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Original Research

$Mn_{0.8}Zn_{0.2}Fe_2O_4$ nanoparticulates spinel ferrites: An approach to enhance the antenna field strength for improved magnitude versus offset (MVO)

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Abstract

Electromagnetic signals in deep reservoir are very weak so that it is difficult to predict about the presence of hydrocarbon in seabed logging (SBL) environment. In the present work, $Mn_{0.8}Zn_{0.2}Fe_2O_4$ nanoferrites were prepared by a sol–gel technique at different sintering temperatures of 450 °C, 650 °C and 850 °C to increase the strength of electromagnetic (EM) antenna. XRD, FESEM, Raman spectroscopy and HRTEM were used to analyze the phase, surface morphology and size of the nanoferrites. Magnetic properties of the nanoferrites were also measured using an impedance network analyzer. However, nanoferrites sintered at 850 °C with initial permeability of 200 and Q factor of 50 were used as magnetic feeders with the EM antenna. Lab scale experiments were performed to investigate the effect of magnetic field strength in scale tank. SPSS and MATLAB softwares were also used to confirm the oil presence in scale tank. It was observed that the magnitude of the EM waves for the antenna was increased up to 233%. Finally, the correlation values also show 208% increase in the magnetic field strength with the presence of the oil. Therefore, antenna with $Mn_{0.8}Zn_{0.2}Fe_2O_4$ nanoferrites based magnetic feeders can be used for deep water and deep target hydrocarbon exploration.

Keywords: Nanoferrites; Transmission Electron Microscopy; Initial permeability; Q factor; Antenna

1. Introduction and background

Currently, the control source electromagnetic (CSEM) method is used for the detection of oil below the seafloor in oil and gas industry. Horizontal electric dipole (HED) antenna is usually towed at 30 m above from the seafloor to transmit the EM signals underneath the sea bed. Receivers are placed on the sea floor to detect direct, reflected and guided waves from the seabed. Guided waves from the deep target have very low magnetic field strength [1–13], whereas oil and gas industry require strong electromagnetic signals with low signal to noise ratio for the detection of the deep targets. Nanoferrites have been used in many practical and technological applications, such as, magnetic devices in electronics, optical and microwave devices, memory storage, waveguides, isolators, permanent magnets, inductors, circulators phase shifters, relays, sensors and antennas etc. [14,15]. Due to their better magnetic characteristics, nanoferrites have been used as a magnetic feeder to enhance the magnetic field strength of the antenna. Spinel ferrites with nanophase characteristics combine interesting soft magnetic properties with rather high initial permeability and large electrical resistivity [16]. Manganese zinc (MnZn) ferrites are one

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of the most important soft ferrite ceramic materials which have stable frequency behavior of the permeability with high saturation magnetization [17,18]. Due to chemical composition and crystal structure of MnZn ferrite, this material has high initial permeability, saturation magnetization and relatively low eddy current losses compared with other alloy cores. In order to synthesize nanoferrites of MnZn spinel ferrites, various processing techniques including non-conventional methods have been developed. However, each of these techniques has its specific limitations. Non-conventional techniques such as co-precipitation, thermal decomposition, sol–gel, auto combustion, hydrothermal, self-propagating high temperature synthesis (SHS) and other wet chemical techniques have been used [19]. A sol–gel method is preferable because it is simple, fast and cost effective as compared to other methods. The major advantage of the sol–gel method is that it is easier and needs inexpensive raw materials with fast reaction rate which resulted better homogeneity and morphology of the final product. It was found that the magnetic properties such as saturation magnetization of manganese ferrites depend on the chemical composition and morphology of the samples as well [20,21].

MnZn ferrites were prepared at low sintering temperature and were reported for medium frequency applications [22]. Meanwhile, the permeability of manganese zinc ferrites was observed to increase with the increase of NiO contents [21]. The maximum permeability for $Mn_{1-x}Zn_xFe_2O_4$ was achieved for Zn-ferrite with $x=0.25$ [23]. Ferrimagnetic materials with their nanostructured characteristics can be used as magnetic feeders to increase the strength of the EM waves. Conventional magnetic feeders (Magnetic frills or magnetic ring current) which were constructed by a toroid coil on a ferrite magnetic feeder have been developed and were used for the excitation of wire antenna. Currently, nanoferrites have been fabricated in the form of magnetic rings and been used for antenna application as well. The antenna with nanoferrites magnetic feeders were used to excite TM wave field components (such as $H\phi$, Ez, and $E\rho$) of the EM waves. The phenomena included magnetic flux energy which was transferred from the magnetic feeders to the current flowing along the antenna and resulted higher magnitude of the EM waves. Higher values of the initial permeability of the nanoferrite with lower magnetic losses resulted higher efficiency of the EM antenna [24–26]. Nickel zinc (NiZn) ferrite has been used for the enhancement of EM field strength whereas manganese zinc ferrite was not used for such application which has good performance over a wide range of frequencies [27]. Akhtar et al. have used NiZn magnetic feeders for deep target hydrocarbon detection. They investigated initial permeability (106.23) for higher Ni concentration at the sintering temperature of 950 °C [28].

Manganese zinc ferrite has been customarily used for ferrite cores and other applications where MnZn nanoferrite for antenna application is still required. In this study, the magnetic samples of MnZn nanoferrites were synthesized using the sol–gel technique. Designed antenna and prepared samples of $Mn_{0.8}Zn_{0.2}Fe_2O_4$ nanoferrite as magnetic feeders were used for the enhancement of field strength from the antenna. Two antennas with and without magnetic feeders were also tested in a built scale tank with a 2000 scale factor. Comparative study of the curve fitting and correlation values was also performed to validate the experimental data.

2. Materials and methods

2.1. Materials preparation

The samples of $Mn_{0.8}Zn_{0.2}Fe_2O_4$ ferrites were prepared by mixing $Mn(NO_3)_2 \cdot 4H_2O$, $Zn(NO_3)_2 \cdot 6H_2O$, and $Fe(NO_3)_3 \cdot 9H_2O$ with 65% of HNO_3. As-prepared samples were stirred for one week and gradually heated until the gel was formed at 70 °C. The sample was then dried in an oven at 110 °C for 24 h. The dry powder was sintered in air at 450 °C, 650 °C and 850 °C for 4 h. Sintered powder at three different temperatures was molded into toroidal shape specimen by using an autopellet press machine and finally sintered in a furnace at 1000 °C for 5 h.

2.2. Experimental setup

X-Ray diffraction analysis was revealed by using Cu Kα radiation($\lambda=1.54056$ Å) to determine the crystal structure of manganese zinc ferrite $Mn_{0.8}Zn_{0.2}Fe_2O_4$ samples at different sintering temperatures. Raman spectroscopy is a non-destructive technique for the material characterization. The study of Raman spectra provides helpful information about the phase and structural properties of the nanoferrites. The Raman spectra for nanoferrites sintered samples were recorded at room temperature in the frequency range of 100–1000 cm^{-1}. The main purpose of Raman spectra is to study the atomic vibration of $Mn_{0.8}Zn_{0.2}Fe_2O_4$ after being sintered at temperatures of 450 °C, 650 °C, and 850 °C for 4 h. The magnetic properties such as initial permeability and Q-factor of the $Mn_{0.8}Zn_{0.2}Fe_2O_4$ were determined by using an Agilent 4294A Impedance Analyzer. A tank with dimensions 1.82 m × 0.91 m × 0.61 m was used as scale model. Tank was filled with salt water having salinity approximately equal to sea water to replicate the marine environment. Oil packets were placed in scale model to represent hydrocarbon layer at different positions. Modified aluminum wire antenna was used as source in the scale model. Aluminum wire of purity (99.9%) having 1 mm diameter was used for antenna and excited with 20 V peak to peak voltage by a function generator. Three flux gate sensors were placed in a scale tank to get the magnetic field response from the hydrocarbon layer (oil packets) placed in a scale model. Magnitude versus offset with and without $Mn_{0.8}Zn_{0.2}Fe_2O_4$ served as magnetic feeders. Antenna was positioned through scale tank with the help of moving setup to acquire the magnetic field response. Magnetic field produced by antenna was detected by a flux gate magnetic field sensor (Mag-03MSS100). Data was recorded with and without oil by the decaport data acquisition system (NI PXI-1042) as a function of source receiver offset. Fig. 1a shows the schematic diagram of scale tank with hydrocarbon reservoir whereas EM antenna with magnetic feeders used in scale tank for deep hydrocarbon detection is also shown in Fig. 1b.