Neodymium (Nd) Doped Yttrium Iron Garnet (YIG) Nanofluid Activated By Electromagnetic Waves for Enhanced Oil Recovery (EOR)

Keanchuan Lee¹,a, Fudhail Mohd Shuhaili², Hasnah Mohd. Zaid³, Beh Hoe Guan⁴
¹,²,³,⁴, Fundamental and Applied Sciences Department
Universiti Teknologi PETRONAS
32610 Seri Iskandar, Perak, Malaysia

a)Corresponding author: lee.kc@utp.edu.my

Abstract. Technology by using nanoparticles have been used in many types of industries nowadays. Due to demand of using hydrocarbon in everyday life has made oil and gas industry to increase their production proportional to the demand. Thus, the usage of using nanoparticles (NPs) to increase the oil production instead of using conventional way has been gradually increase due to its potential that can withstand high pressure and high temperature condition of reservoir. In the first part of this project, the experiment started by preparing and synthesizing Nd doped Nano-YIG using sol-gel method with different composition of Nd particles. Next, the samples of Nd doped Nano-YIG will be characterized accordingly using X-RAY Diffraction (XRD). In this project, the composition of Neodymium equals to 0, 0.25, 0.5, 0.75, and 1.0 have been used and will be annealed under the temperature of 1000 °C. The results showed Nd doped YIG nanofluid resulted in the increases viscosity and reduced , oil-water Interfacial Tension (IFT). Therefore Nd doped YIG nanofluids are believed to produce a better result in oil recovery under the presence of electromagnetic waves.

1. Introduction
Enhanced Oil Recovery (EOR) technology has been established a few years back use to maximize the production of oil from the well [1-6]. The conventional ways of EOR by using chemical injection, gas injection and thermal injection need a better evolvement as these methods are not quite feasible for the wells integrity. The existence of nanotechnology has open a new world in EOR technology as this featured will make the oil recovery be slightly or may be much better than the conventional ways. Not just in oil and gas industry, nanotechnology is a well-known technology worldwide where this technology has been used in other industries such as agriculture, pharmaceuticals, manufacturing of scratch proof eyeglasses, beauty products and many others.

With all the high technology nowadays, NPs are also used together with EM waves as it known to have magnetic properties which will provide promising benefit to EOR technology. It will be such a huge improvement if the rare earth is used as a dopant together with the iron nanoparticle and it can work the best together with the presence of EM waves due to magnetic properties exist in rare earth [7-10].

Conventional EOR methods such as gas injection, thermal injection, and chemical injection, have their own limitation especially under high pressure and high temperature condition of reservoir. However, some of these conventional method in the EOR is not compatible with the reservoir condition. For example, the injection of chemical to the reservoir for EOR might damage the reservoir as the chemical is not suitable with the formation. Recent studies have claimed that due to the extremely small particle of
nanoparticle, it has said that nanoparticles have their own potential to improve oil recovery due to large surface area and can act as an alternative surfactant agent for reservoir problem. In any event, there are still no research and study have been done particularly in the oil and gas industry on the effect of Neodymium Rare Earth doping in Yttrium Iron Garnet (YIG) activated by EM waves for Enhanced Oil Recovery (EOR).

In this study, we prepared the Nd doped YIG NPs and study the effect of its property in the EOR performance in terms of its nanofluids’ viscosity and interfacial tension between the nanofluid and hydrocarbon with and without presence of EM waves.

2. Experiment
Nd doped YIG (Y₃₋ₓNdₓFe₅O₁₂) NPs with different compositions (x=0.0, 0.25, 0.5, 0.75, 1.0) were synthesized using sol-gel auto-combustion method [8-9], and were used after calcining at 1000°C. The Characterization process will be conducted by using X-Ray Powder Diffraction (XRD) and Field Emission Scanning Electron Microscope (FESEM). Different doping composition of Nd of Nd Doped YIG nanoparticles have been synthesized and characterized and dispersed into brine water (nanofluid creation), It has been done to study the optimum composition of Nd needed to be doped into YIG nanoparticles to provide the best result on the alteration of Oil-Nanofluid interfacial tension (IFT) and Nanofluid Viscosity. All Nd doped YIG nanofluid will then be tested to study the effect on Brine Water IFT, Viscosity, Wettability, Magnetic Properties. For IFT, the test will be done by using Goniometer; Viscosity will be done by using Viscometer, Wettability will be done by using Contact Angle Goniometer; Magnetic Properties will be done by using Vibrator Sample Magnetometer (VSM). All of the test data obtained from all instruments for different composition of Nd Doped YIG nanoparticles/nanofluids will then be recorded and tabulated for discussion and analysis. NPs were dispersed in brine as the base fluid and magnetically stirred for 1 hour to produce nanoparticles suspension. Then, the appropriate amount of sodium dodecylbenzenesulfonate (SDBS) was added to the suspensions. These suspensions were agitated in an ultrasonic bath at ambient temperature for an optimum period, to attain the required concentration of nanofluids. The anionic surfactant, SDBS, was chosen as a stabilizer based on our previous stability tests; where the surfactant concentrations were selected using critical micelle concentration (CMC) determination methods. The pH value of the system was also adjusted by using HCl and NaOH solution in order to improve the quality of dispersion. These pH values were monitored by precise pH meter (FE20-Basic) from Mettler Toledo. After the samples are prepared, viscosity and density test were carried out to check the viscosity and density for each sample. The IFT was measured by using Dataphysics Surface Tensiometer. The above measurements were carried out at ambient condition and under EM waves. The EM field was generated at a designed frequency of 18.8 MHz, and a fixed voltage of 3.5 V.

3. Results and Discussions
The XRD patterns for the samples annealed with different compositions are depicted in Fig. 1. All samples matched with the typical YIG pattern [7] with the relevant garnet structure peaks (400), (420) and (422) are sharply reflected. This shows that 1000 °C is sufficient enough to obtain the cubic structure. The results are expected to come out with the peak similarity of Yttrium Iron Garnet(YIG) Phase in XRD results. This is due to the experimental belief that doping will not affect the cubic structure of the nanoparticles. XRD test been done in this experiment is to check whether the samples exert the phase characteristic of YIG. The similarity can be done with the comparison with the standard card pattern of YIG.

Furthermore, XRD results will be obtained in the forms of graph which shown various presence of peaks. The similarity of the peak produced by the samples with YIG standard card peak pattern, this indicates the doping process is successful and it exerts the pattern of YIG. each value of Nd composition doping exerts the characteristic of YIG patterns and having near the same value of it crystalize structures
Table 1 shows the data obtained from viscometer shows that the viscosity reading of each samples under the presence of EM increases. This supports the claim made earlier in this experiment. The viscosity is increase due to the resistance exerted by the fibre-like thread of electron magnetic alignment within the fluid which initiated by the electromagnetic field. The explanation also supported by [3] in their research entitled “Magnetic effect in viscosity of magnetorheological fluids” which stated an electron responds to the electromagnetic field by generated its preferred orientation to the magnetic field causing the existence of resistance to the fluid flow. Viscosity happens when there is a restriction or resistance in the flow of fluids. Moreover, it is advisable to apply the magnetic field parallel to the direction of the flow of fluid. Thus, in order to create resistance on the fluid flow, the electron magnetic alignment (fibre-like) need to be in the positioned aligned with the flow of fluid. Furthermore, direction of the magnetic wave which induced from electromagnetic wave is always perpendicular to the electric wave. In the case of solenoid application like in this experiment it is advisable to positioned the inner area of the solenoid parallel to the flow of fluid during viscosity test.

Figure 1. XRD pattern for Nd doped YIG powder with different composition, x.
Table 1 Viscosity of Nanofluid (0.1 wt% dispersed in 0.025 wt% SBDS) for all samples without and with EM waves

| NO. | COMPOSITION OF ND:YIG | VISCOSITY (WITHOUT EM WAVES) | VISCOSITY (WITH EM WAVES) |
|-----|----------------------|----------------------------|--------------------------|
| 1   | 0.00:3.00            | 1.68                       | 1.71                     |
| 2   | 0.25:2.75            | 1.70                       | 1.73                     |
| 3   | 0.50:2.50            | 1.72                       | 1.75                     |
| 4   | 0.75:2.25            | 1.75                       | 1.78                     |
| 5   | 1.00:2.00            | 1.77                       | 1.80                     |

The tendency of how IFT of nanofluid (0.1 wt% of NPs) decreases when amount of Nd increases is depicted in Table 2. The reduction of surface tension is caused when the nanoparticles attached to surface of the liquid. The absorption process reduces the surface tension. The alteration of the IFT resulted in the reduction of the mobility ratio of the water and crude oil. This reduction helps to generate a better sweeping process. Thus, increase the sweep efficiency of the recovery process. In this experiment, the IFT is reduced as EM wave is exerted. The temperature also experienced an increment. The increase in temperature is due to the energy exerted by electron particles during the alignment process at the axis of magnetic field. The presence of spin-orbit coupling of electrons also causing an energy to be released which converted in the form of heat. Heat will then reduce both IFT and Surface Tension. This theory is supported by a few researchers which stated, “Heating process of causing by the spin-orbit coupling of dipoles will result in reduction of the viscosity of the oil” [3, 8]. Thus, is it agreed that Electromagnetic wave enhanced the reduction of IFT and Surface Tension between oil-water and oil-surface. Moreover, electromagnetic heating also reduced the viscosity of oil thus reducing the mobility ratio of oil-water and increases the sweep efficiency of the recovery.

Table 2 IFT of Nanofluid (0.1 wt% dispersed in 0.025 wt% SBDS) for all samples without and with EM waves

| NO. | COMPOSITION OF ND:YIG | IFT (WITHOUT EM WAVES) (mN/m) | IFT (WITH EM WAVES) (mN/m) |
|-----|----------------------|----------------------------|----------------------------|
| 1   | 0.00:3.00            | 14.28                      | 14.07                      |
| 2   | 0.25:2.75            | 13.53                      | 13.35                      |
| 3   | 0.50:2.50            | 13.11                      | 12.79                      |
| 4   | 0.75:2.25            | 12.39                      | 12.24                      |
| 5   | 1.00:2.00            | 12.25                      | 12.12                      |

4. Conclusion
Synthesis of Nd doped YIG NPs by applying solgel method has been demonstrated. XRD results showed all sample exhibit cubic structures. It is proven that Nd doped into YIG nanoparticles resulting in increased viscosity, reduction in oil and water IFT. This conditions supporting the experimental claimed on the alteration of oil-nanofluid interfacial tension (IFT) and nanofluid viscosity. As the composition of Nd doping into YIG nanoparticle increases under the presence of electromagnetic wave, more reduction of oil-nanofluid interfacial tension (IFT) and increasing nanofluid viscosity. Herefore we believe that Nd doped YIG nanofluids under the presence of EM waves will improve the oil recovery in EOR process.
Acknowledgments
A part of this work was financially supported by YUTP (Grant No. 0153AA-E17) from Universiti Teknologi PETRONAS Malaysia.

References

1. Mike, O.O. and Naomi, A.A. 2010, “Investigating the use of Nanoparticles in Enhancing Oil Recovery,” in Nigeria Annual International Conference and Exhibition, Tinapa - Calabar, Nigeria; Society of Petroleum Engineers.

2. Munshi, A.M., Singh, V.N., Kumar, M., and Singh, J.P., 2008, “Effect of nanoparticle size on sessile droplet contact angle,” Journal of Applied Physics 103(084315). doi: https://doi.org/10.1063/1.2912464

3. Sahni, A., et al, 2000, “Electromagnetic Heating Methods for Heavy Oil Reservoirs,” in SPE/AAPG Western Regional Meeting, Long Beach, California; Society of Petroleum Engineers

4. Suleimanov, B.A., Ismailov .F .S., and Veliyev .E.F., 2011, “Nanofluid For Enhanced Oil Recovery,” Journal of Petroleum Science and Engineering 78(2): 431-437. doi: https://doi.org/10.1016/j.petrol.2011.06.014

5. Soleimani, H., et al., 2016, “Catalytic Effect of Zinc Oxide Nanoparticles on Oil Water Interfacial Tension,” Digest Journal of Nanomaterials and Biostructures 11(1): 263-269.

6. N.A. Oglo, O.A. Olafuyi and M.O. Onyekonwu, “Enhanced oil recovery using nanoparticles,” SPE Saudi Arabia Technical Symposium and Exhibition, Al-Khobar, Saudi Arabia, 2012

7. Skomski, R. and Sellmyer, D.J., August 2009, “Anisotropy of rare-earth magnets,” Journal of Rare Earths 27(4): 675-679. doi: https://doi.org/10.1016/S1002-0721(09)60314-2

8. Baczewski, L.T., et al., 1993, “Magnetism in Rare-Earth-Transition Metal Systems: Magnetization Reversal and Ultra-High Susceptibility in Sandwiched Thin Films Based on Rare-

9. Earth and Cobalt Alloys,” Acta Physica Polonica A 83(5).

Bradley, S.V.G., et al., 2014, “The Rare-Earth Elements - Vital to Modern Technologies and Lifestyles,” USGS Mineral Resources Program FS 2327: 3078. doi: https://dx.doi.org/10.3133/fs20143078.

10. Coey, J.M.D. and Hong, S., 1990, “Improved Magnetic Properties by Treatment of Iron- Based Rare Earth Intermetallic Compounds In Ammonia,” Journal of Magnetism and Magnetic Materials 87(3): l251-l254. doi: https://doi.org/10.1016/0304-8853(90)90756-G.