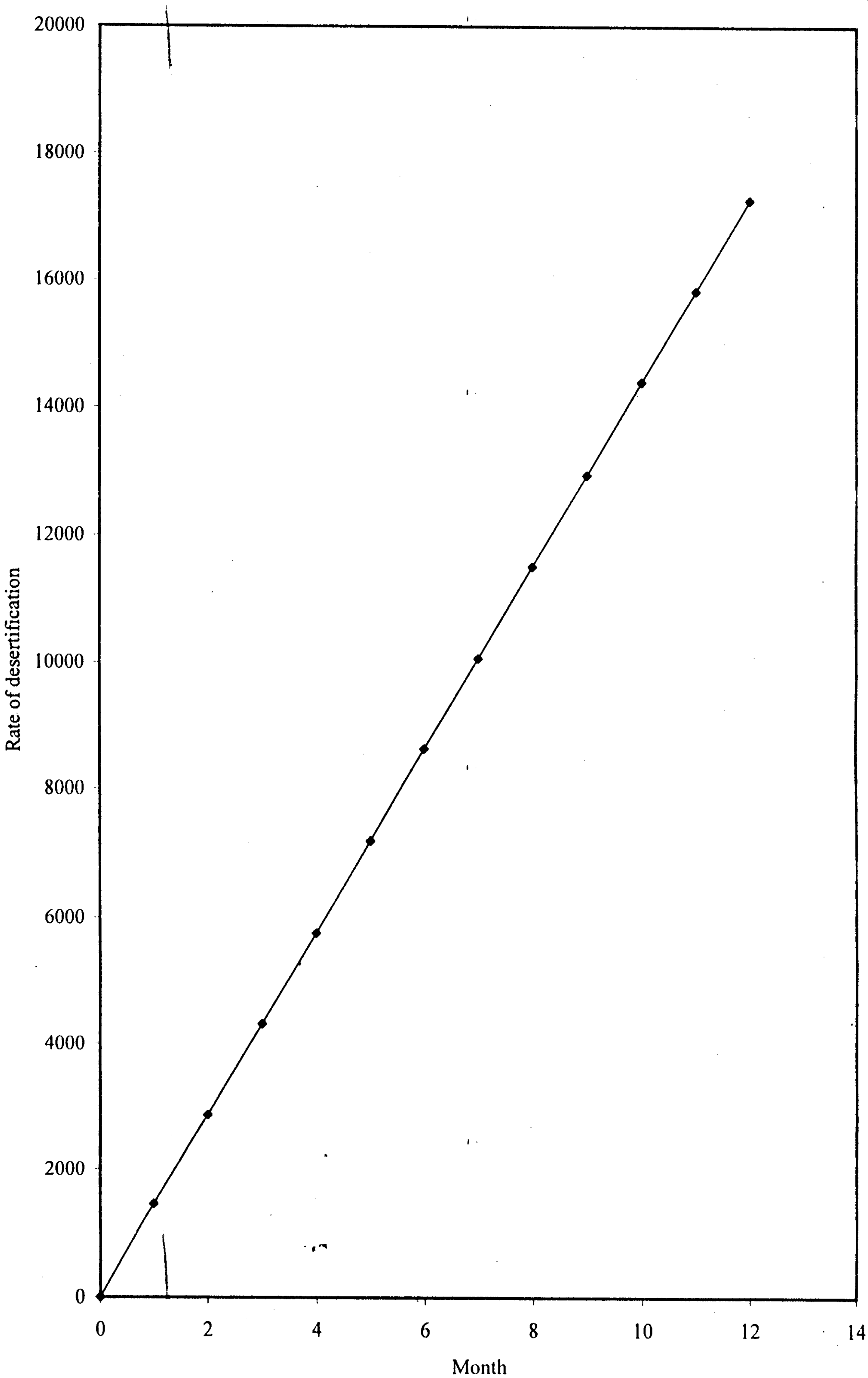

Fig. A1: Plot of desertification rate against month