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ULTRASONIC STUDY OF PURE SYNTHESIZED NICKEL FERRITE ($NIFE_2O_4$) NANOFLUIDS AT DIFFERENT CONCENTRATION AND TEMPERATURES BY USING 5 MHZ ULTRASONIC WAVES

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ABSTRACT

In this present research, the pure $NiFe_2O_4$ nanoparticle was synthesized using the sol-gel method. The obtained nanoparticle undergoes Ultraviolet (UV) spectroscopy to enhance the size, and band gap of $NiFe_2O_4$ nanoparticles. The pure synthesized $NiFe_2O_4$ nanoparticle also was transformed to liquid by mixing and dispersed into Polyethylene Glycol (PEG) polymer at 2%, 4% and 6% concentration for ultrasonic characterization. The obtained liquid was poured into the cylinder of an ultrasonic interferometer and undergoes through ultrasonic characterization by sending ultrasonic wave of frequency 5 MHz to measure the ultrasonic velocity, density, and viscosity at different temperatures (303K to 333K). Also, the related ultrasonic parameters such as adiabatic compressibility, acoustic impedance, and ultrasonic attenuation were determined using the experimental parameters such as ultrasonic velocity, density, and viscosity.

KEYWORDS: Nickel Ferrite Nanoparticle; Nanofluids; Experimental parameters; Ultrasonic wave; ultrasonic parameters.

INTRODUCTION

The ultrasonic study is aims to investigate the molecular interactions within the synthesised pure $NiFe_2O_4$ nanomaterial by utilising ultrasonic methods. Since ultrasound investigations shed light on the elastic and acoustic properties of substances at the molecular level, they are useful instruments for comprehending the physical and structural qualities of substances. The

synthesized $NiFe_2O_4$ nanoparticle guarantees a regulated and precisely characterised sample, paving the way for an in-depth analysis of their behaviour at varying temperatures. Scholars may observe how changes in temperature affect molecular interactions, including bond strength, lattice rattles, and the stability of structure in general. In the context of ultrasound research, the acoustical behaviour of the nanoparticles is examined using high-energy of frequency sound waves. With the use of this non-invasive method, factors such as elastic constants, density, viscosity, and sound velocity would be precisely measured, providing a thorough grasp of the material's characteristics. The temperature and structural dynamics of $NiFe_2O_4$ nanoparticles are clarified by the ultrasound evaluations, which yield useful information concerning how molecular interactions change at any level of temperature. These understandings are essential for maximising the material's performance in upcoming uses such as magnetised gadgets, detectors, as well as catalyst.

EXPERIMENTAL DETAILS

1. *Synthesis of NiFe2O4 nanoparticles*

Sol-gel method has been used for making $NiFe_2O_4$ nanoparticles, Nickel Nitrate Hex-hydrate ($Ni(NO_3)_2.6H_2O$) and Iron Nitrate Nona-hydrate($Fe(NO_3)_3.9H_2O$) are used as precursors and Citric Acid used as chelating/stabilizing agent which helps in controlling the morphological size and help in uniformity formation of nanoparticle.

$$\mathbf{Ni\ (NO_3)_2.6H_2O + Fe_2\ (NO_3)_3.9H_2O + C_6H_8O_7 \longrightarrow NiFe_2O_4 + CO_2 + NO2 + H_2}$$

From the above equation 7.44 grams of Nickel Nitrate Hex-hydrate ($Ni(NO_3)_2.6H_2O$) can be dissolved in 20 ml of deionized water, and stirring the solution until it becomes transparent to create Nickel Nitrate solution, 10.34 grams of Iron Nitrate Nona-hydrate ($Fe(NO_3)_3.9H_2O$) can also be dissolved in 30 ml of deionized water to create Iron Nitrate solution. 5.0 grams of Citric acid is also dissolved in 20 ml of deionized water. Iron Nitrate solution was gradually poured into Nickel Nitrate solution while on magnetic stirrer at room temperature. After fifteen minutes the solution of citric acid has been poured into the solution drop by drop at temperature of 50°C .Keeping stirring the solution at temperature of 50°C until the solution transform to gel for 1 hour. The gel sample has been taken to hot oven at 100°C for 12 hours until dried, and should grinded where the powder can be kept in furnace at 500°C until 4 hours to obtain pure $NiFe_2O_4$ nanoparticle.

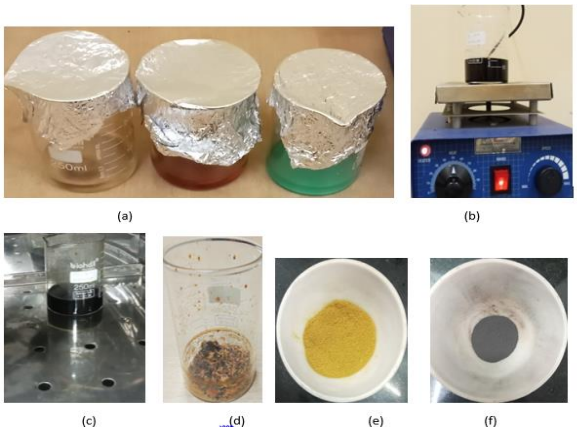


Fig. 1 Synthesis method.

2. *$NiFe_2O_4$-Nanofluids*

Since ultrasonic interferometer does not design for solid materials, therefore the nanoparticle powder was transformed to liquid by dispersed into Deionized water to create Nanofluids at different concentrations (2%, 4%, 6%) for ultrasonic characterization. Ultrasonic velocity, Density and Viscosity are experimentally determined while other ultrasonic parameters such as adiabatic compressibility, Acoustic impedance and Attenuation are calculated theoretically. Those ultrasonic theoretical parameters are calculated using the relations;

i. $\beta = \frac{1}{\rho V^2}$

ii. $Z = \rho V$

iii. $\alpha/f^2 = \frac{8\Pi^2 \eta}{\rho V^3}$

β=*Adiabatic compressibility,*

α/f² = *Attenuation*

ρ =*Density*

V=*ultrasonic velocity,*

Z=*acoustic impedance*

η=*viscosity*

Density (ρ) and Viscosity (η) are also calculated using the relations below;

Density $\boldsymbol{\rho} = \frac{W_3 - W_1}{W_2 - W_1}$

ρ = Density of sample

$\mathbf{W_1}$ = weight of empty specific gravity bottle

$\mathbf{W_2}$ = weight of specific gravity bottle filled with DD water at different temperature

$\mathbf{W_3}$ = weight of specific gravity bottle filled with sample at different temperature

$$\text{Viscosity } \eta = \frac{\rho_2 \times t_2}{\rho_1 \times t_1} \times \eta_w$$

η= Viscosity of sample

ρ1 = Density of water at different temperature (303 K – 333 K)

ρ2 = Density of sample at different temperature

t2 = time taken for sample to drop from high to bottom in Oswald viscometer at different temperature

t1 = time taken for DD water to drop from top to bottom in Oswald viscometer at different temperature

η_w=Viscosity of water at different temperature (303 K – 333 K)

RESULTS AND DISCUSSION

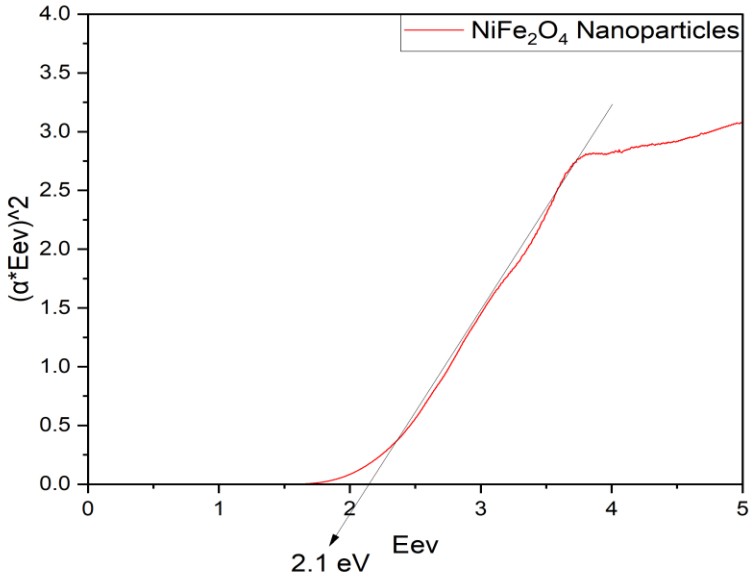


Fig. 2 band gap of $NiFe_2O_4$ nanoparticles.

Table 1. Ultrasonic parameters of sample 1. (2% concentration)

Temp. (Kelvin)	Ultrasonic velocity (m/s)	Density (ρ) kg/m^3	Viscosity (η) (Pa.s) (×10^3)	Adiabatic Compressibility (M^{2}N^{-1}) (×10^{-9})	Acoustic impedance (pa.s/m^3) (×10^5)	Attenuation (S^{2}M^{-1}) (×10^{-12})
303	388	1011	0.793	6.570	3.92268	1.601
308	393	1005	0.863	6.442	3.94965	1.117
313	403	999	0.849	6.163	4.02597	1.025
318	414	998	0.399	5.846	4.13172	0.444
323	420	997	0.483	5.686	4.18740	0.516
328	452	993	0.548	4.929	4.48836	0.472
333	541	989	0.309	3.455	5.35049	0.156

Table 2. Ultrasonic parameters of sample 2. (4% concentration)

Temp. (Kelvin)	Ultrasonic velocity (m/s)	Density (ρ) kg/m^3	Viscosity (η) (Pa.s) (×10^3)	Adiabatic Compressibility (M^{2}N^{-1}) (×10^{-9})	Acoustic impedance (pa.s/m^3) (×10^5)	Attenuation (S^{2}M^{-1}) (×10^{-12})
303	379	1007	0.868	6.913	3.99779	1.250
308	385	1003	0.856	6.726	3.86155	1.181
313	388	1001	0.853	6.636	3.88388	1.152
318	398	1000	0.672	6.313	3.98000	0.842
323	407	997	0.406	6.055	4.05779	0.477
328	445	989	0.400	5.106	4.40105	0.362
333	466	987	0.363	4.666	4.59942	0.287

Table 3. Ultrasonic parameters of sample 3. (6% concentration)

Temp. (Kelvin)	Ultrasonic velocity (m/s)	Density (ρ) kg/m^3	Viscosity (η) (Pa.s) (×10^3)	Adiabatic Compressibility (M^{2}N^{-1}) (×10^{-9})	Acoustic impedance (pa.s/m^3) (×10^5)	Attenuation (S^{2}M^{-1}) (×10^{-12})
303	372	1021	1.319	7.078	3.79812	1.982
308	377	1019	0.856	6.905	3.84163	1.238
313	382	1018	0.811	6.732	3.88876	1.129
318	388	1017	0.538	6.532	3.94596	0.715
323	392	1016	0.498	6.405	3.98272	0.643
328	395	1012	0.452	6.333	3.99740	0.572
333	400	1011	0.405	6.182	4.04400	0.494

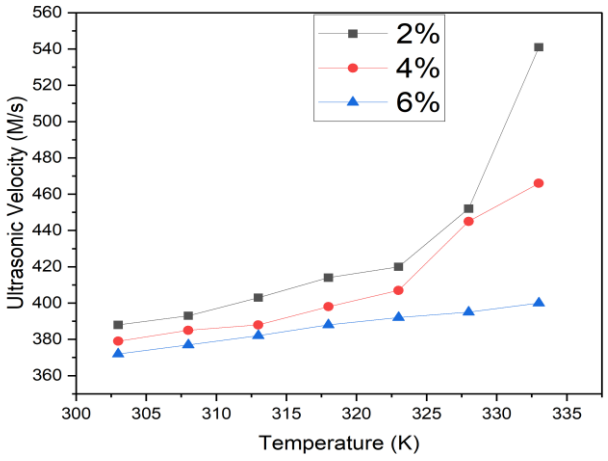


Fig.3 Ultrasonic velocity with Temperature.

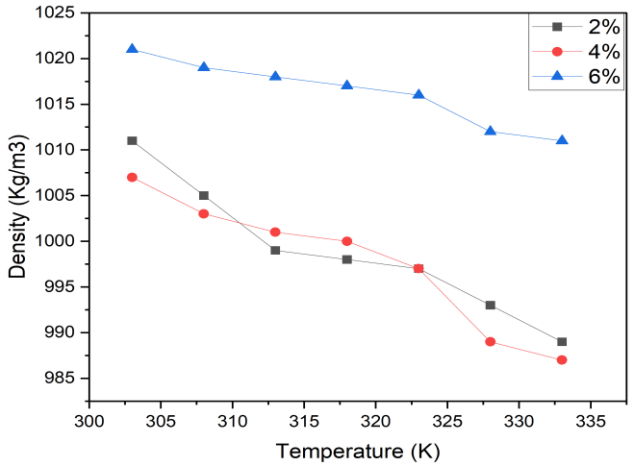


Fig. 4 Density with Temperature.

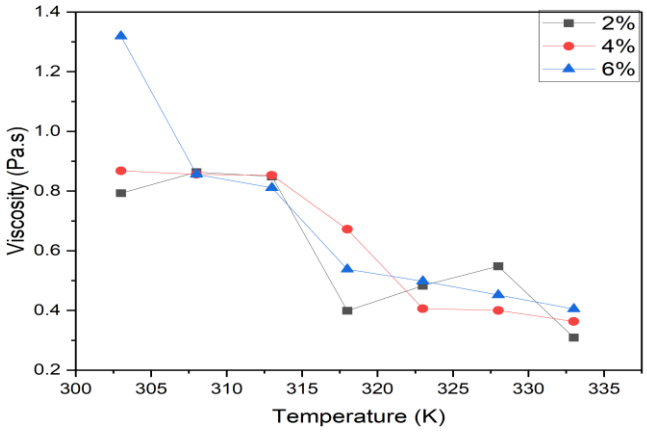


Fig.5 Viscosity with Temperature.

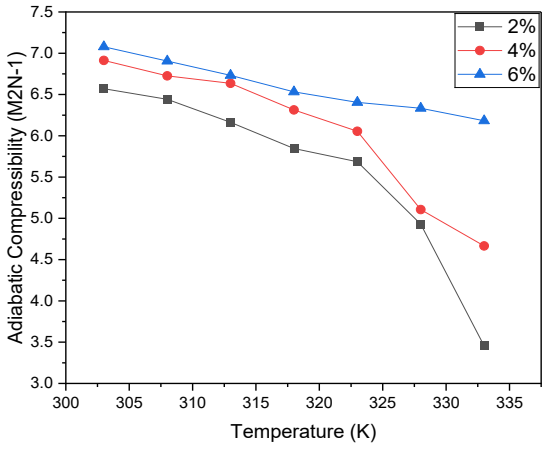


Fig. 6 Adiabatic compressibility with Temperature.

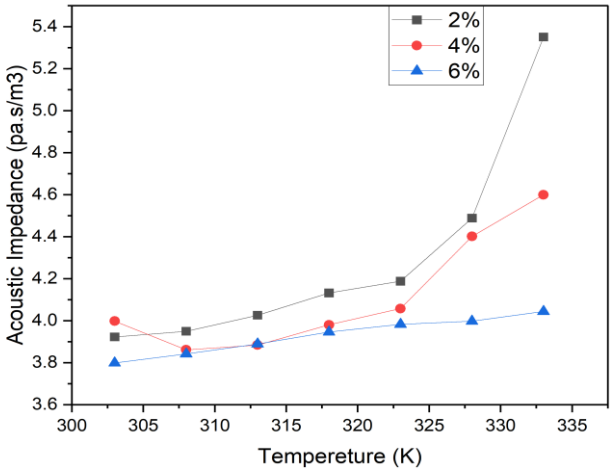


Fig. 7 Acoustic impedance with Temperature.

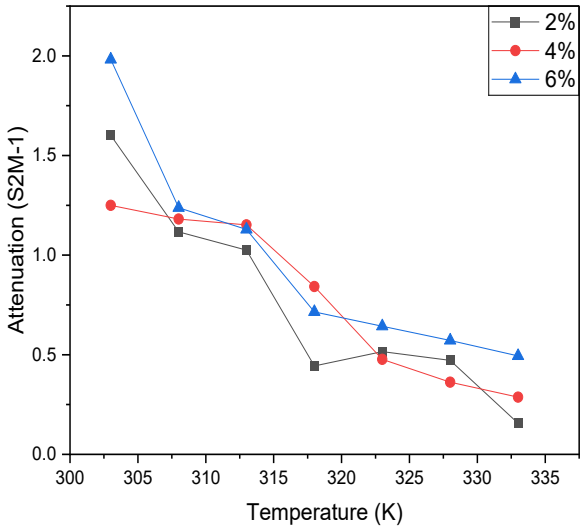


Fig. 8 Attenuation with Temperature.

CONCLUSION

This ultrasonic research is a probe for studying the molecular interaction in $NiFe_2O_4$ nanoparticles using ultrasonic waves. The ultrasonic parameters like adiabatic compressibility, acoustic impedance and attenuation are evaluated using the practical parameters such as ultrasonic velocity, density and viscosity. This is observed that the ultrasonic velocity is increasing as increase in temperature and is high at low concentration this means that ultrasonic wave sent through the material is faster in low concentration. Density and viscosity are decrease as temperature increases and they are being highest at high concentration, the adiabatic compressibility attenuation are also high with high concentration,

which means that the material's molecules are more compressed at adiabatic condition and gradually loss their intensity of a signal of wave propagation at high concentration and otherwise at high temperature. On the other hand, the band gap of nanoparticles was determined as 2.1eV that is indicates that the band gap is direct band gap and the material is a semiconductor.

REFERENCES

1. Mapossa, J. Dantas, M. R. Silva, R. H. G. A. Kiminami, A. C. F. M. Costa, and M. O. Daramola, 'Catalytic performance of NiFe2O4 and Ni0.3Zn0.7Fe2O4 magnetic nanoparticles during biodiesel production', *Arab. J. Chem.*, vol. 13, no. 2, pp. 4462–4476, Feb. 2020, doi: 10.1016/j.arabjc.2019.09.003.
2. Cheraghi, F. Davar, M. Homayoonfal, and A. Hojjati-Najafabadi, 'Effect of lemon juice on microstructure, phase changes, and magnetic performance of CoFe2O4 nanoparticles and their use on release of anti-cancer drugs', *Ceram. Int.*, vol. 47, no. 14, pp. 20210–20219, Jul. 2021, doi: 10.1016/j.ceramint.2021.04.028.
3. Aafiya *et al.*, 'Synthesis and role of structural disorder on the optical, magnetic and dielectric properties of Zn doped NiFe2O4 nanoferrites', *J. Mol. Struct.*, vol. 1253, p. 132205, Apr. 2022, doi: 10.1016/j.molstruc.2021.132205.
4. Aslibeiki *et al.*, 'Magnetic hyperthermia properties of CoFe2O4 nanoparticles: Effect of polymer coating and interparticle interactions', *Ceram. Int.*, vol. 48, no. 19, Part A, pp. 27995–28005, Oct. 2022, doi: 10.1016/j.ceramint.2022.06.104.
5. Dharmaraja, P. E. Nicholas, P. Ramya, I. J. I. Premkumar, V. Vijayan, and N. Senthilkumar, 'Investigation on photocatalytic activity of ZnS/NiFe2O4 NCs under sunlight irradiation via a novel two-step synthesis approach', *Inorg. Chem. Commun.*, vol. 126, p. 108481, Apr. 2021, doi: 10.1016/j.inoche.2021.108481.
6. Ferrer *et al.*, 'Structural and magnetic studies of NiFe2O4 and NiFe2O4@SiO2-Silane agent samples useful for the removal of Cu2+ ions', *J. Alloys Compd.*, vol. 899, p. 163403, Apr. 2022, doi: 10.1016/j.jallcom.2021.163403.
7. Haq, M. A. N. Zein, R. Gabriella, S. R. Putri, A. B. D. Nandiyanto, and T. Kurniawan, 'Literature Review: Synthesis Methods of NiFe2O4 Nanoparticles for Aqueous Battery Applications', *Int. J. Sustain. Transp. Technol.*, vol. 4, no. 2, Art. no. 2, Oct. 2021, doi: 10.31427/IJSTT.2021.4.2.1.
8. H. Dadras Moghaddam, R. Khani, and B. Khodaei, 'Liquid-phase microextraction of ascorbic acid in food and pharmaceutical samples using ferrofluid-based on cobalt ferrite

(CoFe2O4) nanoparticles', *Microchem. J.*, vol. 183, p. 108006, Dec. 2022, doi: 10.1016/j.microc.2022.108006.

9. J. A. Flood-Garibay and M. A. Méndez-Rojas, 'Synthesis and characterization of magnetic wrinkled mesoporous silica nanocomposites containing Fe3O4 or CoFe2O4 nanoparticles for potential biomedical applications', *Colloids Surf. Physicochem. Eng. Asp.*, vol. 615, p. 126236, Apr. 2021, doi: 10.1016/j.colsurfa.2021.126236.
10. L. Mohammadi *et al.*, 'Modeling of phenol removal from water by NiFe2O4 nanocomposite using response surface methodology and artificial neural network techniques', *J. Environ. Chem. Eng.*, vol. 9, no. 4, p. 105576, Aug. 2021, doi: 10.1016/j.jece.2021.105576.
11. M. Ebrahimi, M. Ghasemi, V. Soleimanian, M. Nekoeinia, and A. Mokhtari, 'Effects of annealing temperature on microstructural, optical and FTIR properties of NiFe2O4 spinel nanoparticles', *Chem. Phys. Lett.*, vol. 833, p. 140911, Dec. 2023, doi: 10.1016/j.cplett.2023.140911.
12. M. Hodlevska *et al.*, 'Hydrothermally synthesized NiFe2O4/rGO composites: structure, morphology and electrical conductivity', *Appl. Nanosci.*, vol. 13, no. 7, pp. 5199–5209, Jul. 2023, doi: 10.1007/s13204-022-02741-x.
13. M. Ismael, 'Photo-Fenton reaction enhanced visible-light activity of p- Photo-Fenton reaction enhanced visible-light activity of p-CuFe2O4/n-g-C3N4 heterojunction composites synthesized by a simple ultrasonic-assisted route for organic pollutants degradation', *Mater. Res. Bull.*, vol. 151, p. 111803, Jul. 2022, doi: 10.1016/j.materresbull.2022.111803.
14. M. Kooti and A. N. Sedeh, 'Synthesis and Characterization of NiFe2O4 Magnetic Nanoparticles by Combustion Method', *J. Mater. Sci. Technol.*, vol. 29, no. 1, pp. 34–38, Jan. 2013, doi: 10.1016/j.jmst.2012.11.016.
15. M. M. S. Silva *et al.*, 'Morphology-controlled NiFe2O4 nanostructures: Influence of calcination temperature on structural, magnetic and catalytic properties towards OER', *J. Electroanal. Chem.*, vol. 933, p. 117277, Mar. 2023, doi: 10.1016/j.jelechem.2023.117277.
16. M. S. Matseke, H. Zheng, and Y. Wang, 'The ultrasonication boosts the surface properties of CoFe2O4/C nanoparticles towards ORR in alkaline media', *Appl. Surf. Sci.*, vol. 516, p. 146105, Jun. 2020, doi: 10.1016/j.apsusc.2020.146105.
17. M. Shabani, E. Saebnoori, S. A. Hassanzadeh-Tabrizi, and H. R. Bakhsheshi-Rad, 'Solution Plasma Synthesis of Polymer-Coated NiFe2O4 Nanoparticles for Hyperthermia

Application', *J. Mater. Eng. Perform.*, vol. 32, no. 5, pp. 2165–2182, Mar. 2023, doi: 10.1007/s11665-022-07268-4.

18. P. Sharma, D. V. Shah, S. Thakor, A. D. Watpade, V. A. Rana, and C. R. Vaja, 'Compositional Influence of Synthesized Magnetic Nanoparticles on Epoxy Composites: Dielectric, Magnetic, and Optical Characteristics', *J. Macromol. Sci. Part B*, vol. 0, no. 0, pp. 1–35, 2023, doi: 10.1080/00222348.2023.2263293.
19. S. Das, M. M. Das, P. Dhamodharan, and C. Manoharan, 'Dielectric, magnetic and electrochemical characterization of CoFe2O4 nanoparticles and their application as an anode material in Li-ion battery', *Inorg. Chem. Commun.*, vol. 145, p. 110050, Nov. 2022, doi: 10.1016/j.inoche.2022.110050.
20. S. Gahlot and V. Kulshrestha, 'Graphene based polymer electrolyte membranes for electro-chemical energy applications', *Int. J. Hydrog. Energy*, vol. 45, no. 34, pp. 17029–17056, Jul. 2020, doi: 10.1016/j.ijhydene.2019.06.047.
21. S. Kazi, S. Inamdar, Y. sarnikar, D. Kamble, and R. Tigote, 'Simple Co-precipitation synthesis and characterization of magnetic spinel NiFe2O4 nanoparticles', *Mater. Today Proc.*, vol. 73, pp. 448–454, Jan. 2023, doi: 10.1016/j.matpr.2022.09.590.
22. V. Boychuk, R. Zapukhlyak, M. Hodlevsky, V. Kotsyubynsky, and L. Turovska, 'Surfactant-assisted hydrothermal synthesis of NiFe2O4/reduced graphene oxide composites', *Mater. Today Proc.*, vol. 62, pp. 5705–5711, Jan. 2022, doi: 10.1016/j.matpr.2022.01.485.
23. W. M. Alamier *et al.*, 'Biosynthesis of NiFe2O4 nanoparticles using Murayya koenigii for photocatalytic dye degradation and antibacterial application', *J. Mater. Res. Technol.*, vol. 22, pp. 1331–1348, Jan. 2023, doi: 10.1016/j.jmrt.2022.11.181.
24. Z. E. Gahrouei, S. Labbaf, and A. Kermanpur, 'Cobalt doped magnetite nanoparticles: Synthesis, characterization, optimization and suitability evaluations for magnetic hyperthermia applications', *Phys. E Low-Dimens. Syst. Nanostructures*, vol. 116, p. 113759, Feb. 2020, doi: 10.1016/j.physe.2019.113759.
25. Z. M. A. Abbas, W. A. Shatti, M. M. Kareem, and Z. T. Khodair, 'Synthesis and characterization of NiFe2O4/CuO nanocomposites: Structural and magnetic properties analysis', *Chem. Data Collect.*, vol. 47, p. 101078, Oct. 2023,