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Progress on Electromagnetism: Electromagnetic Sounding of Hydrocarbons and the Role of Antenna

[1]M.E. Emetere, [1]O.C. Olawole and [2]O.A. Odetunmibi
[1]Department of Physics, [2]Department of Mathematics,
Covenant University, Ota, Nigeria

Abstract: The physics of explorative electromagnetic methods for discovering hydrocarbon reservoir was reviewed. The shortcomings of each method were listed to seek how to improve its efficiency. Maxwell's postulates or equations apply to all electromagnetic methods of exploration and have enjoyed several years of successes. However, the common challenge of noise levels had undermined the accuracy of electromagnetic methods. We propose that the noise level is due to multiple particulates interaction that attenuates signals. This challenge can be solved by considering the quantum mechanics of the interacting particles. Seven new electromagnetic postulates/equations have been enacted from literature and four of the postulates-tested. Hence, the applicability of the postulates has been affirmed. Therefore if the computer codes of some of the postulates are developed it may resolve problems relating to noise and improve the efficiency of the methods for geological exploration.

Key words: Electromagnetic methods, electromagnetic sounding, maxwell postulates, electromagnetic codes, efficiency

INTRODUCTION

The economic value of hydrocarbon is quite high and had necessitated its exploration in all parts of the world using various methods. However, there are three broad methods used in sourcing for hydrocarbons from within the earth. These methods include:

- Geophysical method/survey
- Remote sensing
- Wild catting

The electromagnetic method falls within the geophysical method. How is electromagnetism related to the earth crust? The earth we live on, has its own magnetic field which is generated from deep down (the Core) and moves all the way up till it meets the solar wind (produced by the sun). A knowledge of the earth's magnetic field is what aids geoscientist in the exploration of the earth's minerals, hydrocarbons, etc. Some geophysical methods for hydrocarbon exploration that work on the principles of electromagnetism includes:

- Magnetotelluric method (MT)
- Seabed logging method (CSEM)
- Transient electromagnetic sounding method (TEM)

These three technologies provide different information about the earth's interior. The combination of these three techniques will then provide us with information that will enable us to get the actual location of hydrocarbon from deep down the earth (Gregor and Sinha, 2000). Electromagnetic fields travels deep into the earth to survey the earth subsurface and then interacts with conductive layers of the earth crust. The electromagnetic wave reaches the surface layers of the earth and establishes an interaction first with the sea waters and various structures that can readily conduct electricity to a high or low extent. From basic physics, the conductive bodies would cause the electromagnetic waves to experience attenuation. Rocks as we know are very poor conductors of electricity but some fluids of saturation have vast and various conductivity levels. As some rock forms are very good conductors, for example brine and also oil and gas have very high resistivity levels, that is they are very poor conductors of current. So, as the electromagnetic waves move within the earth, they establish various interactions with the conductive matter/ structures that give responses to the waves. They then enhance the further propagation of the wave back to the surface of the earth. Now, we know that when an ordinary seismic wave is propagated into the earth, the irregular geometry of the signal and response is most of the time dissipated but even though that of the electromagnetic

Corresponding Author: M.E. Emetere, Department of Physics, Covenant University, Ota, Nigeria

waves may also show dissipation signs as analogues of the earlier mentioned seismic waves, they are greatly more productive and efficient because of their uncommon behaviour and origin.

When the waves are propagated, the ones that are highly dependent on time (time varying) would induce forms of eddy current loops on the layers of the earth that tend to be current conductive. The characteristics of these currents depend on the magnitude, rate of change in time and also the level of resistance of the parent signal (source signal).

As these currents continue to move, they would establish a magnetic field which in turn proceeds to propagate from the source. The field of current propagated back to the surface of the earth after the currents have completed their cycle is the measured by sensors that are positioned at various points on the surface of the earth. The eddy current that finds its way into the conducting medium tends to lay out an opposition to the charges in the parent field.

When the eddy current is returning, the result that emanates together with that of the energy transfer to the signal of response serves as the attenuation of the electromagnetic wave.

Thus, as the wave progresses further with increased depth into the conducting medium, it begins to weaken which in turn makes the field of response relatively smaller. As this cycle continues, the source signal begins to decay and weaker signals are sent with relative increase in the depth within the conducting medium and this phenomenon is known as the skin effect. The principles of electromagnetism can also be used to distinguish if a particular area is oil bearing or water bearing, depending on the type of activity to be carried out there. In places like India with such geological problems like the presence of sub-basalt and continuous intrusions of carbon, electromagnetic is very essential if any form of geological activity is to be carried out there.

MATERIALS AND METHODS

Documented challenges of using electromagnetic soundings: Electromagnetic methods are very versatile and sometimes would not give the results expected during activities involving seismic. So, great caution is to be taken while carrying out surveys and making predictions on the field. In section one, we mentioned that the knowledge of the earth's magnetic field is what aids Geoscientist in the exploration of the earth's minerals, hydrocarbons, etc. Somehow, the global climate change has greatly influence the earth's magnetic field (Courtillot *et al*., 2007). This has compromised the electromagnetic soundings in a way.

Second, the application of any electromagnetic methods depends on the choice of the geoscientist. Sometimes, these choices may be biased. There are technicalities between the Magneto Telluric (MT) and electromagnetic soundings. The MT measurements do not work properly with thin layers of the earth with high resistivity and are not very effective when used to search for/ explore potential oil reservoirs. But now the electromagnetic sounding method is readily available for this cause. It is quite similar to the MT method of survey because they both produce recordable results using the same receivers. The electromagnetic sounding method focuses on results and interpretations obtained from controlled source.

Nevertheless, when an MT method is initially used, the results and interpretations obtained can serve as a starting foundation for the electromagnetic sounding method. In other words, the technical know-how of the geoscientists dictates what choice to make.

Third, it has been noticed that the earth has become denser with time, so hydrocarbon explorers have to penetrate deeper into the earth in order to attain their desired result.

Theoretical contributions: From the basics, Maxwell postulated four equations which explain the use of electrodes of varying sizes and conductivity. Equation 1-4 represents the Coulomb's law, Faraday's law, Ampere's law and Gauss's law, respectively.

$$\nabla \bullet E = \frac{\rho}{\varepsilon_0} \tag{1}$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \tag{2}$$

$$\nabla \times B = \mu_0 J + \mu_0 \varepsilon_0 \frac{\partial E}{\partial t} \tag{3}$$

$$\nabla \bullet B = 0 \tag{4}$$

Where:
E = The electric field
ρ = The charge density
ε_0 = The permittivity of free space
B = The magnetic induction
μ_0 = The permeability of free space
J = The current density

Resistivity is also commonly used to describe any of the electromagnetic exploration methods. Resistivity is inversely proportional to conductivity but directly related to certain properties such as temperature, porosity, permeability, etc.

$$\rho = \frac{R \bullet A}{L} \quad (5)$$

Where:

ρ = Resistivity of the rock (Ωm)
R = Resistance (Ω)
L = Length (m)
A = Area of the resistive cross section

Laplace equation is used in evaluating the resistivity of the earth and this is done using field data. Electrical resistivity of different rocks depends on the following properties: temperature, porosity of the rock, permeability of the rock, salt content of the fluid. Porosity is the ratio of the pore volume to the bulk volume of the rock body:

$$\phi = \frac{V_p}{V_b} \quad (6)$$

Where:

ϕ = Porosity
V_p = Pore volume
V_b = Bulk volume

Electromagnetic sounding: This method is done vertically into the subsurface. Electromagnetic sounding is used to study the changes in subsurface resistivity in relation to the variations in depth of penetration as a result of skin effect. The skin effect is used for the non uniform distribution of the electromagnetic field.

Electromagnetic sounding methods may be passive or active; that is the ones that use natural sources and the ones that make use of manmade sources. The ones that make use of natural sources of the electromagnetic field is the earth's magnetotelluric methods. This depends on the measurement method for exploration. The active methods can be divided into frequency and transient. In the frequency method, the electromagnetic field of the electric or magnetic dipole is recorded. The frequency sounding with an active source is referred to as Harmonic sounding. The transient method is done according to the distance from the active source into the sounding methods. Electromagnetic sounding methods are used during exploration for hydrocarbon in the subsurface. It helps to determine the distribution of electrical resistivity of rock bodies in the earth's subsurface (Constable *et al*., 1987).

Resistivity is inversely proportional to conductivity, therefore rocks respond to resistivity or conductivity signals. The oil-bearing rocks have very high resistivity and low conductivity while the water-bearing rocks have low resistivity and very high conductivity. The formed resistivity is associated with the porosity of the reservoir and other properties which will be explained below. The main paths in the reservoir rock possess certain values of resistivity between the oil-bearing rocks and the water-bearing rocks. Various electromagnetic methods help to monitor the reservoir rocks closely. Seismic methods make it difficult to acquire the variations in the fluid contents of the reservoir rocks because of the different seismic velocities that the oil-bearing or water-bearing rocks posses. Based on distinguished properties, the electromagnetic methods with advance the resolution to map the oil-water contact better and also monitor the reservoir rocks for future drilling purposes (Fig. 1). The resistivity of a rock is the resistance in ohms

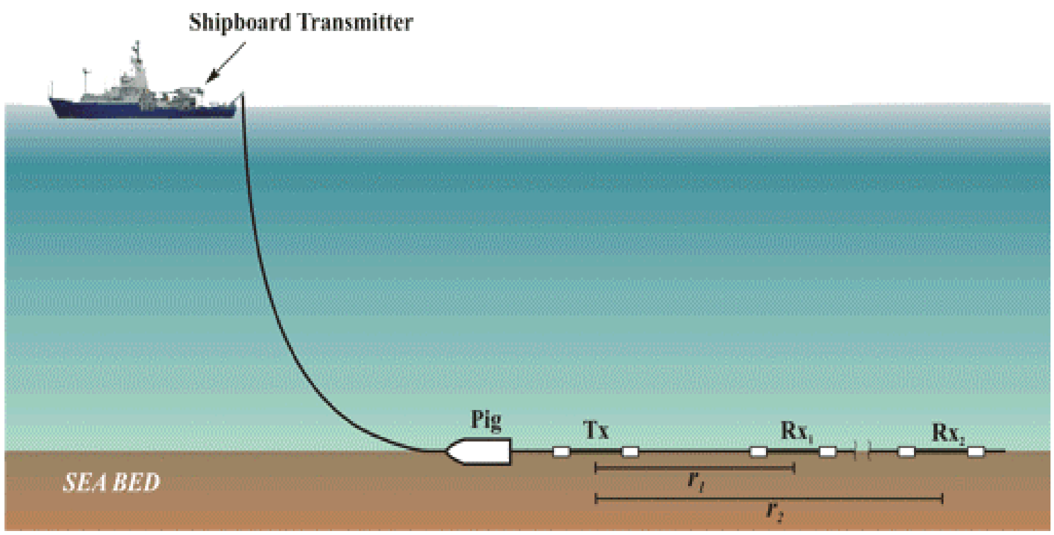

Fig. 1: Off-shore electromagnetic sounding; http://www.physics.utoronto.ca/~edwards/

between the opposite sides of a unit volume of the rock. Resistivity is inversely proportional to conductivity but directly related to certain properties, such as, temperature, porosity, permeability, etc.

RESULTS AND DISCUSSION

Magnetulluric technique: This method has the greatest depth for exploration compared to other methods. In this method, the passive change in the earth's magnetic field is used as source for signal. These variations are induce electric fields (eddy current) into the subsurface which are measured on the earth's surface in orthogonal directions. These electric fields are also known as telluric currents. These magnetic fields are recorded by induction loops while the electric fields are recorded by pair of electrodes (containing solutions like copper sulphate or lead chloride). The earth's natural electromagnetic field is made up of different frequencies, intensities and origin. This earth's subsurface structure has an irregular structure which varies with time in both magnitude and direction. The sun emits charged particles from the sun which are incident the earth's magnetosphere; therefore electromagnetic fields with frequencies less that 1Hz are applied. This effect of the sun's radiation on the earth is agreed between differences in the magnetotelluric fields (Sternberg *et al*., 1988).

The electric composition of the magnetotelluric field is known as telluric component (Fig. 2). The two compositions are magnetic and telluric which show potential horizontal components at the surface of the earth. This is as a result of refraction of certain electromagnetic waves in the subsurface. The Magneto Telluric (MT) method has the largest exploration depth of all resistivity techniques, some are tens to thousands of kilometers, this is depending on the measuring duration and is basically the only technique for understanding the deep resistive futures. This is very similar to the TEM technique, the MT technique possesses but this is due to improvements in the electronic technology and including the data industries in contemporary periods, progressed exceedingly, on even the acquiring terminal which also involves the selected device or equipment and even the measurement methods as well as it is on the data analysis and the upending of the acquired data. Magnetotelluric, MT has arrived and has become practically standard equipment in the area of surface exploration for the geothermal pending resources.

Contemporary magnetulluric technique: The capacity of the contemporary magneto telluric, MT to picture the subsurface features has progressed dramatically in the contemporary ages. This has also equally been controlled by the improvements in both the implementation aspect and equally interpretation. Ancient magneto telluric, MT techniques were attached in vessels and needed apparatuses for the power and an operator to be involved for all of data measuring. This determined and both approach and the volume of mounted receiving stations that could be acquired each day per field member crew. These constituents have been vastly decided with contemporary MT systems. Contemporary magnetotelluric MT equipment are now very concise and broadly and well fully altered. They can be carried out by haversack to localized sites and are left and are not attended to so as to record time group data over the period of the night.

The drastic reduction in instrumental size is exemplified. Another region in which the major progresses have been carried out is in the electric signal processing step by step set of instructions used to transform

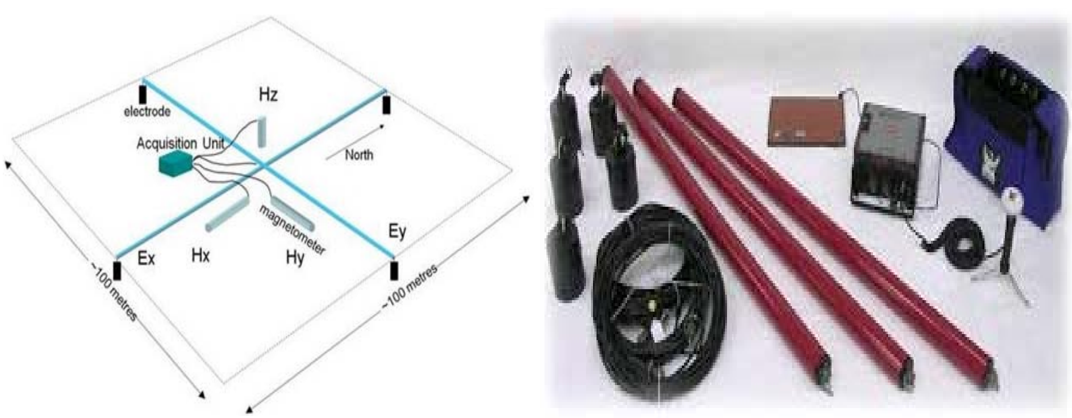

Fig. 2: Magnetulluric electromagnetic soundings; http://en.openei.org/wiki/Magnetotellurics

acquired data from the time domain to the typical frequency domain. Effective noise suppression through the remote source techniques that requires automated recording at various specified stations. In ancient magnetotelluric, MT techniques, this was mostly carried out in a successively and with very precise clocks that were contemporized occasionally. The issue associated with timing has been modernized with the utility of timing electric signals from various specified GPS satellites so far the natural or relative trees permits the sight position of the sky.

Time group manufacturing has benefited from the gradual improvements of step by step of algorithms that make use of largely placed statistics to minimize the various estimates of the obvious resistive properties that are manufactured by a period of time series. These techniques are effectively eliminate bad acquired data sections in an automatized practice, resulting in a monumental dimension in the attempt consociated with magneto telluric, MT period groups of manufacturing. The progresses have permitted for larger sizes of magneto telluric MT acquired data to be acquired and most representation is now available with 2 and 3 dimensional prototyping and alternation of selected algorithms.

Role of antenna for enhanced electromagnetic soundings: Sea bed logging uses the horizontal electric dipole antenna that operates at a short distances from the original position and frequency 0.25-10 Hz (Nasir *et al*., 2011). Frequency and offset of the antenna are important to determine target depth which may be shallow or deep depth. Hydrocarbon at deep depth is usually probed by using multiple frequency range to query the electromagnetic waves interacting with the hydrocarbon reservoir. The common challenge in the electromagnetic method is the presence of different noise level as deeper depth is probed. We propose that the noise level emanates from multiple particulate interactions which is not accounted for in the original Maxwell's equation. Recently, the inclusion of the quantum mechanics of interacting particles and electromagnetism have been suggested (Sinha and Amaratunga, 2015; Emetere *et al*., 2015; Moses, 2015; Emetere, 2014). The mathematical model incorporating the quantum mechanics and electromagnetism has been given (Moses, 2015). Hence, the reconfiguration of the electromagnetic codes of the probe device is essential to improve the control method and reduce its noise level. Emetere *et al.* (2015) gave seven postulates from the mathematical modeling of quantum mechanics and electromagnetism. The first four postulates have been verified upon its application to salient aspect of the antenna. For example, postulate 1 was used to resolve the magnetic field effects on the sheath of the plasma antenna (Gregor and Sinha, 2000). Postulate 2 was used to resolve fading in multipath propagation in ultra wideband application (Gregor and Sinha, 2000). Postulate 3 was used to improve the respond time in detecting natural lightning using any electromagnetic device (Emetere *et al*., 2015). Recently, postulate 4 is applied to the MRI antenna to examine patient's excess exposure to electromagnetic radiation. Hence, new techniques have been propounded to improve the electromagnetic soundings.

CONCLUSION

The physics of explorative electromagnetic methods in discovering hydrocarbon or water reservoir has been discussed to see the need for further improvements. From the basics, Maxwell's postulates are applied to all electromagnetic methods of exploration. However, the common challenge of noise levels had undermined the accuracy of electromagnetic methods. We propose that the noise level is due to multiple particulates interaction which can be solved by considering the quantum mechanics of the particles. Seven postulates have been given and four of the postulates-tested. Hence, the applicability of the postulates has been affirmed. Therefore if the computer codes of some of the postulates are developed it may resolve noise level challenges.

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