Determination of Hydrogen Content of Petroleum Products from Tema Oil Refinery Using Neutron Backscatter Technique

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DECLARATION

This thesis is the result of research work undertaken by Abdallah Suhuyini Salifu in the Department of Nuclear Engineering, School of Nuclear and Allied Sciences, University of Ghana, under the supervision of Dr. C. P. K. Dagadu and Dr. K. A. Danso.

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DEDICATION

I dedicate this thesis to **My Family** for their exceptional effort to support me throughout my studies at School of Nuclear and Allied Sciences.

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I am thankful to Almighty Allah for giving me the strength and power to take up this study.

My sincere gratitude goes to my supervisors, Dr. K. A. Danso and Dr. C. P. K. Dagadu for their patience, encouragement, invaluable advice and kind supervision.

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LIST OF ABBREVIATIONS

ALARA	As Low As Reasonable Achievable
API	American Petroleum Institute
ATK	Aviation Turbine Kerosene
BSS	Basic Safety Standard
CDU	Crude Distillation Unit
Ci^{241}Am-Be	1 curies of Americium-Beryllium Source
DGNAA	Delay Gamma-ray Neutron Activation Analysis
GAEC	Ghana Atomic Energy Commission
GNPC	Ghana National Petroleum Co-operation
GSNAS	Graduate School of Nuclear Allied and Sciences
IAEA	International Atomic Energy Commission
IEA	International Energy Agency
LPG	Liquefied Petroleum Gas
NAA	Neutron Activation Analysis
NBT	Neutron Backscatter Technique
NMR	Nuclear Magnetic Resonance
PFNA	Pulse Fast Neutron Activation
PGNAA	Prompt Gamma-ray Neutron Activation Analysis
RFCC	Residual Fluid Catalytic Cracker
RVP	Reid Vapour Pressure
THR	Threshold
TLD	Thermo- Luminescent Detector

TNA	Thermal Neutron Activation
TOR	Tema Oil Refinery
TVP	True Vapour Pressure

LIST OF SYMBOLS

H	Hydrogen
O	Oxygen
C	Carbon
Al	Aluminum
He-3	Helium-3
N-14	Nitrogen-14
NaI(T)	Thallium Doped Sodium Iodide
Eo	Energy of the incident neutron
M	Mass of the incident neutron
m	Mass of the scattering nucleus
E	Energy of the scattered neutron after a head-on collision
I_0	Specific activities of thermal neutrons induced in a detector without sample
I	Specific activities of thermal neutrons induced in a detector with sample
A	Mass number of a target nucleus
MeV	Mega electron volts
eV	Electron volts
I_{0h}	Average count for horizontal geometry of empty container
I_{0v}	Average count for vertical geometry of empty container
ρ (g/cm^3)	physical density of the petroleum sample
μ (cm^3/g)	Reflection parameter
μ_v	Vertical geometrical arrangement
μ_h	Horizontal geometrical arrangement
H (w %)	Percentage of hydrogen content of standard hydrocarbons
h (w %)	Percentage of hydrogen content of petroleum samples
(% E)	Percentage error

ABSTRACT

The hydrogen content of hydrocarbon materials is very important in several areas of industrial process such as mining, vegetable oil extraction and crude oil exploration and refining. A fast and more universal technique based on thermal neutron reflection was employed to determine the total hydrogen contents of petroleum samples from Tema Oil Refinery (TOR) and Crude oil samples from Jubilee field and Nigeria. The experimental set-up consisted of a source-holder housing a 1Ci Am-Be neutron source and a He-3 neutron detector. Two geometrical arrangements were considered and their sensitivities were compared. The set-up was used to measure the excess neutron count in both geometrical considerations and their reflection parameters were calculated as a function of hydrogen content of the samples. Calibration lines were deduced using liquid hydrocarbons containing well-known hydrogen and carbon contents as standards. Two linear equations were generated from the calibration lines and were used to further determine the hydrogen content of thirteen (13) petroleum samples obtained from Quality Control Department of TOR. The total hydrogen contents were found to be in the range of 7.211(hw %) - 15.069 (hw %) for vertical geometry and 7.206 (hw %) - 14.948 (hw %) for horizontal geometry respectively. The results obtained agreed constructively with other results obtained using different methodologies by other studies. The percentage error of the hydrogen contents denoted by (% E) for the various petroleum samples were also obtained and noticed to be within an acceptable range.

The neutron backscatter technique was observed as an alternative and more generalized method for quality assurance and standardization in the petroleum industries.

CHAPTER ONE

INTRODUCTION

1.1 Background of Research

Fossil fuel – based hydrocarbons are primary energy source for present civilizations, which nowadays accounts for 83 % of global energy demand and the tendency is forecasted to continue, Pratap, 2013. However, the quality of feed stock and crude slate is considerably deteriorating. Hence becoming heavier and sourer which have an effect on the development of energy efficiency, high cost technologies for refinery separation units, poor finish product quality and general production schemes, Lepourtre, 2008.

Crude oil and natural gas with high content of sulfur compounds have low hydrogen content and demand complex, capital intensive processes at all stages of production and handling, from upstream, midstream to downstream segments of petroleum industry.

In refinery process, percentage of hydrogen content at the endpoint is used as one of the specifications that need to be met and therefore considered as an important indicator and a major cost concern in refinery operations, Ante Jukic**,** 2013.

An accurate and faster analytical technique is therefore essential in order to monitor and enhance conformity to authorize specifications in the petroleum industry in particular.

The name Petroleum covers both naturally occurring unprocessed crude oils and refined petroleum products. It is a naturally occurring flammable liquid consisting of a complex mixture of hydrocarbons of various molecular weights and small amounts of sulfur, oxygen and nitrogen as well as compounds with metallic constituents, particularly vanadium, nickel, and sodium that are found in geological formations beneath the Earth's surface, Ante Jukic**,** 2013.

Petroleum products are obtained when crude oil is process in an oil refinery. The majority of crude oil is converted in to finish petroleum products, such as kerosene, petrol (gasoline), diesel (gas oil), light naphtha, heavy naphtha etc.

This research work focuses on thirteen (13) samples of petroleum products obtained from Tema Oil Refinery (TOR).

A petroleum refinery is a highly organized processing plant, which consists of many physical and chemical processes designed to covert crude oil in to finished products with required qualities and volumes demanded by the market. It involves the separation of crude oil in to fractions and subsequently treating of them in to petroleum products, Bland W. F. and Davidson M., 1974.

There are two major methods of processing crude oil, these are physical process method and chemical process method. The physical processes (electromagnetism, distillation etc.) involve the separation of substances based on physical properties such as density, particle size, boiling point, temperature, etc. In the petroleum industry, distillation is the separation of crude oil into simple useful products. In chemical processes method, chemical bonds are broken down with the formation of new bonds. Pyrolysis is a chemical process for producing ethylene, Forster Wheeler Corporation, 1974.

Depending on the type of crude oil used, the refineries may have to include one or more hydrogen process plant. Hydro treating and hydrocracking decrease the molecular weights, increase the hydrogen content and remove metals, sulfur, nitrogen and oxygen-containing compounds, Meyers R., 1997.

1.2 Research Problem Statement

In the petroleum process industry, hydrogen content is among the most important characteristics of crude oil and natural gas. The International Energy Agency (IEA) estimates that ~70 % of the world's remaining oil reserves consist of heavy, low hydrogen and high sulfur crude, EIA, 2013. The crude oil from recent oil fields tends to have high sulfur and low hydrogen content. Crude oil of low sulfur and high hydrogen content (sweet crude) is more preferred by refineries as it is safer to extract, easier to refine and also causes less damage, lower maintenance cost over time, FSU, 2010. There is a correlation (even though weak) between the quality of petroleum product and its hydrogen content. The presence or the addition of hydrogen in petroleum products removes about 90 % of undesirable contaminants including nitrogen, sulfur, oxygen, metals, and unsaturated hydrocarbons (olefins) from liquid petroleum fractions. Thus, the increase in hydrogen demand over past decades is as a result of the increase in heavy sulfur crude refining and more strict quality requirements for fuels and feedstock for catalytic process, Speight, 2007. Knowledge of hydrogen contents of petroleum products has therefore become necessary for the determination of the followings:

- High yield of finished product.
- Knowledge of crude oil brand.
- Efficiency of Plant operations.
- Quality control and standardization of petroleum products.

However, there is no generalized method of determining quality and standard of petroleum products in the petroleum and petro-chemical industries. The chemical methods been used by the industries are not only destructive and product specific, but sometimes, requires several hours of samples heating at high temperatures up to about 700 °C in the refineries in particular.

There is therefore the need for an alternative method which is more general and requires less time and independent on temperature.

1.3 Research Objective

Main aim objective of this study is to:

Determine hydrogen content of petroleum products using neutron backscatter technique as an alternative method.

1.4 Specific Objectives

The objectives of the research are to:

- To determine hydrogen content of finished and unfinished petroleum products from Tema Oil Refinery (TOR).
- To determine hydrogen content of commercial crude oil samples from Ghana (Jubilee field) and Nigeria.
- Compare results with already known laboratory methods and other results obtained from previous studies.

1.5 Research Relevance and Justification

The method could be used for the following purposes:

- To check finished petroleum products adulteration.
- To provide faster means of quality control and standardization of petroleum products.

1.6 Scope of Research

The scope of the research work involved the determination of hydrogen content of petroleum products from TOR, commercial crude oil samples from Ghana and Nigeria using neutron backscatter technique.

Total of (13) different types of petroleum products will be considered for this study.

Data of known hydrocarbon compounds and its chemical formulae with relevant densities (g/cm^3) shall be considered for calibration curves for determination of hydrogen contents for vertical and horizontal geometrical arrangements

Recommendations and suggestions for further research would also be presented

1.7 Outline of the Thesis

The objective of this thesis is to determine the hydrogen content of petroleum products using neutron backscatter technique as an alternative method.

This fundamental goal will be divided into subsidiary objectives, which will be covered as separate chapters within the thesis.

The theoretical background to this work is discussed in chapter 2. This will include the study of fundamental of radiation interactions with matter, review of related previous studies. Laboratory Method for Determining of Petroleum Quality will also be discussed. This chapter will also discuss Composition of Petroleum (Crude Oil) and Radiation safety considerations in Neutron Backscatter applications.

Chapter 3 will describes methodology adopted for the experimental set-up, sample collection and preparation of various petroleum products from Tema Oil Refinery plants (RFCC, CDU) and some crude oil samples from Ghana and Nigeria. Instrument used and its calibrations will also be considered, the radioactive source (1Ci^{241}Am-Be) and its respective detector used will be discuss.

Chapter 4 will focus on the results of the study. This will include calibration lines deduced using liquid hydrocarbons containing well-known hydrogen and carbon contents as standards in order to measured reflection parameter ($\boldsymbol{\mu}$) for different hydrogen (H) content in the various standard liquid hydrocarbons for vertical and horizontal geometry arrangements. Also, measured average counts and the reflection parameters of the samples for the vertical and horizontal geometrical arrangements will be obtained and the results will be provided on tables and graphs plotted respectively. The percentage error (% E), for all geometries will also be calculated using an appropriate formulae. The experimental results will be validated using other methods employed by previous studies. Finally, Chapter 5 will contain summary of the main findings of the research and also discuss some economic potentials and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The study of the fundamental of radiation interactions with matter has become an interesting developing research area in the petroleum industry. An understanding of total hydrogen content of petroleum products using Neutron Backscatter technique which was developed by Buczko M., et. al., 1979 can therefore, not be under estimated.

The recent discovery of crude oil in commercial quantities in Ghana has evoke a growing interest of research works in the petroleum industry. Hence, a research work to determine the hydrogen/moisture contents of petroleum products is necessary for Quality Assurance and Standardization of petroleum products in Ghana.

Currently, there is no generalized method of determining quality and standard of petroleum products in Tema Oil Refinery and other petro-chemical industries in Ghana. The chemical methods been employed by the petroleum industries are not only destructive and product specific, but also involves more than one method which often requires several hours of heating the samples at high temperatures up to 75 0℃ to obtain results, (Quality Control Department, TOR).

An alternative method based on neutron reflection which is more general, non-destructive and does not require long hours of heating is therefore indispensable.

Neutron Backscattering Technique (NBT) is based on the fact that petroleum products are hydrogen-rich and therefore when exposed to a fast neutron source, the number of backscattered thermal neutrons produced by the moderation process will give an indication from which the presence of high or low hydrogen content can be deduced, Semel S. and Helf S., 1969.

This thesis presents an investigation based on the thermal neutron reflection technique for determination of hydrogen contents of petroleum products in Tema Oil Refinery as well as crude oil samples from Ghana and Nigeria.

Thermal neutron reflection technique which was developed by Buczko M., et. al., 1979 and used by a number of researchers to determine the hydrogen content of petroleum products will be adapted for this work.

Thermal Neutron Reflection Method using a source holder housing a $1\mathrm{Ci}^{241}$Am -B*e* neutron source and He-3 neutron detector was used for Measurement of Total Hydrogen Contents in some Ghanaian Petroleum Products by Akaho E. H. K., et. al., 2000.

Based on their theoretical analysis and the experimental evidence, they concluded that:

1. The technique could be used as part of the quality control and standardization of petroleum products in the local market.
2. The technique was successfully applied to the analysis of diluted petrol with aviation fuel.
3. It is envisaged that the technique was fast and can be employed for quality assessment of agricultural produce, manufacturing industrial and petroleum products obtained from Ghana.

Also, Neutron backscatter methodology using $1\mathrm{Ci}^{241}$Am-Be neutron source was used for Liquid Level Investigation on Desalters at NATREF refinery, Sasolbug by Dagadu C. P. K., et. al., 1999. This research was able to measure and locate liquid interfaces in two desalters. The study indicated that, the deviation from the expected profile on desalter 2 between approximately 0.2 m and 0.9 m can be attributed to a possible longer distance between the measuring head and the liquid inside the desalter 2. The study concluded that three hydrogen liquid phases were present in both desalters.

Similarly, a study of the Geometrical Configuration of a set-up for the purpose of analyzing organic materials for their hydrogen content and their (C+ H)/H using Neutron Backscattering with an Am-Be source and a He-3 detector was carried-out by Idiri Z., et. al., 2007. They noticed that, the sensitivity for side by side geometry is higher than that of vertical geometry.

Furthermore, determination of total hydrogen content of some oil samples from Nigeria using an Am-Be neutron source was carried-out by Jonah S. A., et. al., 1999. Their experimental set-up consisted of a 5 Ci Am-Be neutron source embedded in a cylindrical paraffin block of diameter 30 cm and of height 30 cm. Their investigations concluded that, the hydrogen content of spent lubricants appears to decrease with usage. Thus, the result confirms the possibility of using the set-up as a quality control facility.

Additionally, the establishment of calibration curve for water measurement in a bulky paper recycling by neutron devic**e** was carried-out by Norpaiza Mohamad Hasan, et. al., 2010. They detected that, the phenomenon could probably be explained by the fact that the paper is classified as an organic compound which contains one or more C-H bonds. Thus, the hydrogen atoms from an organic compound have resulted in the increase in the hydrogen concentration and thereafter increase in the thermal neutron counts that were detected.

They generally observed, the detected thermal neutron counts increase sharply with the increasing of water in used paper and finally achieved plateau at above 26% of water content and noted that, the thermal neutron counts detected are similar from the standard block of polyethylene and finally concluded that:

1. The neutrons are vastly sensitive in detecting hydrogen (water) in a bulky used paper.
2. The thermal neutron calibration curve for water content in used paper has been successfully established.
3. The established calibration curve has a brilliant prospective in order to develop a smart neutron gauge for rapid and non-destructive detection of water in bulky used papers.
4. The manufactures of the paper-recycling industry can have direct advantage from the technique.

2.2 Laboratory Method for Determination of Petroleum Quality

2.2.1 Density, Specific Gravity and API Gravity

Density is defined as the mass of unit volume of a material at a specific temperature.

A more useful unit used by the petroleum industry is specific gravity, which is the ratio of the weight of a given volume of a material to the weight of the same volume of water measured at the same temperature, Chirk S. and Levine L., 2008.

Specific gravity is used to calculate the mass of crude oils and its products.

Usually, crude oils and their liquid products are first measured on a volume basis, and then changed to the corresponding masses using the specific gravity.

The American Petroleum Institute (API) gravity is another way to express the relative masses of crude oils. The API gravity could be calculated mathematically using the relationship that Specific gravities of crude oils roughly range from 0.82 for lighter crudes to over 1.0 for heavier crudes (41 - 10 °API scale), Hatch L. F and Matar, 1981. From the relationship, one can deduce the following:

2.2.2 Salt Content

A low API gravity indicates a heavier crude oil or a petroleum product, while a higher API gravity means a lighter crude or product, Rand S., 2003.

The salt content expressed in milligrams of sodium chloride per liter oil (or in pounds/barrel) indicates the amount of salt dissolved in water. Water in crudes is mainly present in an emulsified form. A high salt content in a crude oil presents serious corrosion problems during the refining process. In addition, high salt content is a major cause of plugging heat exchangers and heater pipes. A salt content higher than 10 lb/1,000 barrels (expressed as NaCl) requires desalting, Rand S., 2003.

2.2.3 Pour Point

The pour point of a crude oil or product is the lowest temperature at which oil is observed to flow under the conditions of the test. Pour point data indicates the amount of long-chain paraffin (petroleum wax) found in a crude oil, Welch L. M., et. al., 1978.

Paraffinic crudes usually have higher wax content than other crude types. Handling and transporting crude oils and heavy fuels is difficult at temperatures below their pour points. Often, chemical additives known as pour point depressants are used to improve the flow properties of the fuel.

Long-chain n-paraffin ranging from 16–60 carbon atoms in particular, are responsible for near-ambient temperature precipitation, Rand S., (2003). In middle distillates, less than 1% wax can be sufficient to cause solidification of the fuel.

2.2.4 Ash Content

This test indicates the amount of metallic constituents in a crude oil. Ash left after completely burning an oil sample usually consists of stable metallic salts, metal oxides, and silicon oxide. The ash could be further analyzed for individual elements using spectroscopic techniques, Speight. J. G., 2000.

2.2.5 Flash Point

Flash point of a fuel is essentially the lowest temperature at which vapours above a liquid ignites by a test flame under specified conditions, Cleveland, 2013.

2.2.6 Distillation Range

The objective is to determine the boiling range of liquid petroleum products boiling point below 370℃.

Distillation range may be carried out manually or the use of automated equipment. A measured sample is heated at a controlled rate and when the first drop of liquid emerges from the condenser, the temperature is recorded as the initial boiling point. Heating is continued at the specified rate and temperature readings taken at volume intervals as the distillate collects in the receiver, Daubert T. E., 1994.

Distillation method gives very good indication of product type, product volatility, Douglas James, 1988.

2.2.7 Vapour Pressure and Reid Vapour Pressure

As the temperature of a fluid become high, the quantity of vapour generated increases, and the vapour pressure also increases. The maximum vapour pressure generated at the temperature by a fluid is called the True Vapour Pressure (TVP), Reid R. C., et. al., 1987. The True Vapour Pressure is a good yardstick for knowing the quantity of vapour generated (volatility) from an oily mixture. However, measurement of TVP is not an easy task, and generally, the quantity of vapour generated is indicated by the Reid Vapour Pressure (RVP), which can be measured easily. The Reid Vapour Pressure is the vapour pressure of the fluid measured when the fluid is heated to a temperature of 100 ºF (37.8 ºC) in a container having four times the space of the fluid above it, and is expressed in PSI units; (1 Psi＝0.0069 MPa＝0.07031 kg/cm2) and mostly applied to light(less dense) petroleum products such as gasoline in order to determine the volatility of the petroleum products, Hinkebein T. E., 2003.

Accordingly, the RVP is useful for comparing the quantity of vapour generated (volatility) from a wide range of oils, but it is of no use under special conditions when the temperature and gas/fluid ratio vary, Riazi M .R., et. al., 1987.

Stewart, 1959, formulated the first theoretical method to predict RVPs of fuel blending.

2.2.8 Viscosity

Viscosity is a measure of fluid's resistance to flow. It is one of the most important properties of a fluid and plays a very prominent role in the petroleum industry, Janet L. Lane and Kenneth O. Henderson, 2004. It is determined in either absolute units or arbitrary.

Absolute viscosity units are related to the force required to shear a definite cross-section of oil, while arbitrary unites are simply related to the time a volume of sample takes to flow through the orifice of a specified type of apparatus. The most commonly used is absolute method which measures kinematic viscosity by means of a specialized calibrated table.

This method provides an indication of:

- 'Pumpabiliy' at a given temperature.
- Identification of a main factor for the selection of oils for particular application
- Measure as a function of temperature which is an important factor for oils operating over a wide range of temperature.

2.2.9 Colour

Colour is determined by comparison methods. A quantity of sample is placed in a glass cell of specified dimensions and the depth of colour it possesses is compared with standard colour glasses, Alan G. Lucas, 2001.

Other laboratory methods used to determine the quality of crude oil and finished petroleum products includes: octane number, cetane number, lubricant assessment etc.

Generally, Petroleum refineries transform crude oils into finished petroleum products which includes LPG, gasoline, jet fuel, diesel fuel, petrochemical feed stocks, home heating oil, fuel oil, and asphalt, Speight J. G. and Baki Ozum, 2002. Refiners therefore face a key economic choice in meeting product demand and quality standards.

2.3 Composition of Petroleum (Crude Oil)

Hundreds of different petroleum (crude oils) is processed in greater or lesser volumes, in the world's refineries. Each crude oil is unique and a complex mixture of thousands of compounds. Most of the compounds in crude oil are hydrocarbons (organic compounds composed of carbon and hydrogen atoms) other compound includes elements –most notably sulfur, as well as nitrogen and certain metals, e.g., nickel, vanadium, etc., Bawazeer, et. al., 1997.

Element Percent range composition by weight includes:

- Carbon 83 to 87 %
- Hydrogen 10 to 14 %
- Nitrogen 0.1 to 2 %
- Oxygen 0.05 to 1.5 %
- Sulfur 0.05 to 6.0 %
- Metals < 0.1 %

The physical and chemical properties of any given hydrocarbon species, or molecule, depends not only on the number of carbon atoms in the molecule but also the nature of the chemical bonds between them, Robert, et. al., 1995.

Carbon atoms readily bond with one another and with hydrogen and hetero-atoms in various ways – single bonds, double bonds, and triple bonds – to form different classes of hydrocarbons.

The proportions of the various hydrocarbon classes, their carbon number distribution, and the concentration of hetero-elements in a given crude oil determine the yields and qualities of the refined products that a refinery can produce from that crude, and hence the economic value of the crude.

Crude oils differ appreciably in their properties according to origin and the ratio of the different components in the mixture. Therefore, it require different refinery facilities and operations to maximize the economic value of the product, Roussel and Boulet, 1995. The higher the crude quality, the higher the market price relative to the prevailing average price for all crude oil.

The lighter grades of crude oil produce the best yields of products, nonetheless as the world's reserves of light and medium crude oil are depleting, oil refineries increasingly have to process heavy crude oil and bitumen. This require refineries to employ more complex and expensive methods to produce best products required. Heavier crude oils have high carbon and not enough hydrogen, thus the processes generally includes removing carbon from or adding hydrogen to the molecules through the use fluid catalytic cracking units, Ante Jukic**,** 2013.

Also, Crude oil may be considered light if it has low density or heavy if it has high density; and it may be referred to as sweet if it contains relatively little sulfur or sour if it contains substantial amounts of sulfur.

Light crude oil is more desirable than heavy oil since it produces a higher yield of petrol, while swee*t* oil commands a higher price than sour oil because it has fewer environmental problems and requires less refining to meet sulfur standards imposed on fuels in consuming countries, Ante Jukic**,** 2013.

2.4 Oil Fields in Ghana

The global economy relies heavily on petroleum to fulfill majority of its energy demands. It is therefore a key indicator of the economic wellbeing of both developed and developing nations. The International Energy Agency (IEA) predicted that global oil demand will reach about 104 million barrels/day by 2020, World Energy Outlook, 2009.

The coast of West Africa along the Gulf of Guinea is reported to be endowed with rich hydrocarbon reserves. Production of oil and gas in this region, which is estimated to have over 547 offshore oil and gas structures, has the potential to meet the energy demands of the European Union and the United States of America, Ayoade, 2002; IMF, 2005.

Angola, Nigeria, Equatorial Guinea and Gabon are already producing crude oil in this region.

Apart from the huge hydrocarbon reserves, countries along the Gulf of Guinea, including Ghana, are now of global interest due to the geopolitical and geographical locations as well as the quality of crude oil. Ghana’s oil and gas exploration dates as far back as 1896, and the commercial discovery in the Jubilee Field in June 2007, G N P C, 2009, was without doubt a welcome news, as it can enhance revenue generation and job creation and also significantly improve the national economy. The Jubilee Field is located 60 km off the coast of Cape Three Points in the Western Region of Ghana (Figure 2.1). It is situated in the Deep water Tano and West Cape Three Points blocks of the Tano Basin which is one of the three offshore sedimentary basins in Ghana. The Field is jointly owned by a consortium of companies named the Jubilee Joint Venture and managed by Tallow Ghana Ltd. Water depth within the Jubilee Field Unit area ranges from (1,000 m to 1,700 m).

Crude oil has a 1,000–1,200 gas-to-oil ratio and little sulfur content by international standards, Sunu Attah, 2009/2016. The reserve is estimated to hold about 800 million to 1.5 billion barrels of oil, Adjaye, 2009.

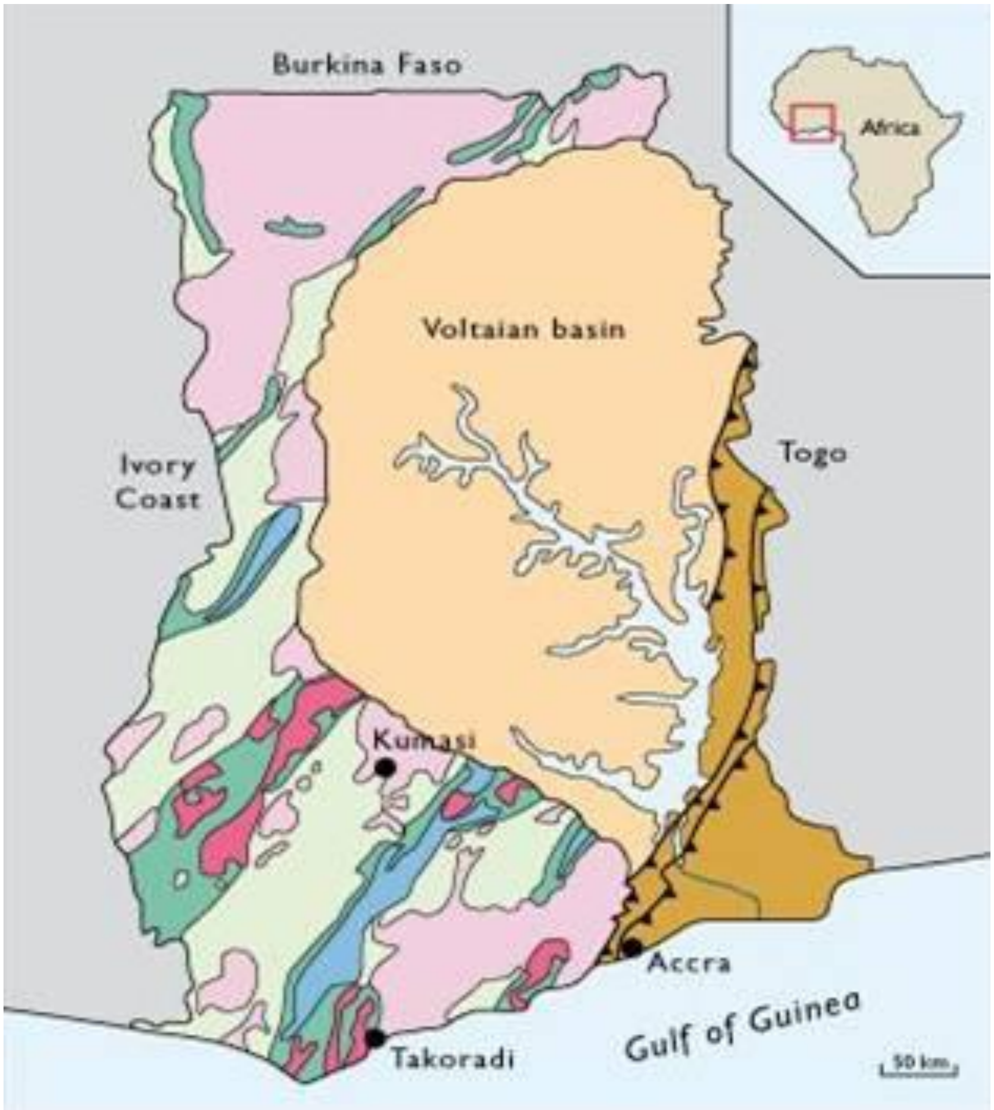

Figure 2.1: (Robin Sutherland, 2008, GNPC, 2009), ‘Exploration history and regional geology’

2.5 Neutron Interactions

In 1920 scientists proposed the existence of a neutral (i.e., no charge) particle: in 1932, Sir, James Chadwick correctly interpreted the results of experiments conducted by French physicists Frederic and Irene Joliot-Curie and other scientists and confirmed its existence. He named it the neutron, IAEA/RCA. May, 2006. It is one of the elementary particles of which matter is formed. The neutron is part of all atomic nuclei of mass number greater than 1; that is, all nuclei except ordinary hydrogen. Neutrons are said to be uncharged particles; they do not interact with electrons, nor directly cause excitation or ionization, they interact exclusively with the nucleus of an atom. Figure 2.2 illustrates neutron interaction with the nucleus of an atom.

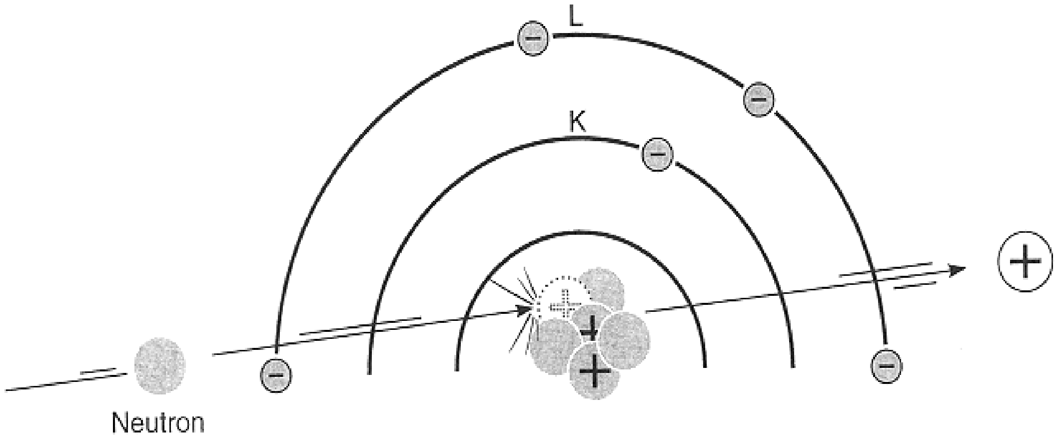

Figure 2.2: Neutron interaction with a nucleus of an atom, (IAEA/RCA. May, 2006).

Free neutrons - those outside of atomic nuclei - are produced in nuclear reactions.

Ejected from atomic nuclei at various speeds or energies, they are slowed down to very low energy by collisions with light nuclei, such as those of hydrogen, deuterium, or carbon, IAEA/RCA. May, 2006.

A free neutron is unstable and decays, forming a proton, an electron, and a neutrino.

Neutron irradiation of material causes the material to become radioactive (neutron activation) by changing the neutron to proton ratio in the nucleus.

Each category of interaction in the Figure 2.3 consists of all those linked below it. The total cross section σ_t expresses the probability of any interaction taking place.

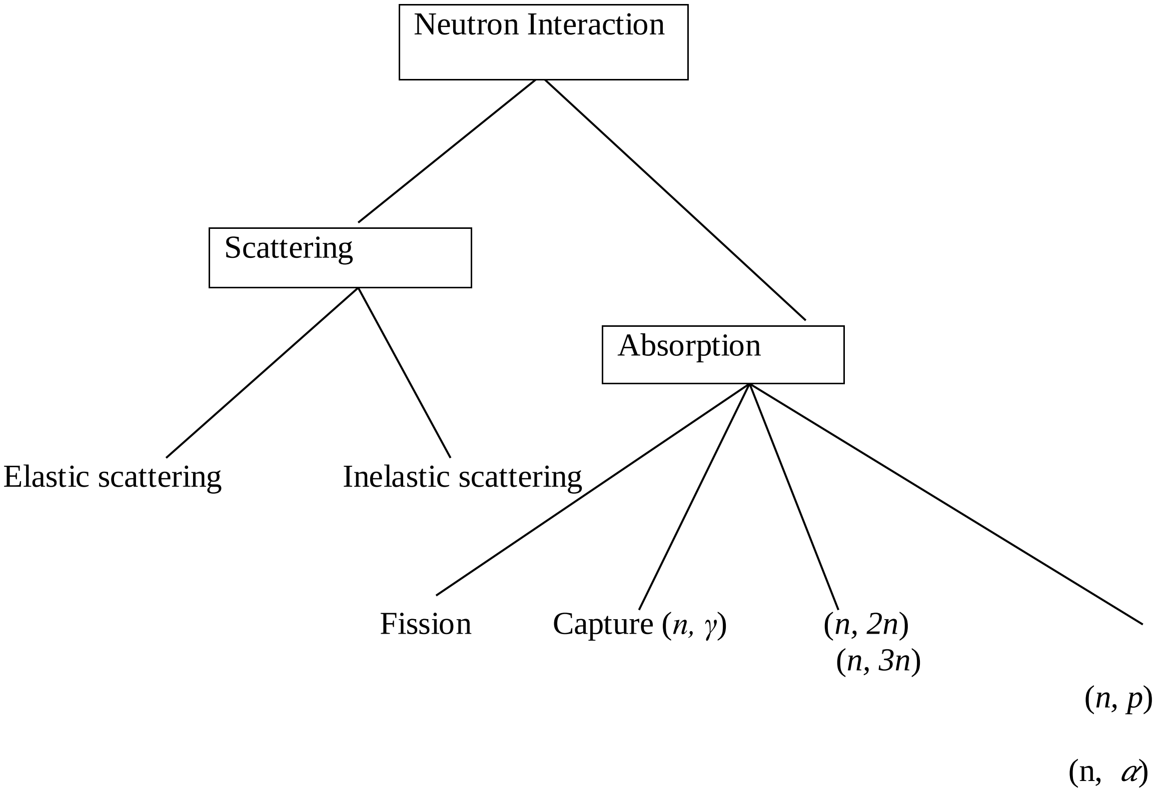

Figure 2.3: Neutron interactions and its cross sections

Scattering events can be subdivided into elastic and inelastic scattering. In elastic scattering the total kinetic energy of the neutron and nucleus is unchanged by the interaction. During the interaction, a fraction of the neutron's kinetic energy is transferred to the nucleus.

Elastic scattering is the most likely interaction between fast neutrons and low atomic-numbered absorbers, when a neutron is absorbed a compound nucleus in an excited state often results. The excited nucleus returns to the ground state by emitting one or more capture gamma rays, as illustrated in Figure 2.3. These gamma rays are characteristic of the target nucleus.

For a neutron of kinetic energy E encountering a nucleus of atomic weight A, the average energy loss is expressed as $2EA/(A+1)^2$. This expression shows that in order to reduce the speed of neutrons (that is, to moderate them) with the fewest number of elastic collisions target nuclei with small 'A' should be used. By using hydrogen, with $A = 1$, the average energy loss has its largest value of $E/2$, Garber D. L. and Kinsey R. R., 1976.

Inelastic scattering is similar to elastic scattering except that the nucleus undergoes an internal rearrangement into an excited state from which it eventually releases radiation.

During inelastic scattering some of the kinetic energy that is transferred to the target nucleus excites the nucleus, and the excitation energy is emitted as a gamma photon, that is nucleus usually returns to the ground state by emission of an inelastic scatter gamma ray.

The total kinetic energy of the outgoing neutron and nucleus is less than the kinetic energy of the incoming neutron; part of the original kinetic energy is used to place the nucleus into the excited state. It is no longer easy to write an expression for the average energy loss because it depends on the energy levels within the nucleus.

But the net effect on the neutron is again to reduce its speed and change its direction, IAEA/RCA. May, 2004.

The hydrogen nucleus in particular, does not have excited state so only elastic scattering can occur in that case. In general, scattering moderates or reduces the energy of neutrons and provides the basis for some neutron detectors (for example, proton recoil detectors).

Hydrogen is the most efficient for slowing down fast neutrons; this is the reason that water and paraffin are commonly used to thermalize fast neutrons.

2.5.1 Microscopic Interaction

The probability of a particular event occurring between a neutron and a nucleus is expressed through the concept of the cross section, Glenn Knoll, 2010. If a large number of neutrons of the same energy are directed into a thin layer of material, some may pass through with no interaction, others may have interactions that change their directions and energies, and still others may fail to emerge from the sample. There is a probability for each of these events. For example, the probability of a neutron not emerging from a sample (that is, of being absorbed or captured) is the ratio of the number of neutrons that do not emerge to the number of originally incident on the layer, Herman Cember, 1996. The cross section for being absorbed is the probability of neutrons being absorbed divided by the areal of the atom density (the number of target atoms per unit area of the layer). The cross section thus has the dimensions of area; it must be a small fraction of a square centimeter because of the large number of atoms involved. Because this type of cross section describes the probability of neutron interaction with a single nucleus is called microscopic cross section and is given the symbol**(σ).**

If the probability of a single neutron attempting to pass through a thin layer of material that has an area *A* and contains *N* target nuclei, each of cross-sectional area s, the sum of all the areas of the nuclei is *Ns*. The probability of a single neutron hitting one of these nuclei is roughly the ratio of the total target area *Ns* to the area of the layer *A*.

In other words the probability of a single neutron having a collision with a nucleus s *Ns/A* or *(N/A)* s, the areal target density times, Frank H. Attix, 1986.

2.5.2 Macroscopic Interaction

Although study of the interactions of a neutron with a single nucleus on the microscopic scale provides a basis for understanding the interaction process, measurements are actually performed with thick samples that often contain a mixture of elements. These additional features are described by using the macroscopic cross sections appropriate for bulk materials, Garber D. L. and Kinsey R. R., 1976. The definition of the macroscopic cross section arises from the transmission of a parallel beam of neutrons through a thick sample. The thick sample can be considered to be a series of atomic layer; for each layer the results found can be apply with the microscopic cross-section concept. By integrating through enough atomic layers to reach a depth x in the sample, the intensity I(x) of the collided neutron beam is:

$$I(x) = I_0 e^{N\sigma_t x} \qquad 2.1$$

Where I_0 is the intensity of the beam before it enters the sample, N is the atom density, and σ_t is the total cross section.

$I(x)/I_0$ depends on the energy of the neutrons through the energy dependence of the microscopic total cross-section σ_t, Lamarsh J. R., 1966.

2.6 Neutron Interactions and Applications in Industries

2.6.1 Backscattering

Whenever a radiation beam interacts with matter a fraction of it is transmitted, a fraction absorbed and a fraction is scattered from its original path, Welsh J. S., 2006. If the scattering angle is greater than 90^0 some photons or particles will come back towards the original emission point; the measurement of this radiation is the basis of the backscattering method, Young M. E. J., 1967.

2.6.2 Neutron scattering (moderating)

Fast neutrons of high energies emitted from the neutron source collide with nuclei of investigated matter reducing their energy. In general, neutrons lose more energy on collision with light nuclei than with heavy nuclei. Due to its light nucleus hydrogen is most effective in moderating neutrons from the source. As hydrogen is major constituent of most liquids detection of the liquid through container walls is possible, as well as measurement of the moisture (hydrogen density) of soils, coke or other materials, Nebbia G., (2005).

2.6.3 Nuclear Magnetic Resonance

Nuclear Magnetic Resonance (NMR) imaging uses radiofrequency photons. The object is placed in a strong magnetic field in which radiofrequency photons are absorbed by neutrons.

The neutrons then de-excite by releasing a photon of almost the same energy as the original photon. The material of an object can be identified because different elements absorb radiofrequency photons of different frequencies. Only elements with odd numbers of protons can be imaged because pairs of protons and neutrons cancel one another out, Stone G. M., 1990. Additionally, since a high-powered magnet is used, NMR cannot be applied to objects containing or encased in metal, Hussein E. M. A. and Waller E. J., 1998.

2.6.4 Neutron Activation Analysis

Neutron activation analysis (NAA) is a nuclear process used for determining the concentrations of elements in a vast amount of materials. NAA relies on excitation by neutrons so that the treated sample emits gamma-rays. It allows the precise identification and quantification of the elements, above all of the trace elements in the sample. NAA has applications in chemistry but also in other research fields, such as geology, archaeology, medicine, environmental monitoring and even in the forensic science.

The sequence of events occurring during the most common type of nuclear reaction used for NAA, namely the neutron capture or (n, gamma) reaction, is illustrated in Figure 2.4.

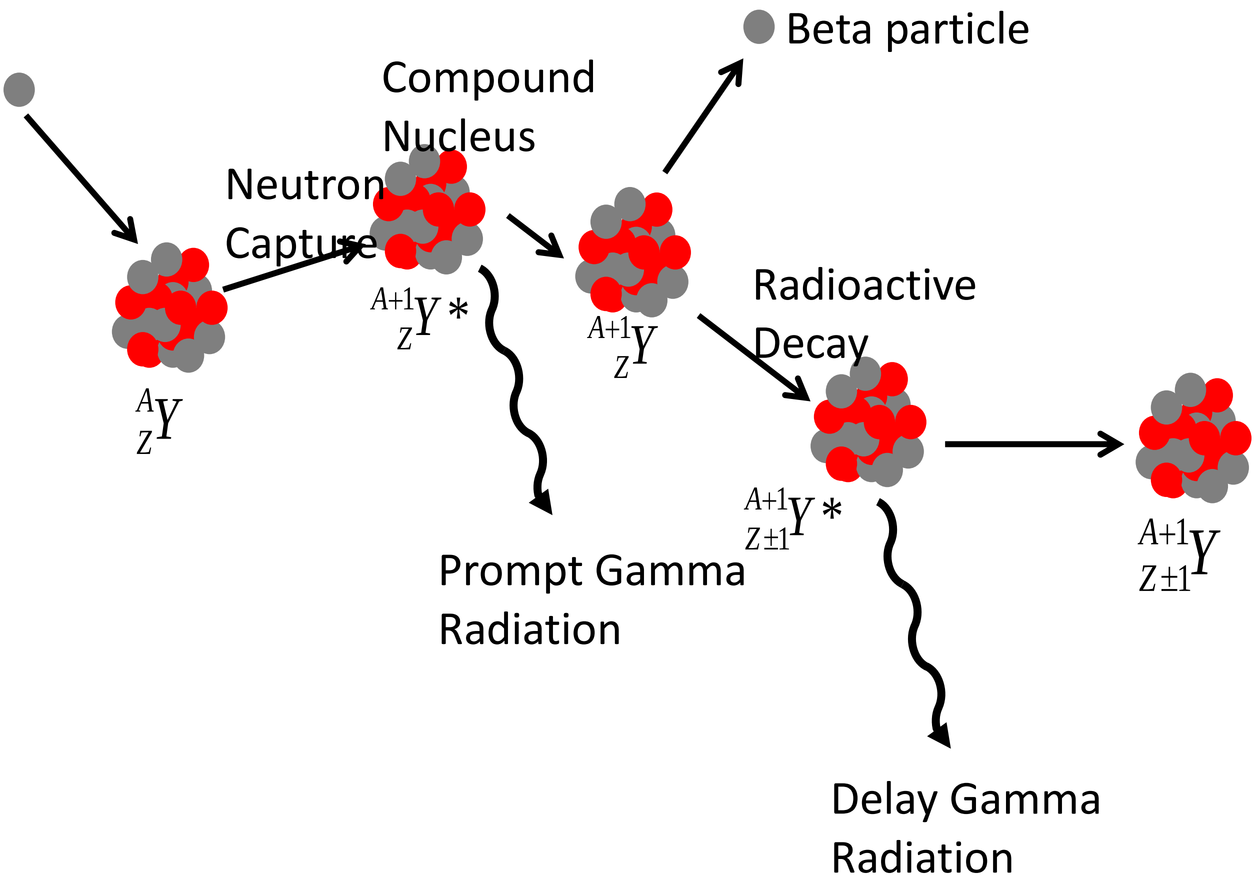

Figure 2.4: Neutron capture by a target nucleus followed by the emission of gamma rays, Jovan Thereska, 2000.

Creation of a compound nucleus forms in an excited state when a neutron interacts with the target nucleus via a non-elastic collision. The excitation energy of the compound nucleus is due to the binding energy of the neutron with the nucleus. The compound nucleus will almost instantaneously de-excite into a more stable configuration through emission of one or more characteristic prompt gamma rays. In many cases, this new configuration yields a radioactive nucleus which also de-excites (or decays) by emission of one or more characteristic delayed gamma rays, but at a much lower rate according to the unique half-life of the radioactive nucleus. Depending upon the particular radioactive species, half-lives can range from fractions of a second to several years.

In principle, therefore, with respect to the time of measurement, NAA falls into two categories:

1. Prompt gamma-ray neutron activation analysis (PGNAA), where measurements take place during irradiation, Jovan Thereska, 2000.

2. Delayed gamma-ray neutron activation analysis (DGNAA), where the measurements follow radioactive decay. The latter operational mode is more common; thus, when one mentions NAA it is generally assumed that measurement of the delayed gamma rays is intended. About 70 % of the elements have properties suitable for measurement by NAA.

The PGAA technique is generally performed by using a beam of neutrons extracted through a reactor beam port. Fluxes on samples irradiated in beams are in the order of one million times lower than on samples inside a reactor but detectors can be placed very close to the sample compensating for much of the loss in sensitivity due to flux. The PGAA technique is most applicable to elements with extremely high neutron capture cross-sections (B, Cd, Sm, and Gd); elements which decay too rapidly to be measured by DGAA; elements that produce only stable isotopes (e.g. light elements); or elements with weak decay gamma-ray intensities. 2D, 3Danalysis of (main) elements distribution in the samples can be performed by PGAA.

DGNAA (sometimes called conventional NAA) is useful for the vast majority of elements that produce radioactive nuclides. The technique is flexible with respect to time such that the sensitivity for a long-lived radionuclide that suffers from interference by a shorter-lived radionuclide can be improved by waiting for the short-lived radionuclide to decay or quite the contrary, the sensitivity for short-lived isotopes can be improved by reducing the time irradiation to minimize the interference of long-lived isotopes. This selectivity is a key advantage of DGNAA over other analytical methods.

In most cases, the radioactive isotopes decay and emit beta particles accompanied by gamma quanta of characteristic energies, and the radiation can be used both to identify and accurately quantify the elements of the sample. Subsequent to irradiation, the samples can be measured instrumentally by a high resolution semiconductor detector, or for better sensitivity, chemical separations can also be applied to reduce interferences. The qualitative characteristics are: the energy of the emitted gamma quanta ($E\gamma$) and the half-life of the nuclide ($T½$). The quantitative characteristic is: the Iγ intensity, which is the number of gamma quanta of energy Eγ measured per unit time. The n-gamma reaction is the fundamental reaction for neutron activation analysis.

2.6.5 Thermal Neutron Activation

The primary objective of thermal neutron activation (TNA) system is to identify nitrogen, usually via detection of the 10.83 MeV capture gamma ray from N-14. Neutrons produced by a radioisotope source or a neutron generator are moderated (thermalized) to thermal energies that average about 0.025 eV. The thermal neutrons then bombard the object in question and a fraction of the neutrons are absorbed by the nuclei of the elements within the object. The nuclei de-excite by emitting prompt gamma rays of energy characteristic of the nuclei. This system can only be used to determine if an element such as nitrogen is present, not for what use it is intended, i.e., the results of analysis are the same for an explosive containing nitrogen and a fertilizer containing nitrogen. Due to this characteristic, there can be a high false positive rate. This method has limited sensitivity and can be quite expensive. Also, it must be corrected for background created by thermal neutron interactions with shielding, detectors, and surrounding materials, Singh S. and Singh M., 2003; Thiesan L, Hannum D, Murray D. W, and Parmeter J. E., 2004.

2.6.6 Fast Neutron Analysis

Fast Neutron Analysis (FNA) identifies not only nitrogen, as in the TNA method, but also hydrogen, oxygen, and carbon. The technique employs high energy fast neutrons, usually from a neutron generator to excite nuclei via inelastic scattering. The nuclei de-excite by releasing characteristic gamma rays. The gamma rays are detected by several detectors surrounding the object in question .The intensity of the gamma rays is indicative of the amount of an element within an object while the energy is indicative of the type of element. However, the use of high energy neutrons causes a high background in the gamma ray detectors which skew the results, Gozani T., 1994.

2.6.7 Pulse Fast Neutron Analysis

Pulsed Fast Neutron Analysis (PFNA) is similar to FNA, except the neutron source is pulsed instead of a constant stream in an attempt to reduce the high gamma ray background that occurs in FNA. The neutron pulses are usually nanoseconds long and must be as mono-energetic as possible in order to ensure that all neutrons travel at identical velocities, Geneva International Centre for Humanitarian Demining, 2006; Bruschini C., 2001.

The neutrons produce gamma rays through inelastic scattering and the gammas are detected with an array of thallium doped sodium iodide (NaI (Tl)) detectors, Micklich J, Fink C. L and Yule T. J, Dallas T. X, 1995; Buffler A., 2004. The time from the start of the neutron pulse to the detection of a gamma ray is measured. This allows for the determination of not only elemental composition of the object, but also the spatial location of the elements within the object.

2.6.8 Fast Neutron Scattering Analysis

Mono-energetic neutron beam alternating between two energies bombards an object in question. Neutrons scattered by the object are detected at forward and backward angles, the type, number, intensity, and scattering angle of the neutrons are characteristic of the elements composing the object.

An explosives signature is created by combining measurements from the two detectors, Buffler A., 2004.

Other method of neutron detections include: Pulsed Fast Neutron Transmission Spectroscopy, Pulsed Fast/Thermal Neutron Analysis etc.

2.6.9 Nucleonic Gauges

A nucleonic gauge consists of a suitable source (or a number of sources) of alpha, beta, gamma, neutron or X ray radiation arranged in a fixed geometrical relationship with one or more radiation detectors. Most of nucleonic gauges are based on a few most common nuclear techniques, Abu-Jarad F., et. al., 2007.

Nucleonic Gauges operate on the principle of changes in the intensity of radiation, from a sealed source, measured by a suitable detector. It is designed to measure contactless level of medium in tanks and containers. It is a continuous measurement of level for a large range of level fluctuations, Types of nucleonic gauges include:

- Density gauge
- High/Low Level Alarm
- Proportional level indicator

2.6.10 Nuclear Moisture-Density Gauges

Nuclear moisture-density gauges are advanced radiation based technology which provides highly accurate measurements of moisture content, compaction and density of soil and construction materials such aggregate and asphalting concrete without the use of core samples or other destructive methods. Usually a nuclear moisture gauge contains a gamma radioactive source such as Cs-137 and neutron source such as (Cf-252) or 241-Am-Be. The density measurements are based on the attenuation of gamma radiation emitted by a Cs-137 source due to scattering and absorption of radiation, which are directly related to the electron density of the materials being measured. The radiation detector located in the gauge indicates the mass density of the materials with a chemical composition similar to the earth crust. The moisture content measurements are based on the interaction of neutron radiation emitted by the neutron source with the hydrogen atoms in the materials to be tested. Special neutron detectors located in the gauge detect the scattered neutrons and through microprocessor determines the moisture content in the tested medium, Abu-Jarad F., et. al., 2007.

2.7 Radiation safety considerations in Neutron Backscatter applications

All equipment, tools and machinery have hazards associated with their use, and radiation-based technologies are not different. It is therefore important to follow proper operating and protection procedures to maximize the benefits and minimize the risk of such technologies.

Radiation source emit ionizing radiations, which are potentially hazardous to health and therefore radiation protection measures are necessary throughout all aspects of operations. The dose rate at a point is inversely proportional to the square of the distance between the source and the point, IAEA/RCA. May, 2006.

Therefore a radiation worker has to maintain maximum possible distance from a radiation source. The dose received is directly proportional to the time spent in handling the source. Thus the time of handling should be as short as possible. The radiation intensity at a point varies exponentially with the thickness of shielding material. Thus a radiation worker has to use an optimum thickness of shielding material against the radiating source.

The most elementary means of protection is known as "TDS" or "Time, Distance and Shielding, IAEA/RCA. May, 2006.

- Decreasing the time spent around a radiation source decreases the exposure
- Increasing the distance from a source decreases the exposure
- Increasing the thickness of shielding to absorb or reflect the radiation decreases the exposure

For exposures from any source, except for therapeutic medical exposure, the doses, the number of people exposed and the likelihood of incurring exposures shall all be kept as low as reasonably achievable (ALARA) principle.

All safety measures must be taken to avoid unnecessary exposure to radiation. The following can be used to facilitate planning of an investigation, IAEA/RCA May, 2006.

- Handling of radioactive source must not pose a risk to the user nor the environment involved.
- During transport of radioactive source to the site of investigation, care should be taken so that the dose rate on the container is not be higher than 2 mSv/h (200 mR/h). If transported by vehicle the radiation dose rate must not be higher than 15 mSv/h (1.5 mR/h) in the cabin.
- ALARA (As Low As Reasonably Achievable) must always be the slogan when planning a radioactive tracer investigation.

Before commencing any radioactive investigation, a complete study must be made wherein the objectives of the investigation are considered. This will allow the investigator to decide upon the methodology as well as the radioactive tracer to use. The annual dose limit has to be taken into account and no individual should be exposed beyond the prescribed limit. This dose limit is 1 mSv/year for a member of the public and 20 mSv/year for a radiation worker, according to European regulations.

An effective national infrastructure is a fundamental requirement for safety and security of sources. Safety Series 120, Radiation Protection and the Safety of Radiation Sources, Principle 10 states that: “the government shall establish a legal framework for the regulation of practices and interventions, with a clear allocation of responsibilities, including those of a Regulatory Authority”, IAEA/RCA May, 2006.

The preamble to the Basic Safety Standards (BSS) defines the elements of a national infrastructure to be: legislation and regulations; a regulatory authority empowered to authorize and inspect regulated activities and to enforce the legislation and regulations; sufficient resources and adequate numbers of trained personnel, IAEA/RCA May, 2006.

The Regulatory Authority must also be independent of the registrants, licensees and the designers and constructors of the radiation sources used in practices. Further information on the legal and governmental infrastructure can be found in the IAEA requirements document. Hence users of radioactive source should have an authorization from the appropriate regulatory authority.

A useful IAEA document that should be used in the preparation of safety assessments for radiation sources is IAEA-TECDOC-1113, Safety assessment plans for authorization and inspection of radiation sources. This document provides practice-specific checklists with items to be considered during the performance of safety assessments that will be included in authorization applications and during the performance of inspections by the Regulatory Authority.

Safety assessments should be made for each application of a source having an activity above the exemption level, since circumstances and the application environment will differ. Each application should consider both occupational and public exposures and ensure that all exposures are as low as reasonably achievable. The level of the assessment should be commensurate with the hazard posed by the source. Hence detailed assessments should not be required where the risk is small, as is the case with many experiments.

The procedures for monitoring workers, including the type of dosimeter, should be chosen in consultation with a qualified expert, such as the Radiation Protection Officer, or as specified by the Regulatory Authority.

Depending on the situation, both direct reading dosimeters and Thermo luminescent Dosimeters (TLDs) or film badges may be needed. For non-uniform exposures, it may be necessary to wear additional dosimeters e.g. for the hands or fingers. Dose records should be kept for each application, where possible, and be available to the Regulatory Authority if requested.

CHAPTER THREE

METHODOLOGY

3.1 Overview

This chapter describes methodology adopted for the experimental set-up, sample collection and preparation of various petroleum products from Tema Oil Refinery plants (RFCC, CDU) and some crude oil samples from Ghana and Nigeria. Instrument used and its calibrations were also discussed.

The Neutron Backscatter Technique (NBT) principle is suitable for interaction of neutron with matter. The radioactive source (1Ci^{241}Am-Be) used in this work emits fast neutrons with high energies which are difficult to detect. These fast neutrons interact with hydrocarbons to become slow or thermal neutrons.

Fast neutrons do not interact with electric fields of atoms or molecules. In addition, because of the large mass of the neutron compared with that of the electron, neutrons are slightly affected by electron collision. The only way in which a fast neutron passing through matter can lose its energy is by direct collision with an atomic nucleus, therefore, fast neutrons are penetrating particles, capable of passing through substantial thickness of material.

Thermal neutrons are most likely to interact with atoms of a similar size to the neutron itself. Hydrogen is the closest atom in size and mass to the neutron and therefore accounts for the majority of the collisions that reduce the fast neutrons to thermal neutrons

These fast neutrons interact mostly with the hydrogen atom through elastic collisions and after successive collisions it will be slowed down to thermal energies. A fraction of these thermal neutrons is backscattered and detected by a He-3 neutron detector. The number of detected thermal neutrons is proportional to the hydrogen concentration in the sample.

Fast neutrons, in the range of (0.5 -11MeV), lose their energy by scattering process. In elastic scattering, the neutron is slowed down in the collision and its direction of motion is changed IAEA/RCA, 2004.

In the energy range (30 e V- 0.5 M eV), elastic scattering is essentially the only process by which a neutron can be slowed down. If neutron energy before collision is denoted by E_1, and after collision by E_2, it is possible to show that in a head-on collision, the energy transferred to the nucleus is:

$$E_2 / E_1 = \left[\frac{A-1}{A+1}\right]^2 \qquad 3.1$$

Where 'A' is the mass number of the target nucleus.

It can be noticed from equation (3.1) that, it is possible for a nucleus to loss all of its kinetic energy in a head-on collision with a hydrogen nucleus. Therefore, the presence of hydrogen in a given sample is a major factor in slowing down of fast neutrons.

As the fraction of backscattered neutrons will depend strongly on the geometrical configuration of the irradiation and detection set-up; this study considered two geometrical configurations of the set-up: the one in which the neutron source, the detector is side by side with sample container and in the other one, the sample container is placed on top of the source and the detector.

The set-up as shown in Figures. 3.5a and 3.5b uses a 1Ci Am-Be neutron source and a

He-3 neutron detector at the Non-Destructive Testing Laboratory at Ghana Atomic Energy Commission (GAEC), and the results obtained would be compared with similar studies in the petroleum industry.

3.2 Instruments used and Calibrations

3.2.1 Ludlum Model 16 Analyzer

The Ludlum Model 16 Analyzer was employed for this test. It has complete electronic requirements for scintillation, proportional, or GM monitoring with the added feature of a window discriminator circuit.

A two-position switch, marked WIN IN/OUT allows the instrument to operate as a gross count rate-meter or as a single-channel analyzer. With the WIN switch in the OUT position, the discriminator level is controlled by the threshold (THR) potentiometer, which is adjustable from 2 to 60 mV. In this mode, the instrument performs as a gross count rate-meter. With the WIN switch in the IN position, the WIN potentiometer controls the high discriminator level. The high discriminator level may be adjusted between the THR level and two times the threshold level (not to exceed 60 mV).

Other features include AUD ON/OFF and fast/slow (F/S) meter response switches, meter RESET and high voltage (HV) test buttons.

Figure 3.1 shows the schematic diagram of Ludlum model 16 analyzer.

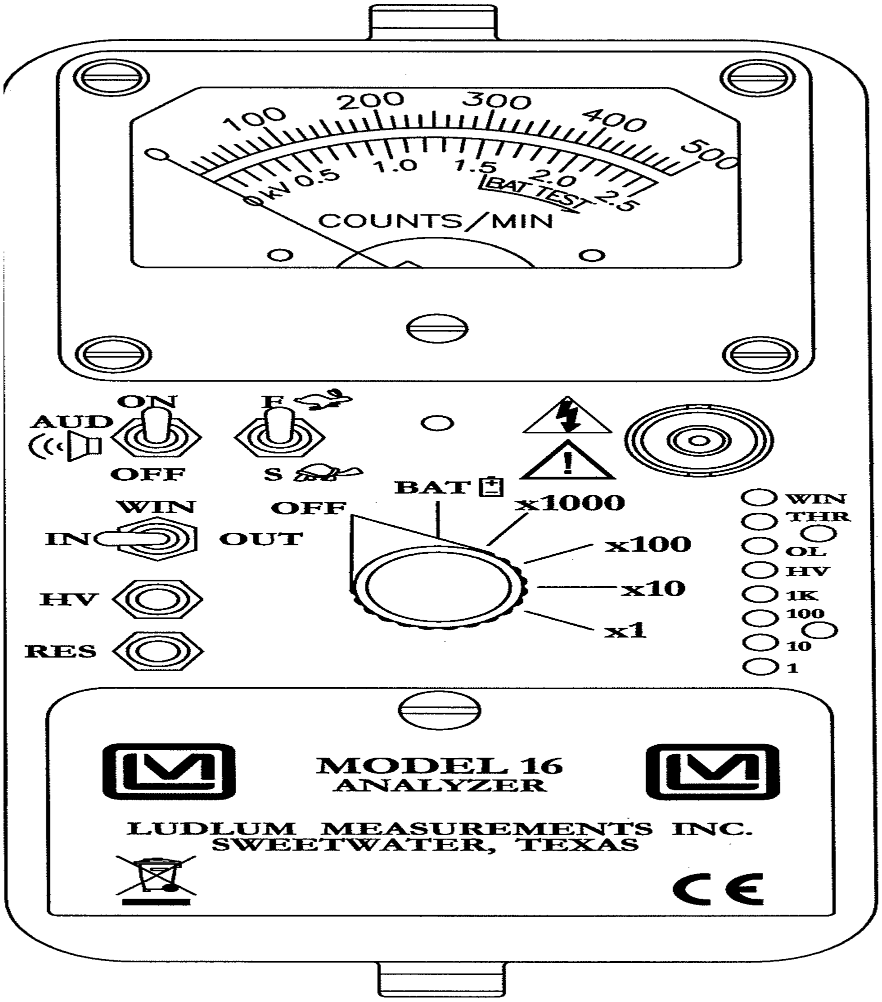

Figure 3.1: Schematic Diagram of Ludlum Model 16 Analyzer (Ludlum measurement, Inc. July 2011)

3.2.1.1 Ludlum Model 16 Analyzer Calibration

To guarantee proper operation of the instrument, operational checks including battery test and instrument test were performed prior to its use. According to Ludlum Measurement Inc., 2011, if the instrument fails to read within 20% of a proper reading, it should be sent to a calibration facility for recalibration.

The Model 16 serial number is located on the front panel below the battery compartment.

Most Ludlum Measurements, Inc. detectors have a label on the base or body of the detector for model and serial number identification. The device was carefully calibrated with gamma calibrating sources before usage.

3. 2.1.2 Battery Installation and Test

To install the battery, the Model 16 range selector switch is always put in the OFF position. The battery lid is open by pushing down and turning the quarter-turn thumbscrew, counterclockwise a quarter of a turn and installs two ″D″ size batteries in the compartment.

The (+) and (-) marks inside the battery door are always noted and the battery polarity is matched to these marks. The strength of batteries is checked each time the instrument is turned on by moving the range switch to the BAT position with the meter needle deflecting to the battery check portion on the meter scale.

3.2.1.3 Instrument Test

After checking the batteries, the instrument range switch was selected at ×1000 position, the AUD ON-OFF was also placed at the ON position and the WIN IN/OUT switched to the OUT position and the detector is exposed to a check source. The instrument speaker emits ″clicks″ relative to the rate of counts detected.

The AUD ON/OFF switch silences the audible clicks if in the OFF position. It is recommended that the AUD ON/OFF switch be kept in the OFF position when not needed in order to preserve battery life. Ludlum Measurement Inc., July 2011.

The range switch was rotated through the lower scales until the meter reading is indicated. While observing the meter, fluctuations between the fast and slow response time (″F/S″) positions were selected and variations in the display were observed.

According to Ludlum Measurement Inc., July 2011, the ″S″ position should respond approximately 5 times slower than the ″F″ position; the slow response position is normally used when the instrument is displaying low numbers, which require a more stable meter movement. The fast response position is used at high rate levels.

The meter reset function was also checked by depressing the RES pushbutton and ensuring the meter needle drops to “0.” When the RES pushbutton was released the meter needle recovers to the original reading.

The HV pushbutton was also depressed and it was noted that the meter indicated the high voltage set point.

3. 2.1.4 Operating Point

The operating point of the instrument and probes are established by the setting of the probe voltage and instrument sensitivity (HV and THR). The proper selection of this point is key to the instrument performance according to Ludlum Measurement Inc., July 2011**.**

Efficiency, background sensitivity, and noise are fixed by the physical makeup of the given detector and rarely vary from unit to unit. However, the selection of the operating point makes a marked difference in the apparent contribution of these three sources of count.

In setting the operating point, the final result of the adjustment is to establish the system gain so that the desirable signal pulses (including background) are above the discrimination level, and the unwanted pulses from noise are below the discrimination level, and are therefore, not counted.

Total system gain is controlled by adjusting either the instrument threshold or high voltage. Voltage affects control in the probe; THR (threshold) controls the amplifier gain. The operating point for each detector is set at a compromise point of sensitivity, stability, and background contribution. These operating points are best for general monitoring. However, the factory set point may be adjusted for specific operation.

In the special case of GM detectors, a minimum voltage must be applied to establish the Geiger-Mueller characteristic. Further changes in gain will not affect this type of probe.

3.2.1.5 Identification of Controls and Functions Range Selector Switch:

The Ludlum Model 16 Analyzer has six-position switch marked OFF, BAT, ×1000, ×100, ×10, and ×1.

Turning the range selector switch from OFF to BAT provides the operator with a battery check of the instrument. A BAT check scale on the meter provides a visual means of checking the battery-charge status Ludlum measurement Inc., July 2011**.** Moving the range selector switch to one of the range multiplier positions (×1000, ×100, ×10, and × 1) provides the operator with an overall range of 0 to 500,000 cpm. One can multiply the scale reading by the multiplier to determine the actual scale reading.

- **Battery Compartment**: The sealed compartment houses two ″D″ cell batteries.
- **AUD ON/OFF Toggle Switch**: In the ON position, this switch operates the unimorph speaker, located on the left side of the instrument. The frequency of the clicks is relative to the rate of the incoming pulses, the higher the rate, the higher the audio frequency. The audio should be turned OFF when not required, to reduce battery drain.
- **HV Pushbutton Switch**: When depressed, displays the detector high voltage on the meter.
- **RES Pushbutton Switch**: When depressed, this switch provides a rapid means of driving the meter needles to zero.
- **F-S Toggle Switch**: provides meter response. Selecting the fast, ″F″ position, of the toggle switch provides 90% of full-scale meter deflection in four seconds. In the slow, ″S″ position, 90% of full-scale meter deflection takes 22 seconds. In the ″F″ position, there is fast response and large meter deviation. The ″S″ position should be used for slow response and damped meter deviation.
- **WIN IN/OUT**: This toggle switch disables the window circuit for gross counting.
- **HV Adjustment**: This recessed potentiometer located under the calibration cover provides a means of varying the high voltage from 400 to 2500 V.
- **Range Calibration Adjustment**: recessed potentiometers located under the calibration cover. These controls allow for individual calibration of each range multiplier.

- **THR**: recessed potentiometer located under the calibration cover, which allows the input sensitivity (threshold) to be adjusted from 2 to 60 mill volts. The threshold is normally set for 10 mill volts at the factory.
- **WIN**: recessed potentiometer located under the calibration cover, which allows the window width to be adjusted from 0 to 2.0 times the threshold setting (input sensitivity). The window is normally set for 1.5 times the threshold.
- **OL**: This recessed potentiometer is located under the calibration cover, which allows for calibration of the detector overload function.

3.2.2 He-3 Neutron Detector

Helium-3 is a very important isotope used in the instrumentation for neutron detection. It has a high absorption cross section for thermal neutron beams and is used as a converter gas in neutron detectors, Ahamed S. N., 2007.

The Helium-3 gas absorbs slow neutrons returning to the probe, after thermalization, according to the nuclear reaction, Ward A. L. and Witt man R. S., August, 2009.

He-3 + P+ T+ 765 Kev.

The emitted photons are detected as electrical pulses with an electronic counting device, each count therefore corresponds to an electrical pulse originating from one slow neutron reaching the detector. The pulses coming from the detector are first pre-amplified in the probe and the pre-amplified pulses are then transmitted to the electronic counting system through the cable that connects probe to the electronic device.

Helium-3 neutron detectors are widely used in oil and gas exploration and petroleum refinery plants. These detectors are used in conjunction with a neutron source to locate hydrogenous materials such as oil, natural gas, water etc. In oil and gas exploration, neutron measurements in conjunction with inputs from other drill string instruments are used to locate hydrocarbon reservoirs during drilling and to further sketch out the reservoirs during logging operations. The overwhelming majority of nuclear porosity tools used in the oil and gas industry today depends on the unique properties of Helium-3 neutron detectors; they have a high neutron sensitivity, which enables them to be packaged to fit inside the tool string.

3.2.3 Am-Be Neutron Source

Americium-241 is an unstable (radioactive) isotope with a half-life of 432.7 years. When it decays, it releases alpha and gamma radiation and changes in to Neptunium-237, which is also radioactive, Radiochemical Center, Amersham, 1977/8. The decay chain ends with Bismuth 209, a stable non- radioactive element and has atomic number of 95. By far, the largest and most widespread use of americium-241 is as a component in household and industrial smoke detectors, where small amount is used in an ionization chamber inside the detector. A mixture of americium-241 and beryllium emits neutrons for industrial use, Royal Australian Chemical Institute, 2011.

3.4 Samples Collection and Preparation

Samples of finished petroleum products from Tema Oil Refinery plants (CDU and RFCC), Jubilee field crude oil from Ghana, and Forcados and Bonny light crude oil from Nigeria were considered for the analysis. Figure 3.2 is a pictorial view of sampling point at CDU of TOR.

A total of thirteen (13) samples were collected and prepared for the analysis, density (ρ) and specifications of each sample were also obtained from the Quality Control Department, TOR. Table 3.1 and 3.2 consist of a list of some of the samples from Crude Distillation unit and Residual Fluid Catalytic Cracking unit respectively. Table 3.3 shows the densities of crude oils from Ghana and Nigeria.

Figure 3.2: Pictorial View of CDU Sampling Point-TOR

Table 3.1: Samples from Crude Distillation Unit (CDU) – TOR

Sample	$\rho\ (g/cm^3)$
Light Napha (Light Gasoline)	0.725
Heavy Napha (Heavy Gasoline)	0.763
Aviation Turbine Kerosene (ATK)	0.823
Kerosene	0.825
Gasoil (Diesel)	0.867
Residual Fuel Oil (CDU)	0.928

Table 3.2: Samples from Residual Fluid Catalytic Cracker (RFCC)-TOR

Sample	$\rho\ (g/cm^3)$
Gasoline (Petrol)	0.744
Light Cycle Oil	0.918
Heavy Cycle Oil	0.985
Cracked Residue (RFCC)	1.057

Table 3.3: Crude Oil Samples from Ghana and Nigeria

Sample	$\rho\ (g/cm^3)$
Jubilee Crude Oil –Ghana	0.849
Forcados Crude Oil-Nigeria	0.877
Bonny Light Crude Oil- Nigeria	0.848

3.5 Experimental Set-Up

The experimental set-up shown in Figure 3. 3 and Figure 3.4 consist of samples in an aluminum container of diameter 10 cm and height 12 cm, a source holder housing a 1Ci^{241}Am-Be neutron source and He-3 neutron detector respectively. The back and sides of the source holder are shielded with 1 mm thick cadmium lining to reduce the neutron dose to the user. The neutron source when not in use is stored in a separate container which is lined with paraffin as a moderator and provides personnel shielding against radiation hazards. As stated earlier, the analysis was carried out in two geometrical arrangements; Figure 3.3 is a vertical (top) geometrical arrangement and Figure 3.4 is horizontal (side by side) geometrical arrangement respectively. For the purpose of standard and data accuracy, the petroleum products, each of a volume of 500 milli-liters were poured into an aluminium container with the help of a funnel. To avoid product contamination, each of the containers was cleaned with highly volatile Light Naphtha (Naphtha is mostly used for cleaning in the petroleum industry).

An empty allumimiun (Al) container was irradiated to establish the initial intensity (I_0).

The container was then filled in turns with 500 milli-liters of petroleum samples under test and was also irradiated to obtain intensity through the container with sample (I).

An average time of ten seconds (10 s) was set for each count.

Block Diagram of Experimental set-up for Nuetron Backscatter Technique for Vertical/Top Geometry

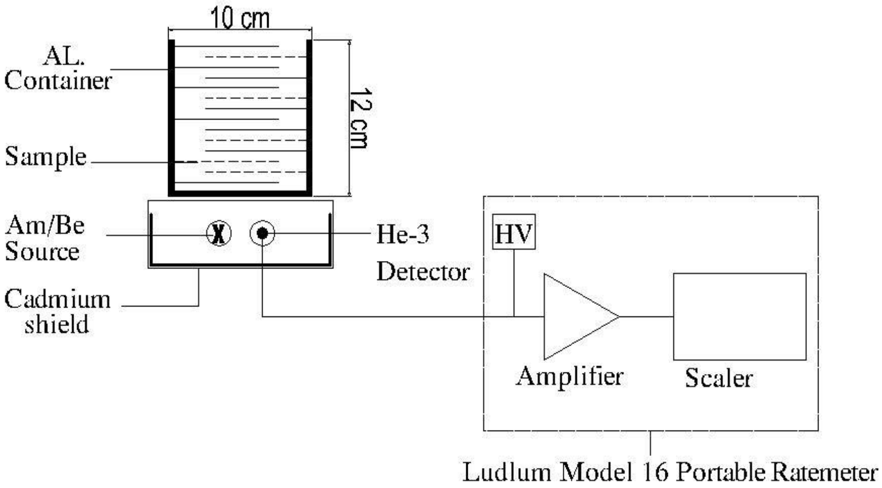

Fig 3.3 Vertical/ Top Geometry set-up

Block Diagram of Experimental set-up for Nuetron Backscatter Technique for Horizontal/Side Geometry

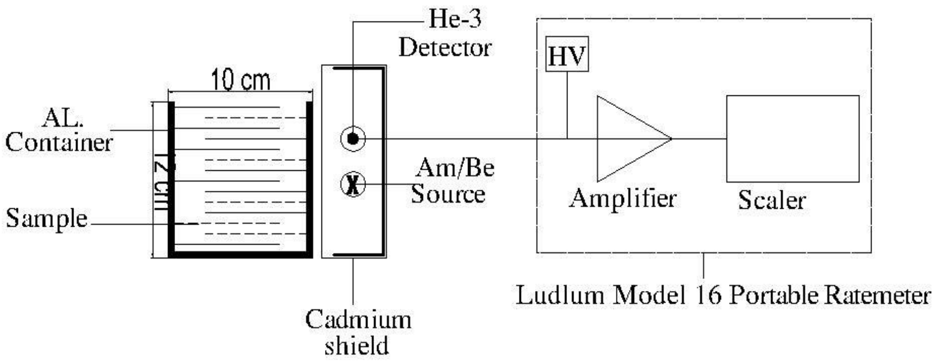

Fig 3.4 Horizontal/Side by Side Geometry set-up

Figure 3.5a and 3.5b are photographs for the experimetal set-up of the analysis

The alpha particles emitted by the decay of the americium collide with the light beryllium nuclei, producing fast neutrons. When these fast neutrons collide with hydrogen nuclei present in the target sample being studied, they lose much of their energies. The detection of slow neutrons returning to the probe allows an estimate of the amount of hydrogen content present in the test sample.

To confirm proper instrument operation, NaI (T) scintillation detector and caesium-137 gamma test sources (1μCi ,2μCi and 3μCi) were used to check the rate meter readings and calibrations.

Figures 3.5a and 3.5b are photographs for the experimental set-up of the analysis.

A total exposure registered by radiation monitor (Thermo-Luminescent Detector) from the beginning of test to the end was 0.48 msv/h minimum to 0.98 msv /h maximum.

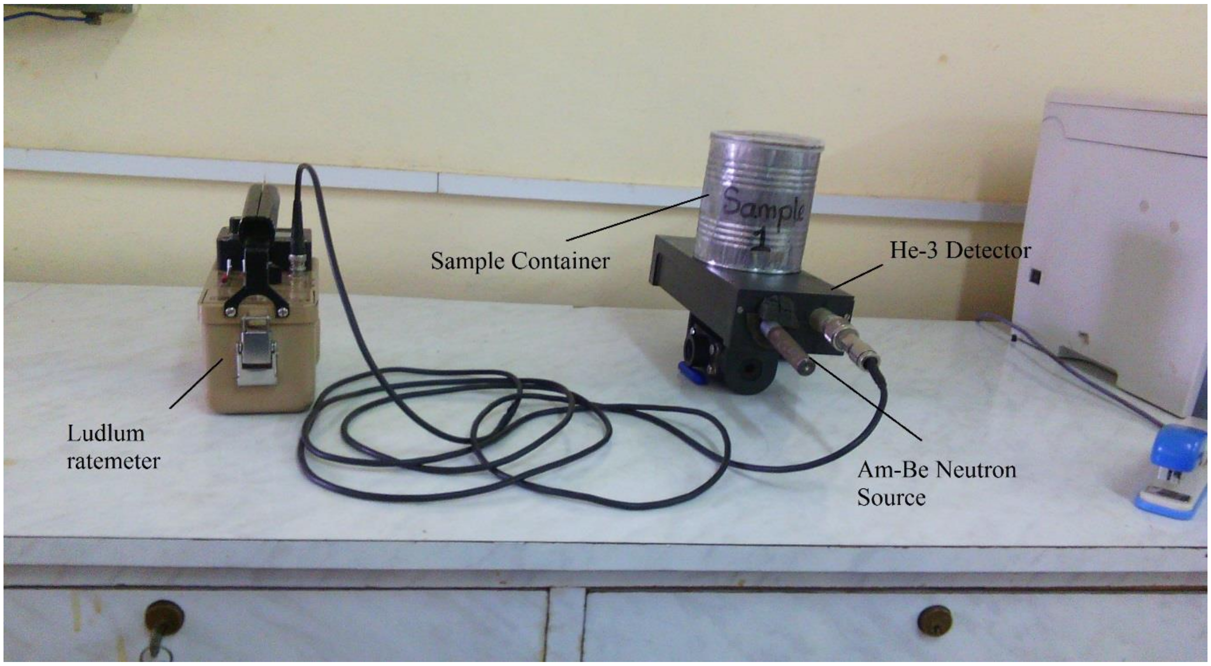

Figure 3.5a: Photograph of Vertical/Top Geometry Set-up

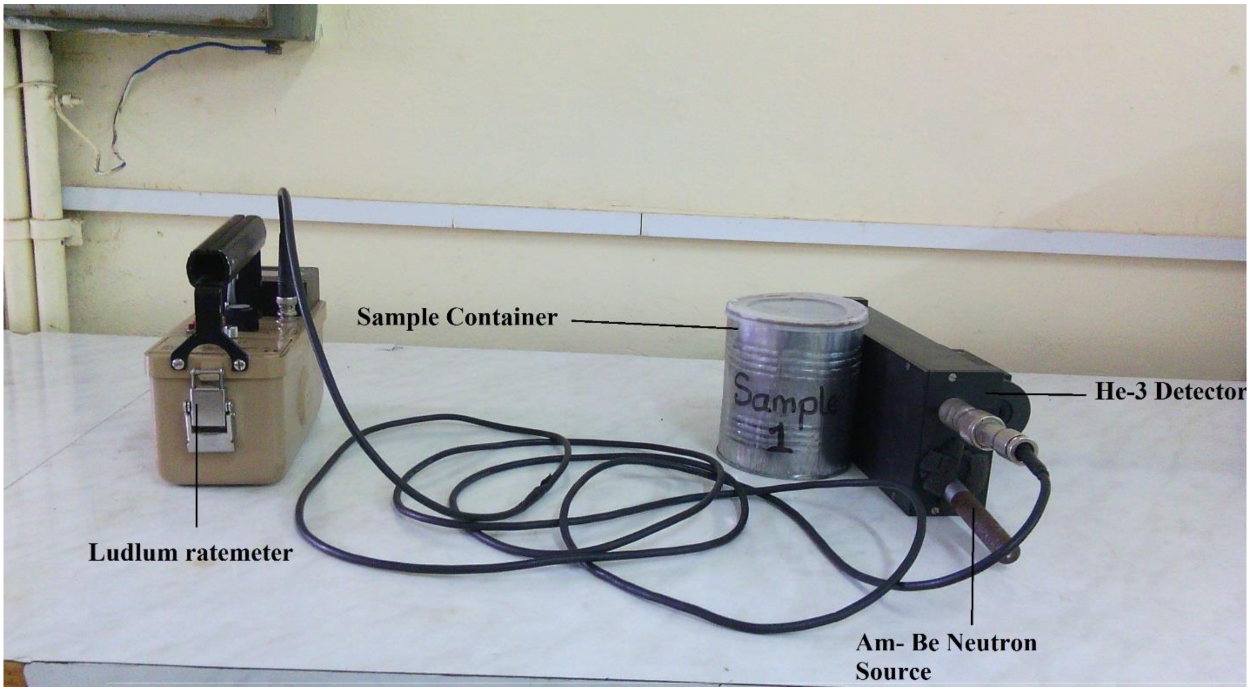

Figure 3.5b: Photograph of Horizontal/Side by Side Geometry Set-up

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Results

Calibration lines were deduced using liquid hydrocarbons containing well-known hydrogen and carbon contents as standards. The measured reflection parameter (**μ**) for different hydrogen (*H*) content in the various standard liquid hydrocarbons for vertical and horizontal geometry arrangements were determined from the Tables 4.1 in Appendix A and plotted in Figure 4.1 and 4.2 respectively. Table 4.2 in Appendix b contains the nuclear data for H, C, and O used in calculating the parameters.

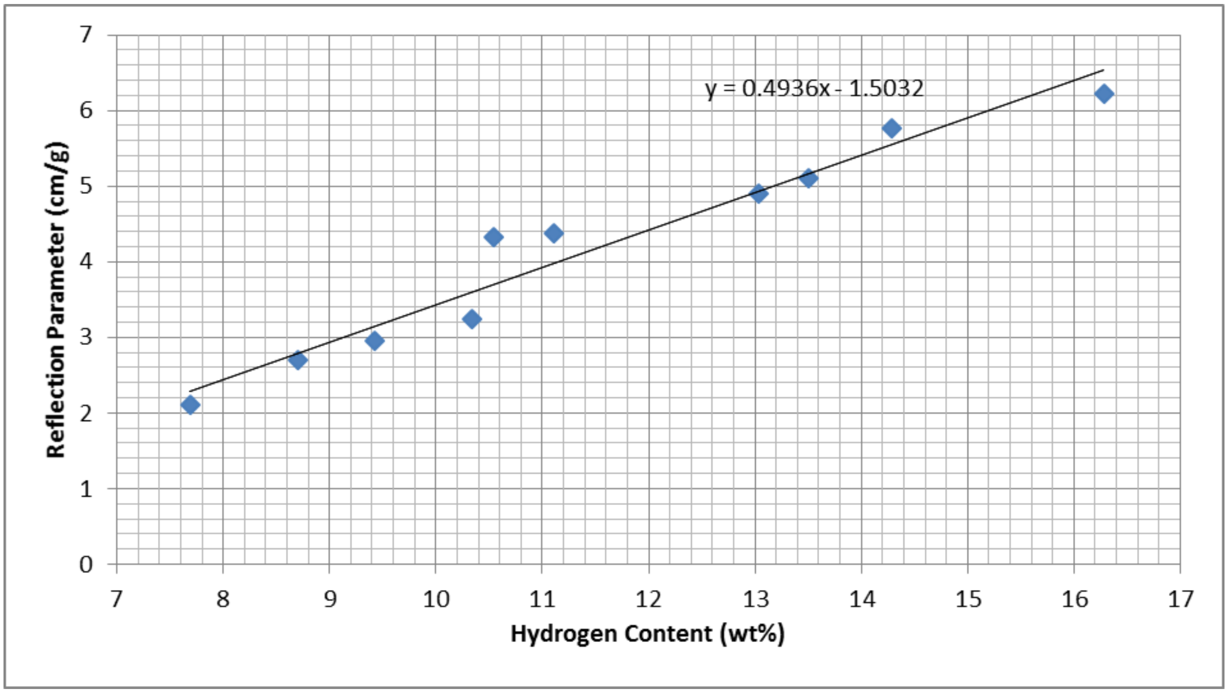

Figure 4.1: Reflection parameter versus hydrogen content for vertical geometry arrangement.

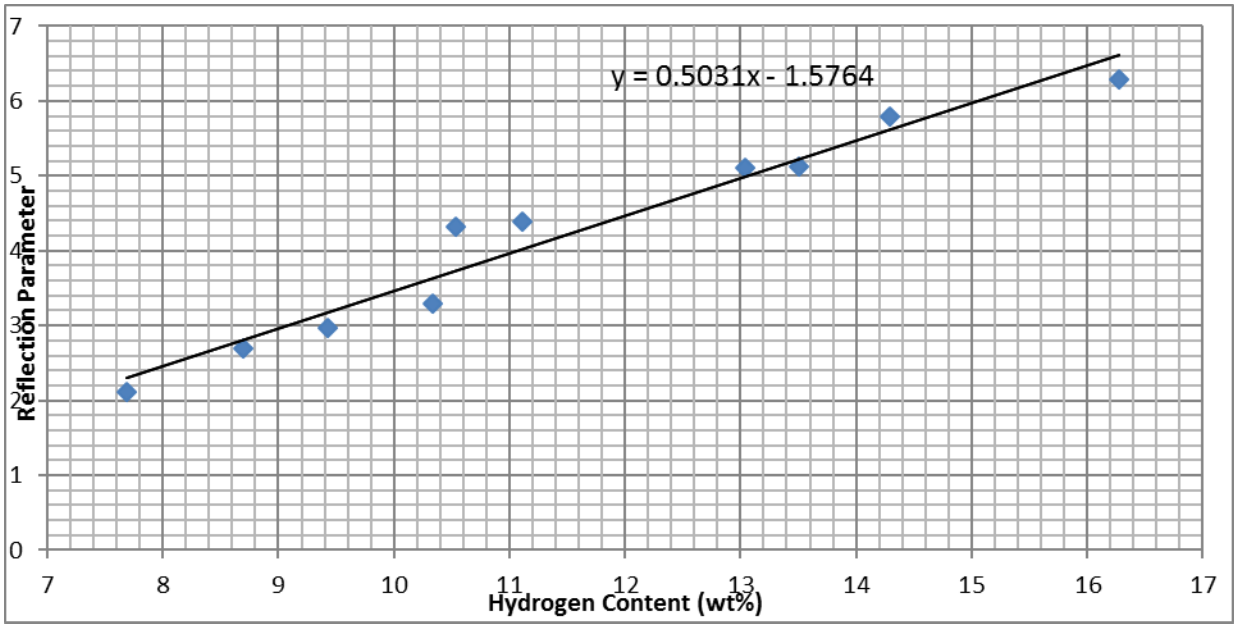

Figure 4.2: Reflection parameter versus hydrogen content for horizontal geometry arrangement.

From the two graphs above, the corresponding equations for the vertical and horizontal geometries are respectively:

- $y = 0.4936x - 1.5032$ 4.1
- $y= 0.5031x - 1.5764$ 4.2

According to [Akaho, et. al., 2001; Jonah, et. al., 1997], for a given geometry,

- $\mu_g = \mu_{0,} + m_g H$ (w %). 4. 3

Where *H* (w %) is percentage weight of hydrogen content in the sample and g is the type of geometry arrangement.

μ_0, *m* varies depending on the regime of hydrogen content in the moderator.

Equation (4.1) and (4.2) can therefore be expressed respectively:

- μ_v = -1.5032 + 0.4936H (wt %) 4.4
- μ_h = -1.5764 + 0.5031H (wt) 4.5

Equation (4.4) and (4.5) would be used further to determine the hydrogen content of the petroleum samples and μ_g can be calculated using a general formula employed by

Akaho, et. al., 2001; Jonah, et. al., 1997, in the form:

$$\mu_g = \frac{1}{\rho}\frac{I-Io}{Io}\ (cm^3/g). \qquad 4.6$$

(I-Io)/Io =relative excess neutron count.

I_0 = thermal neutron count of empty container.

I = thermal neutron count of the container with sample.

$\rho(g/cm^3)$ = physical density of the petroleum product.

It was noticed in the plots of Figure 4.1 and 4.2 that, the trend of results for the two different geometrical arrangements are almost the same and the variation of the reflection parameter (**μ**) with hydrogen *(H)* content, for hydrogen content less than or equal to 10.4% for $\mu \leq$ 3.31, was different from the trend exhibited by higher hydrogen contents in the hydrocarbons.

After irradiating through the empty container, the average count for the vertical geometry (I_{0v}) and the horizontal geometry (I_{0h}) were also determined as follows:

- I_{0v} = (8395+8227)/ 2 =8311 cps 4.7

- I_{0h} = (8628+7988)/ 2 =8308 cps 4.8

The measured average counts and the reflection parameters of the samples for the vertical and horizontal geometrical arrangements were obtained and the results are shown in tables and plotted respectively as follows:

Crude Distillation Unit (CUD) Products

Table 4.3a: Vertical or Top geometry of CUD Products

Sample	Count 1. (I_1)cps	Count 2. (I_2)cps	Average count (I_{av})cps	ρ (g/cm^3)	$\mu_v(cm^3/g)$	**H** (w t %)
Light Napha (Light Gasoline)	11841	11933	11887	0.725	5.935	15.069
Heavy Napha (Heavy Gasoline)	11825	11765	11795	0.770	5.444	14.075
Aviation Turbine Kerosene (ATK)	11839	11893	11866	0.823	5.197	13.574
Kerosene	11937	11861	11899	0.825	5.233	13.647
Gasoil (Diesel)	11939	11891	11915	0.867	5.002	13.179
Residue Fuel CDU	11427	11361	11394	0.925	4.010	11.169

4.3b: Horizontal Geometry of CDU

Sample	Count 1. (I_1)cps	Count 2. (I_2)cps	Average count (I_{avh})cps	ρ (g/cm^3)	$\mu_h(cm^3/g)$	H (wt %)
Light Napha (Light Gasoline)	11931	11845	11888	0.725	5.944	14.948
Heavy Napha (Heavy Gasoline)	11775	11793	11784	0.770	5.434	13.934
Aviation Turbine Kerosene (ATK)	11867	11829	11848	0.823	5.177	13.424
Kerosene	11844	11896	11870	0.825	5.197	13.463
Gasoil (Diesel)	11972	11910	11941	0.867	5.044	13.159
Residue Fuel Oil CDU	11496	11440	11468	0.925	4.112	11.307

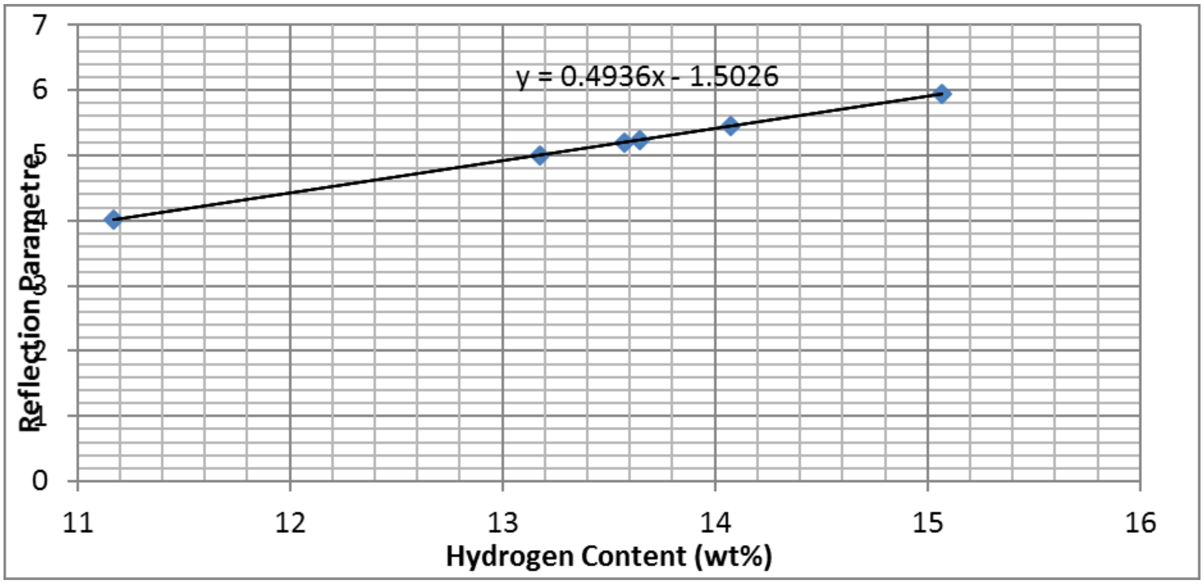

Figure 4.3a: Reflection parameter versus hydrogen content for vertical geometrical arrangement products

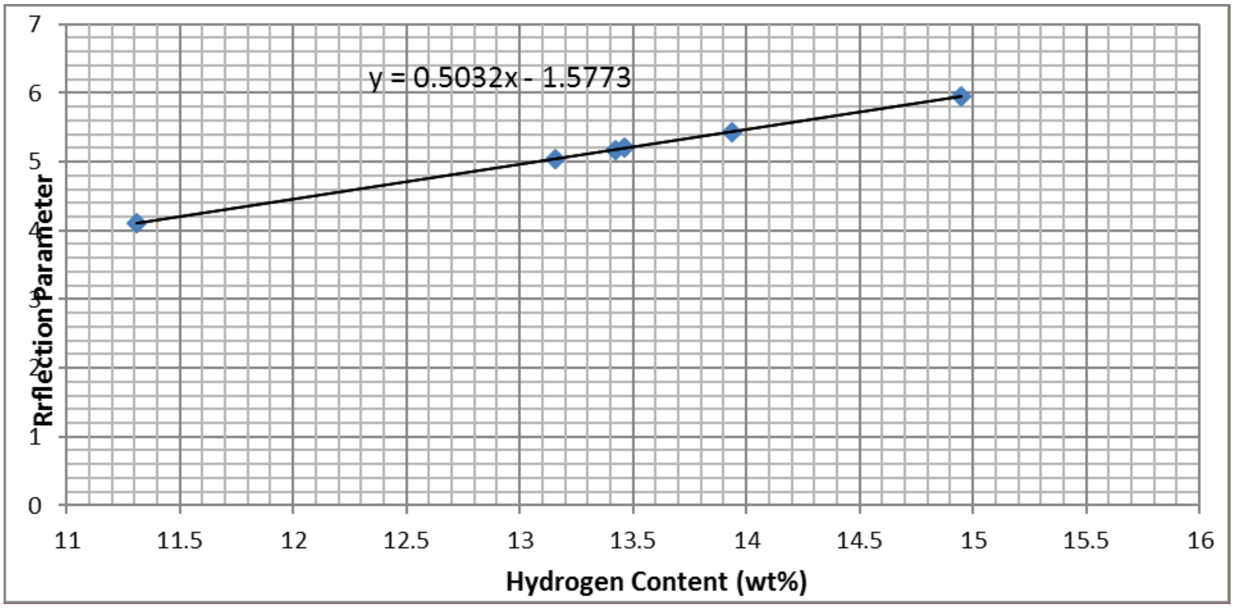

Figure 4.3b: Reflection parameter versus hydrogen content for horizontal geometrical arrangement for CDU products

Residue Fluid Catalytic Cracker (RFCC) Products

Table 4.4a: Vertical or Top geometry of RFCC Products

Sample	Count 1. (I_1)cps	Count 2. (I_2)cps	Average count (I_{avh})cps	$\rho\ (g/cm^3)$	$\mu_v (cm^3/g)$	H (wt %)
Gasoline (Petrol)	11737	11627	11682	0.744	5.452	14.091
Light Cycle Oil	11487	11405	11446	0.918	4.109	11.370
Heavy Cycle Oil	11169	11193	11181	0.985	3.506	10.148
Cracked Residue RFCC	10113	10121	10117	1.057	2.056	7.211

Table 4.4b: Horizontal or Side by Side Geometry of RFCC Products

Sample	Count 1. (I_1)cps	Count 2. (I_2)cps	Average count (I_{avh})cps	$\rho\ (g/cm^3)$	$\mu_h (cm^3/g)$	H (wt %)
Gasoline (Petrol)	11714	11632	11673	0.744	5.444	13.954
Light Cycle Oil	11282	11342	11312	0.918	3.939	10.963
Heavy Cycle Oil	11205	11169	11187	0.985	3.518	10.126
Cracked Residue RFCC	10178	10036	10107	1.057	2.049	7.206

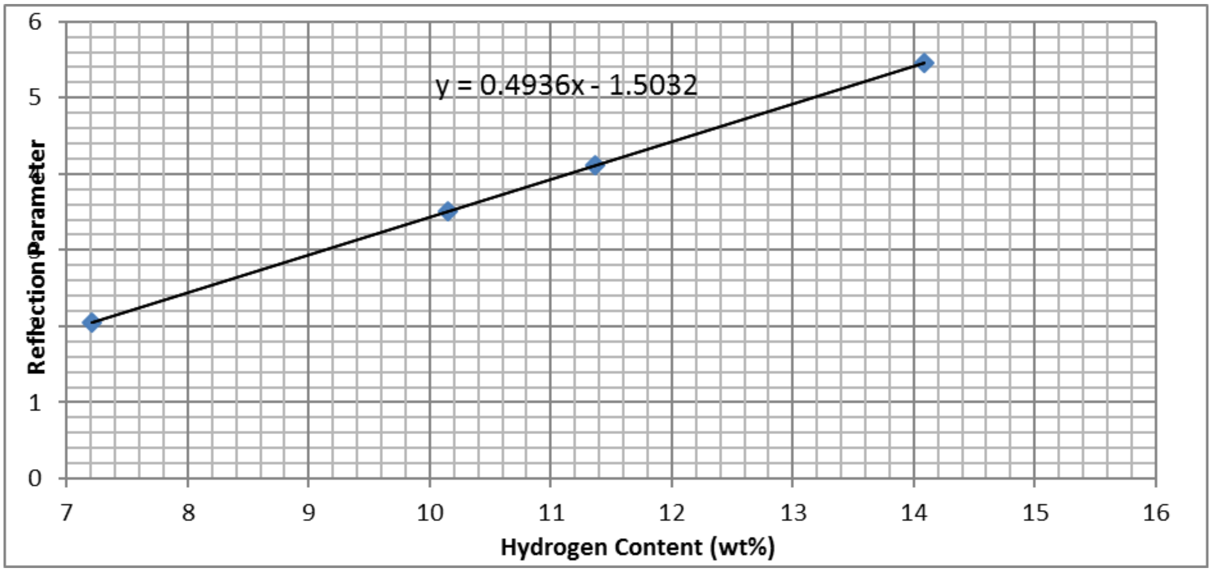

Figure 4.4a: Reflection parameter versus hydrogen content for vertical geometrical arrangement for RFCC products

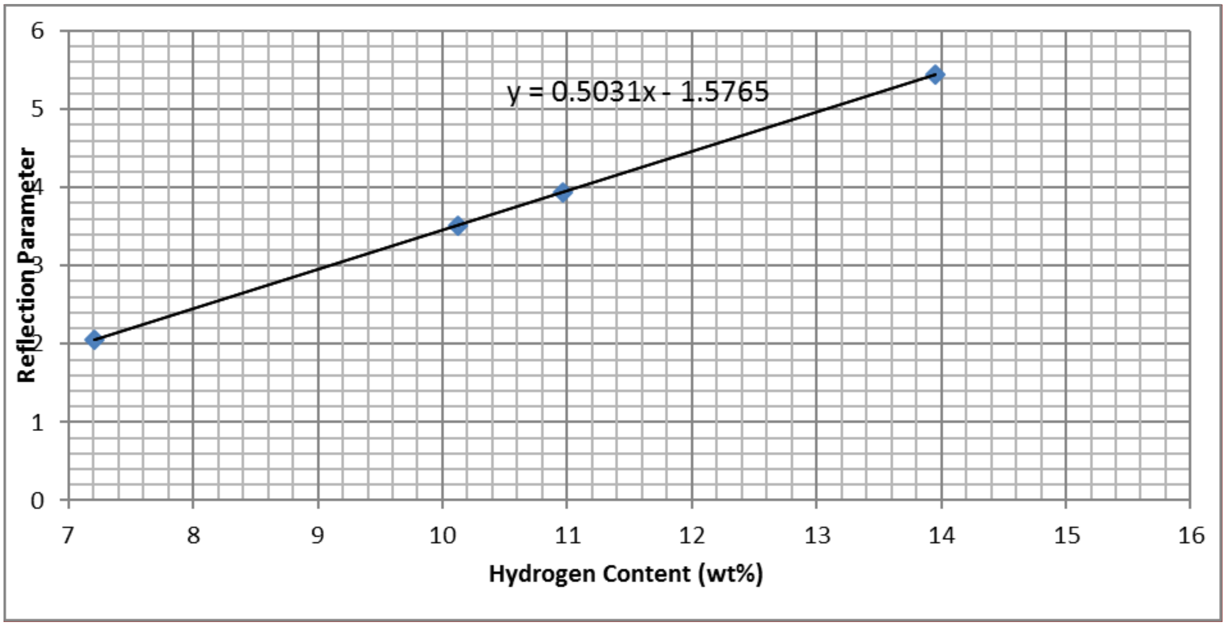

Figure 4.4b: Reflection parameter versus hydrogen content for horizontal geometrical arrangement for RFCC products

Crude Oil Samples

Table 4.5a: Vertical or Top geometry of Crude Oil Samples

Sample	Count 1. (I_1)cps	Count 2. (I_2)cps	Average, count (I_{avh})cps	ρ (g/cm^3)	μ_h(cm^3/g)	H (wt %)
Forcados Crude Oil	11823	11885	11854	0.877	4.861	12.893
Jubilee Crude Oil	11939	11993	11966	0.861	5.108	13.394
Bonny Light Crude Oil	11989	11967	11978	0.857	5.148	13.475

Table 4.5b: Horizontal or Side by Side Geometry of Crude Oi Samples

Sample	Count 1. (I_1)cps	Count 2. (I_2)cps	Average count (I_{avh})cps	ρ (g/cm^3)	μ_h(cm^3/g)	H (wt %)
Forcados Crude Oil	11811	11849	11830	0.877	4.834	12.742
Jubilee Crude Oil	11970	11944	11957	0.861	5.101	13.273
Bonny Light Crude Oil	11932	11994	11963	0.857	5.133	13.336

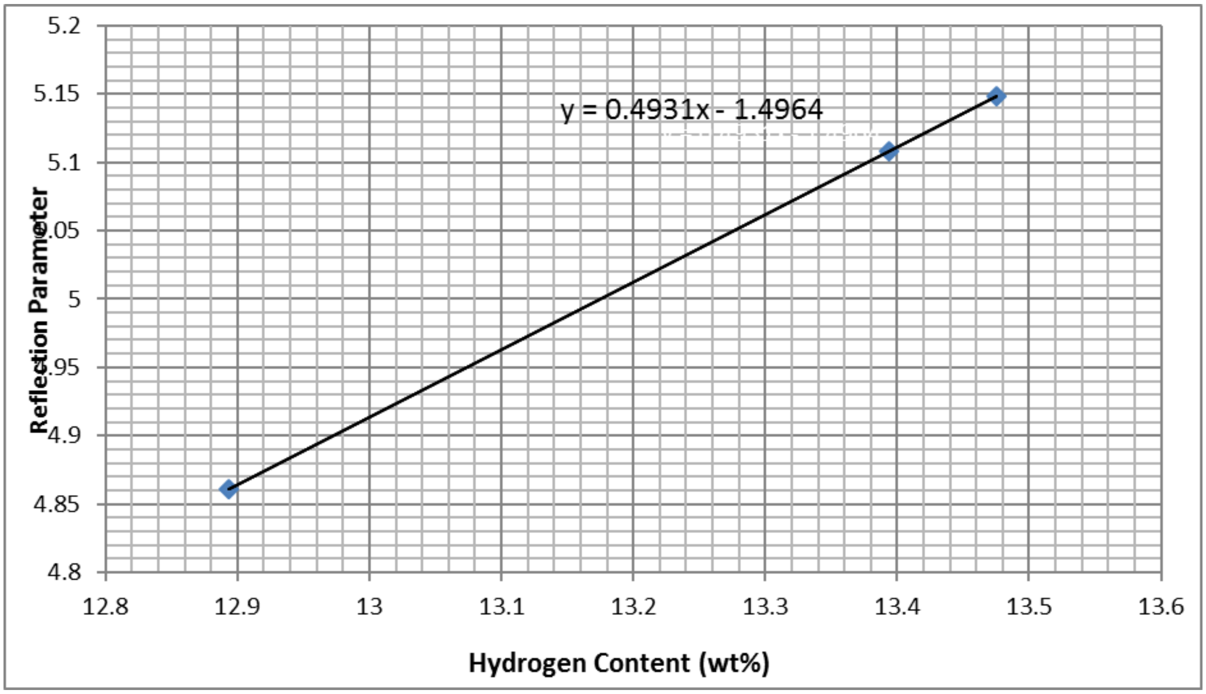

Figure 4.5a: Reflection parameter versus hydrogen content for vertical geometrical arrangement for crude oil samples

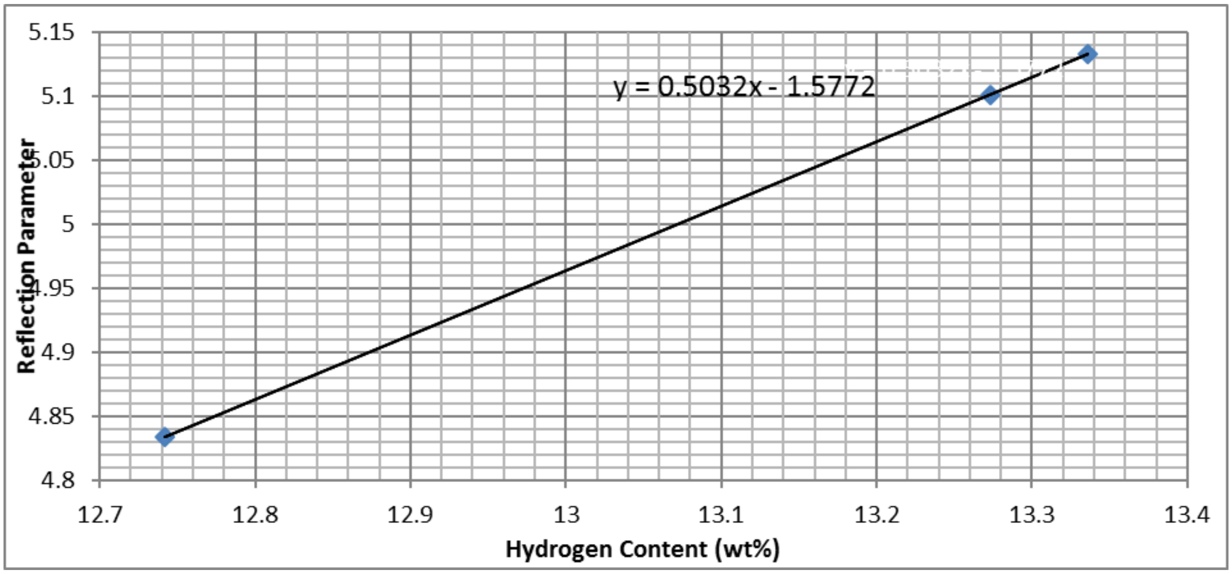

Figure 4.5b: Reflection parameter versus hydrogen content for horizontal geometrical arrangement for crude oil samples

Based on the results of this investigation, it was generally observed that, an increase in the thermal neutron counts indicates high hydrogen count or concentration in a given sample as shown in the tables above. Thus, the more hydrogen atoms present in a petroleum sample, the more thermal neutrons that are produced and can be detected by the neutron counter.

The slope of the linear curves for reflection parameter (**μ**) versus hydrogen content

(hw %) represent the sensitivity of the geometrical arrangement as stated by

Akaho, et. al., 2001; Jonah, et. al., 1997. It was further realized that, the sensitivity was higher with horizontal geometrical arrangements despite the high values registered for average relative excess count in the case of vertical geometrical arrangements. Furthermore, it was noticed that, hydrogen contents determined in the petroleum products such as; aviation fuel, petrol, diesel and kerosene as well as crude oil samples from Nigeria (Bonny light and Forcados) are comparable to values obtained with those reported for previous studies using different methodologies, Jonah, et. al., 1997; Akaho et. al., 2001.

The results also revealed that, the volatility of petroleum products increases with increases in hydrogen content and decreases with increasing in density of the products.

In addition, it was recognized from the trends shown in the tables that samples of high percentage of hydrogen content are likely to be of most volatile and therefore more combustive.

It was equally appreciated that, the hydrogen content was high in Nigeria bonny light crude oil and Ghana Jubilee crude oil samples whiles a low percentage was recorded in Forcados crude oil sample. This indicates that, bonny light and Jubilee crude oils can be classified as ‘Light / Sweet Crude Oil’ and therefore can be recommended as of high economic value and best crude oil for refining.

4.2 Percentage Error

The percentage error (% E), for all geometries were calculated using a general formula:

- $$\% = \frac{\text{Actual value} - \text{measured value}}{\text{actual value}} \times 100 \qquad (4.9)$$
- $$\%\,E = \frac{(Hw\%) - (hw\%)}{(Hw\%)} \times 100 \qquad (4.10)$$

✓ (Hw %) is percentage hydrogen content of known liquid hydrocarbon.

✓ (hw %) is percentage hydrogen content of petroleum products.

h(w %) was deduced from the equations of the graphs for all the geometries of the petroleum samples and are shown in the tables below:

Percentage error for hydrogen content h(w %) of CDU products

Table 4.6a: Vertical or Top geometry for h(w %) of CDU Products

Sample	$\mu_v(cm^3/g)$	**H** (w t %)	h(w %)	% E
Light Napha (Light Gasoline)	5.935	15.069	15.068	0.0066
Heavy Napha (Heavy Gasoline)	5.444	14.075	14.073	0.0142
Aviation Turbine Kerosene (ATK)	5.197	13.574	13.573	0.0074
Kerosene	5.233	13.647	13.645	0.0147
Gasoil (Diesel)	5.002	13.179	13.177	0.0152
Residue Fuel CDU	4.010	11.169	11.168	0.009

Table 4.6b: Horizontal Geometry for h(w %) of CDU Products

Sample	$\mu_h(cm^3/g)$	H (wt %)	h(w %)	% E
Light Napha (Light Gasoline)	5.944	14.948	14.947	0.0067
Heavy Napha (Heavy Gasoline)	5.434	13.934	13.933	0.0072
Aviation Turbine Kerosene (ATK)	5.177	13.424	13.422	0.0149
Kerosene	5.197	13.463	13.462	0.0074
Gasoil (Diesel)	5.044	13.159	13.158	0.0076
Residue Fuel CDU	4.112	11.307	11.306	0.0088

Percentage error for hydrogen content h(w %) of RFCC products

Table 4.7a: Vertical or Top geometry for h(w %) of RFCC Products

Sample	$\mu_v(cm^3/g)$	H (wt %)	h(wt %)	% E
Gasoline (Petrol)	5.452	14.091	14.089	0.0142
Light Cycle Oil	4.109	11.370	11.369	0.0088
Heavy Cycle Oil	3.506	10.148	10.146	0.0197
Cracked Residue RFCC	2.056	7.211	7.208	0.0416

Table 4.7b: Horizontal Geometry for h(w%) of RFCC Products

Sample	$\mu_h(cm^3/g)$	H (wt %)	h(wt %)	% E
Gasoline (Petrol)	5.444	13.954	13.952	0.0143
Light Cycle Oil	3.939	10.963	10.961	0.0182
Heavy Cycle Oil	3.518	10.126	10.125	0.0099
Cracked Residue RFCC	2.049	7.206	7.204	0.0278

Percentage error for hydrogen content h(w %) of crude oil samples

Table 4.8a: Vertical or Top geometry for h(w%) of Crude Oil Samples

Sample	$\mu_v(cm^3/g)$	H (wt %)	h(wt %)	% E
Forcados Crude Oil	4.861	12.893	12.892	0.0078
Jubilee Crude Oil	5.108	13.394	13.392	0.0149
Bonny Light Crude Oil	5.148	13.475	13.474	0.0074

Table 4.8b: Horizontal Geometry for h(w%) of Crude Oil Samples

Sample	$\mu_v(cm^3/g)$	H (wt %)	h(wt %)	% E
Forcados Crude Oil	4.861	12.893	12.892	0.0078
Jubilee Crude Oil	5.108	13.394	13.392	0.0149
Bonny Light Crude Oil	5.148	13.475	13.474	0.0074

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The NBT method has been used to determine the hydrogen content of the petroleum products. The experimental set-up consists of a source-holder housing a 1Ci Am-Be neutron source and a He-3 neutron detector.

A total of thirteen (13) petroleum samples were considered and a good relationship between the values were obtained.

The following conclusions have been drawn:

1. From the two plots, the gradient of the horizontal geometries are noticed to be higher, this shows that the sensitivity of this arrangement is better despite the high excess count recorded in the case of the vertical arrangements as stated by Akaho, et. al., 2001; Jonah, et. al., 1997. Therefore, horizontal geometry is recommended for this method.
2. The method also confirmed that, products with high hydrogen content have less densities and more volatile (combustive), therefore, this method could be used to check adulteration of petroleum products in the Ghanaian market.

3. It was also noticed that, the hydrogen content was high in both Nigeria bonny light and Ghana Jubilee crude oil samples but low in Forcados crude oil sample. This confirmed that, the Jubilee crude is one of best crude oil brand and therefore suitable

for refining. This suggests that the method could be used to determine and classify crude oil samples for purposes of standardization and quality control.

4. Based on the theoretical analysis and the experimental evidence, the measured values which were fitted to two linear equations were compared and established to be consistent with those obtained using different methodologies employed by Akaho, et. al., 2001; Jonah, et. al., 1997.

5. The ranges of the errors were obtained and noticed to be within the recommended ± 10% deviation from the true value and therefore suggested that, all measurements were such as instrument calibration, count observation and many more were done in accordance with lay down procedures in order to obtain reliable data.

6. This study has demonstrated that, the neutron backscatter technique could generally be used as an alternative method for quality control and standardization in the petroleum industries.

5.2 Recommendations

1. It is recommended that a more portable system must be built based on the present studies for field determination of adulterated fuel in Ghanaian market.

2. The technique can also be employed to look at oil content of shea nut in Ghana, comparing the stages (ripe, and under ripe fruit) in order to maximize extraction.

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APPENDICES

Appendix A

Table 4.1: Data for calibration curves for determination of H contents for the top and side by side geometrical arrangements.

Standard	ρ (g/cm^3)	μ_v (cm^3/g)	μ_h (cm^3/g)	***H*** (wt %)
Benzene (C_6H_6)	0.879	2.11	2.11	7.69
Toluene (C_7H_8)	0.866	2.70	2.69	8.70
Xylene $C_6H_4(CH_3)_2$	0.864	2.96	2.96	9.43
Acetone $(CH_3)_2CO$	0.792	3.24	3.29	10.34
Propylene glycol $\{CH_3CH(OH)\,CH_2OH\}$	1.044	4.32	4.32	10.53
Water (H_2O)	1.00	4.37	4.39	11.11
Ethanol (C_2H_5OH)	0.790	4.90	5.10	13.04
Butyl-Alcohol (C_4H_{10})	0.789	5.10	5.13	13.51
Paraffin oil (CH_2)	0.88	5.77	5.79	14.29
Hexane (C_6H_{14})	0.66	6.23	6.23	16.28

Appendix B

Table 4.2: Nuclear data for H, C, and O used in calculating the parameters

Element	Atomic Weight
Hydrogen (H)	1.00797
Carbon (C)	12.01115
Oxygen (O)	15.99940